Curve number estimates for conventional and conservation tillages in the southeastern Coastal Plain

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Abstract: The USDA Natural Resource Conservation Service curve number (CN) method for estimating surface runoff is frequently used in natural resource modeling. Water yield and subsequently water quality estimates depend heavily on CN selection. This study was conducted to estimate CNs for a cotton-peanut rotation under conventional and strip tillage (ST) methods for growing and dormant seasons. A comparison between alternative methods for calculating CN and their applicability was also made. Rainfall-runoff data measured from 1999 to 2005 at a field study site in South Georgia were used to calculate CNs by averaging, lognormal, and data-censoring methods. For conventional and STs, CNs by the averaging method using year-round data were 89 and 84, respectively, and by the lognormal method were 89 and 83, respectively. Results from the data-censoring method were 81 and 75, respectively, which matched standard table values developed from a long-term series of annual maximum runoff. Values were also found to vary by season. Curve numbers by the lognormal method for ST were 83 and 88 for growing and dormant seasons, respectively; however, there was no difference between growing and dormant seasons, 89, for conventional tillage. The corresponding CNs by the data-censoring method for ST were 71 and 79 for growing and dormant seasons, respectively, and for conventional tillage were 82 and 79 for growing and dormant seasons, respectively. Based upon errors of the estimates, runoff estimates showed no improvement when separate CNs for the two seasons were used. The data-censoring method CNs yielded lower runoff estimate errors than CNs obtained by the lognormal method. The data-censoring method is recommended for determining CNs from plot rainfall-runoff data pairs.

Key words: conservation tillage—curve number—hydrologic modeling—runoff

The widely used watershed-scale hydrologic model Soil and Water Assessment Tool (SWAT) (Arnold et al. 1998) has been selected by the USDA Agricultural Research Service to evaluate the effectiveness of soil and water conservation practices applied to agricultural management systems in benchmark watersheds across the United States as part of the Conservation Effects Assessment Project (Mausbach and Dedrick 2004). One of the challenges of using a modeling approach for the evaluation is the determination of realistic model input parameters for field conditions with and without the conservation practices, given regional variation in soils, climate, and practices, and often a lack of field data upon which to make the determination. In the Coastal Plain physiographic region of the southeastern United States, a conservation tillage practice known as strip tillage (ST) has been gaining producer acceptance over the past two decades (Lascano et al. 1994). Strip tillage involves planting into narrow strips of cultivated soil cut through the residue of the previous crop or a winter cover crop that was planted after harvest of the previous crop. In a field scale study on the Coastal Plain (Bosch et al. 2005), ST was shown to reduce surface runoff and to conserve soil moisture over the growing season in a cotton-peanut crop rotation compared to conventional tillage (CvT). Extending the field-scale work by simulation modeling can address one of the needs of conservation practices assessment in the Coastal Plain: a comparison of the effects of CvT and ST on hydrology and water quality at a watershed scale.

Often model input parameters are obtained from standard tables and represent average values for samples taken over a broad area. Basing the estimates for these input parameters on field-measured values should reduce model output uncertainty due to input parameter uncertainty and allow development of range limits to bound regional parameter variability. Focusing effort on the most sensitive model input parameters should in turn have the greatest impact on reducing model output uncertainty and providing policy-relevant estimates or expected ranges of responses in a region. An analysis of the sensitivity of SWAT input parameters on hydrology for the Little River Experimental Watershed, located near Tifton, Georgia, indicated that curve number (CN) for crop land (CN2[crop]) was the most sensitive parameter for total water yield and that the most sensitive input parameters for stormflow and baseflow were (CN2[crop]) and CN for forested land CN2(forest) (Feyereisen et al. 2007). Since CN2(crop) was the most sensitive parameter for total water yield, stormflow and baseflow, work has been undertaken to determine CN2(crop) for both CvT and ST from the Gibbs Farm field data reported by Bosch et al. (2005).

The USDA Natural Resource Conservation Service (NRCS) publishes CNs for soil hydrologic groups and soil-cover complexes in the National Engineering Handbook (NEH) (Part 630, Hydrology) (USDA NRCS 2001). These CNs are based upon a series of annual maximum runoff events. Historically, other criteria have been used to determine CNs, for example using storms that produce runoff over a certain threshold value or for which the ratio of precipitation to soil storage is greater than a given value. However, it is well known that CN estimates based upon all the runoff-rainfall pairs from

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an experimental plot or watershed will be higher than estimates based upon data pairs selected only from larger storms (Hjelmfelt 1991). The CN is determined as the median value of the data pairs. However, the only data pairs included in the analysis are for events with associated runoff. Presumably, low CNs would have been associated with precipitation events for which there was no measured runoff. Since low CNs associated with the non-runoff events are "missing" from the calculation, CN is biased to the high side. The following paragraph details a few of the studies and methods in the literature that have been used to determine CN through alternative methods.

Rawls and Richardson (1983) incorporated CN values for conservation tillage practice into what has become NEH Part 630 table 9-1, "Runoff CNs for agricultural lands" (USDA NRCS 2001), based upon research that showed a relationship between the amount of residue left on the soil surface and a reduction in surface runoff. Curve numbers for conservation tillage were reduced one to four units, depending upon soil group and hydrologic condition. Hauser and Jones (1991) calculated CNs for a wheat/sorghum/fallow crop rotation on the western Great Plains, selecting annual maximum runoff events from a 32-year record and their associated rainfalls, as data pairs to perform the analysis. Yoo et al. (1993) determined CNs for a silt loam planted to cotton in northern Alabama under conventional and conservation tillage. The researchers used all rainfall-runoff data pairs for the three years under each tillage type to calculate CN. Their results showed a higher CN for conservation tillage than for CvT, contrary to the expected reduction of CN for conservation tillage based upon NEH 630 table 9-1 (USDA NRCS 2001). To determine CNs for several experimental Northern Great Plains watersheds having record lengths from 4 to 15 years, Hanson et al. (1981) used rainfall-runoff data for all summer runoff events with runoff greater than or equal to 6 mm (0.24 in), although they provided no rationale for the 6 mm cutoff. Hjelmfelt (1991) summarized data from several watersheds, showing that CN for average antecedent soil moisture conditions (AMCs) can be represented as the central tendency of CNs associated with events causing annual maximum peak discharge. He discussed the bias toward higher CNs when using data sets consisting of all events for only a few years of record. Hawkins et al. (1985) proposed a method to determine CN from observed rainfall-runoff data pairs for small watersheds by including the larger rainfall events for which the ratio of rainfall to potential maximum retention (P/S) was greater than 0.46. Mills et al. (1992) described a procedure employing numerical integration and nonlinear least squares optimization to correct the bias in CN calculated with all rainfall-runoff data rather than a subset of annual or larger events. Thus, past investigators have used various criteria by which to obtain rainfall-runoff data pairs from which CN could be determined for watershed records of a few years to a few decades.

Two of the major reasons for our research are as follows: (1) evaluation of the influence of conservation tillage on surface water quantity and quality in the Southeast Coastal Plain is a priority of the Conservation Effects Assessment Project effort; and (2) CN, used by SWAT to partition rainfall, is the most sensitive hydrologic parameter—thus, finding field-derived ranges for CN should reduce model uncertainty due to input parameter uncertainty. In addition, SWAT currently does not differentiate landscape position during delineation of hydrologic response units. Thus, the SWAT input value for CN, CN2, is an average value regardless of landscape position. As the model is improved and the landscape positions of hydrologic response units are recognized, calibrated model CN2 values should more nearly reflect those obtained by field experiment.

The specific objectives of the research were to (1) calculate and report CN for CvT and ST on Tifton loamy sand soil for a cotton-peanut crop rotation via four methods, which included published table values, a method finding the mean of the event CNs, a lognormal method for finding the median event CNs, and the method of Hawkins et al. (1985), which censors data from smaller rainfall events; (2) investigate the effect that using a range of rainfall-runoff data pairs has on CN calculation; and (3) compare CNs for the growing and dormant seasons for the two tillages.

We hypothesized that (1) CNs for CvT would be greater than for ST; (2) CN estimates would be less as fewer and larger events were used in the calculation; and (3) CNs for dormant seasons would be greater than for growing seasons.

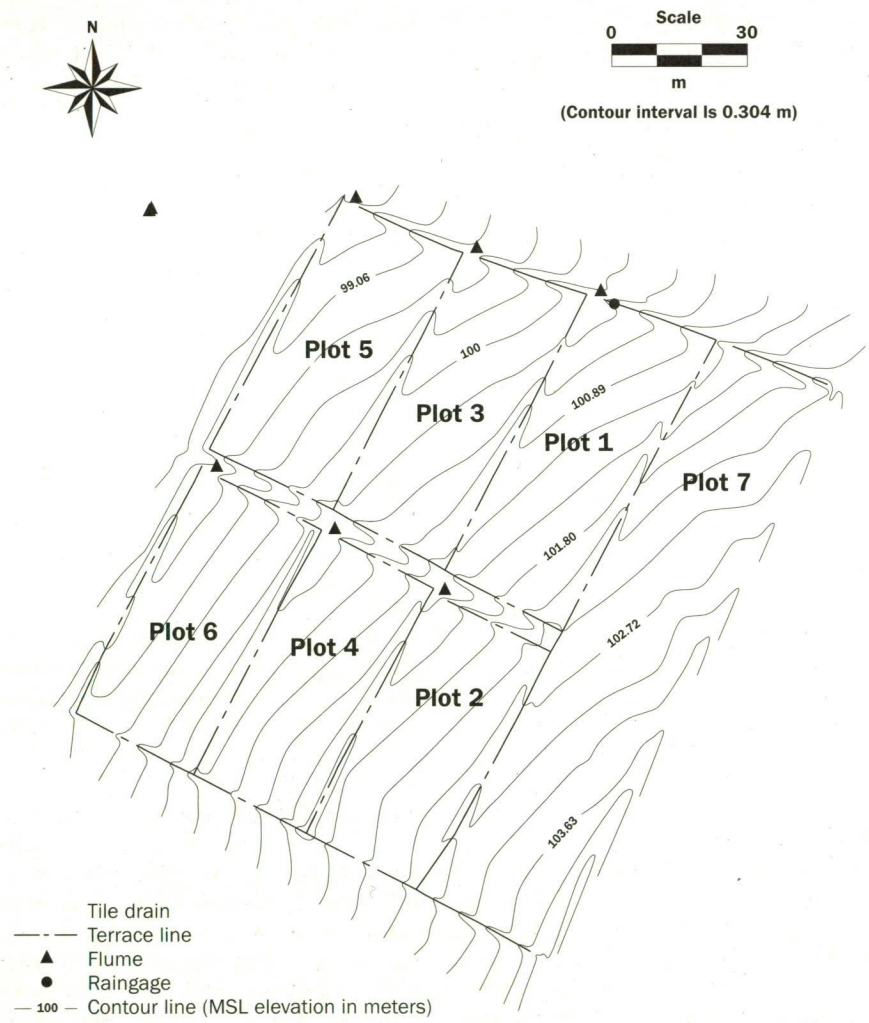
Materials and Methods

Description of Field Plots. The data used in this analysis came from a 1.7-ha (4.2-ac) parcel on the University of Georgia's Gibbs Farm, located 3 km (2 mi) southwest of Tifton in southwest Georgia. The study site was established in 1999 for the purpose of investigating the effects of conservation ST in a cotton-peanut crop rotation on soil infiltration-runoff characteristics, surface and subsurface runoff water quality, and soil quality. There were three 0.2-ha (0.5-ac) plots for each treatment, CvT and ST (figure 1). The land at the site sloped at 3% to 4% to the northwest. Each plot was surrounded by a 0.6-m (2-ft) high earthen berm, which isolated runoff from the plot and directed it through a 0.46-m (24-in) H flume that was installed in the plot's northwest corner. The depth of flow through the flume was measured with a pressure transducer and data logger. Lateral subsurface flow was also measured for the two treatments. Two separate 15-cm (6-in) drain tubes were installed at a 1.2-m (4-ft) depth down slope of the plots; one tube intercepted lateral flow from the CvT plots and the other from the ST plots. Each tube emptied down slope into a separate 0.24-m (9-in) HS flume. Precipitation was measured at the site with a tipping bucket rain gauge; data were collected at 1-minute intervals during rainfall events.

The soils at the site are from the Tifton series, fine-loamy, siliceous, thermic Plinthic Paleudults. The surface soil is sand, extending to an approximate depth of 25 cm (10 in). The surface horizon is underlain by a loamy sand to sandy loam layer continuing to a depth of approximately 50 cm (20 in). The depth to an argillic layer varies from 25 to 50 cm across these plots. The subsoil is a sandy loam to a sandy clay loam layer that continues to a depth of 3 m (9.8 ft). The increasing clay content with depth reduces hydraulic conductivity and effects lateral subsurface flow down slope. Additional details about the plots can be found in Bosch et al. (2005) and Bosch et al. (2006).

Published Table Values. The USDA NRCS maintains the published table of CN values for combinations of hydrologic soil groups and land use and treatment classes. The data are tabulated in Chapter 9, "Hydrologic Soil-Cover Complexes," of NEH Part 630 (USDA NRCS 2001). There, table 9.1, "Runoff curve numbers for agricultural lands," con-

Figure 1
Topographic map of Gibbs Farm cotton tillage research plots.



tains values for row crops appropriate for the Gibbs Farm experimental plots.

Curve numbers for CvT and ST were obtained from NEH 630 table 9.1, hydrologic soil group B, given that the soil at the Gibbs Farm plots is Tifton loamy sand. Cover type, treatment, and hydrologic condition were as follows: row crops, straight row, and poor for CvT; and row crops, straight row plus residue cover, and good for ST. We chose poor hydrologic condition for CvT because the soil surface was bare after field operations and crusting was evident after planting.

Table 1
Rainfall amounts on which antecedent moisture condition was selected for average curve number method.

Antecedent moisture condition	Description	Growing season	Dormant season
I	Lowest runoff potential	<35.6 mm	<12.7 mm
II	Average condition	35.6 to 53.3 mm	12.7 to 27.9 mm
III	Highest runoff potential	>53.3 mm	>27.9 mm

Average Curve Number Method. The Soil Conservation Service (SCS) Curve Number method for estimating direct runoff from storm rainfall is described in NEH Part 630 Chapter 10, "Estimation of Direct Runoff from Storm Rainfall" (USDA NRCS 2001). Runoff, Q, is calculated by the equation:

$$Q = \frac{(P - I_a)^2}{(P - I_a) + S} \quad \text{for } P > I_a, \tag{1}$$

$$Q = 0 \quad \text{for } P \leq I_a, \tag{2}$$

where P is the depth of rainfall, I_a is the initial abstraction, and S is the maximum potential retention. The initial abstraction is often assumed to be equal to $0.2S$. Substituting $0.2S$ for I_a in equation 1 and solving for S yields (Haan and Schultz 1987):

$$S = 5P + 10Q - 10\,(Q^2 + 1.25PQ)^{0.5}. \tag{3}$$

Note that the units for P and Q in equation 3 are inches. The curve number (CN) is a transform of S:

$$\text{CN} = \frac{1{,}000}{S + 10}, \tag{4}$$

for S in inches.

Event values for S were calculated when daily rainfall plus irrigation resulted in surface runoff. The runoff values used were the average values for the three plots for each treatment. Curve numbers were determined for each S value. The AMC for each event was determined by the criteria given in the SCS documentation (USDA SCS 1972) (table 1).

For events associated with AMC-I and AMC-III, the CN was corrected to AMC-II (Yoo et al. 1993) by rearranging formulas developed for estimating AMC-I (equation 5) and AMC-III (equation 6) from AMC-II (Chow et al. 1988; Haan et al. 1994):

$$\text{CN}_{\text{I}} = \frac{4.2\,(\text{CN}_{\text{II}})}{10 - 0.058\,(\text{CN}_{\text{II}})}, \tag{5}$$

$$\text{CN}_{\text{III}} = \frac{23\,(\text{CN}_{\text{II}})}{10 + 0.13\,(\text{CN}_{\text{II}})}. \tag{6}$$

The AMC-II CNs (CN-II) were then averaged to determine the CNs for CvT and ST. Once CN for AMC-II had been determined, the CN values corresponding to AMC-I and AMC-III, which were CN-I and CN-III, respectively, were calculated using equations 5 and 6.

Lognormal Method. The basis of the lognormal method for determining CN is the assumption that the curve number for AMC-II (CN-II) will divide the plot of rainfall versus runoff pairs into two groups of equal number. Under this assumption, CN-II represents the median of the data and is found statistically by calculating the mean of the logarithms of the event S values calculated by equation 3, and converting that mean to CN. The CNs corresponding to AMC-I (CN-I) and AMC-III (CN-III) have been shown to agree with the 10% and 90% probability values of the logarithms of the S values (Hjelmfelt 1991). The logarithms of the retention parameters S_{10} and S_{90}, representing the 10% and 90% probability values, respectively, were calculated with the equations found in Chapter 5 of NEH Part 630 (USDA NRCS 2001):

$$\log S_{10} = \overline{\log S} + 1.282\, sd\, (\log S)\ , \qquad (7)$$

$$\log S_{90} = \overline{\log S} - 1.282\, sd\, (\log S)\ . \qquad (8)$$

CN-I and CN-III were calculated by inserting the antilogs of $\log S_{10}$ and $\log S_{90}$ into equation 4.

Initially, event S values and CNs for each tillage type were calculated using rainfall-runoff data pairs for which average runoff for the three treatment plots was greater than 0. Then, S and CN were calculated using data pairs for which treatment average runoff was greater than 1, 2, 3, 4, 5, 10, 20, and 30 mm (0.04, 0.08, 0.12, 0.16, 0.20, 0.39, 0.79, and 1.18 in) to chart the effect of using smaller events in the calculation and to reduce the influence of runoff measurement errors at low flows. The lognormal method was chosen for the threshold runoff depth investigation because it has been shown to produce similar results to the average CN method (Yoo et al. 1993), is the current method recommended by the USDA NRCS (2001), and is simple to perform.

Data-Censoring Method. Hawkins et al. (1985) described the data-censoring method of determining S and CN. The researchers proposed using the rainfall-runoff data from relatively large storms, that is, storms for which $P/S > 0.46$, to determine CN. At the ratio of 0.46 between rainfall (P) and watershed maximum potential retention (S), 90% of all storms will create runoff. The method involves the following steps:

1. Sort all rainfall-runoff data pairs in descending order of rainfall.
2. Use the largest rainstorm and calculate S from equation 3.
3. Check for $P/S > 0.46$.
4. If $P/S > 0.46$, then add the next largest storm to the calculation, and use S calculated from the mean of the log S values. Go back to step 3.
5. Include all events down to the point where the last P divided by the mean S is greater than 0.46.

Analysis by Season. The rainfall-runoff data for Gibbs Farm were separated into two groups, growing season and dormant season, and CN-IIs for CvT and ST were calculated using the lognormal method. The growing and dormant seasons were defined as the portion of the year between planting and harvest, and harvest and planting, respectively. We chose dates of May 1 and October 31 to define the beginning and ending of the growing season, respectively. The data-censoring method was also used to calculate growing and dormant season CNs. The original data were separated by season, and then the data-censoring method outlined above was performed.

Statistical Analyses. The distribution of the data subsets by tillage, and by tillage and season, were tested for normality using the Statistical Analysis System (SAS) (SAS Institute 2002) UNIVARIATE procedure. The Shapiro-Wilk test statistic was used given that $n < 2{,}000$. The data subsets by tillage for the average, lognormal, and data censoring methods were not found to be normally distributed; therefore, comparisons of CNs by tillage were made with the Wilcoxon two-sample test within the SAS NPAR1WAY procedure for nonparametric tests (SAS Institute 2002). The assumption that the data subsets by season and tillage for the lognormal method were normally distributed could not be rejected; therefore, comparisons were made with the SAS TTEST procedure (SAS Institute 2002). Significant differences were noted for $p < 0.05$ unless stated otherwise. Statistical comparisons were made for CN-II values only because the mean and variance of the data pertain to CN-II; CN-I and CN-III are simply calculated values based upon CN-II.

Estimated runoff was calculated by the NRCS CN method with CN-IIs derived by the lognormal and data-censoring methods. Results were obtained using CN-IIs from the annual and seasonal analyses. The root mean square error (RMSE) and normalized mean square error (NMSE) were used to compare the methods and the annual vs. seasonal differences. The RMSE is defined as follows:

$$RMSE = \sqrt{\sum_{i=1}^{n} (O_i - S_i)^2 / n}\ , \qquad (9)$$

where O_i is the observed runoff for rainfall-irrigation event i, S_i is the simulated value for the same event, and n is the number of rainfall and/or irrigation events. The NMSE is defined as follows:

$$NMSE = \sum_{i=1}^{n} (O_i - S_i)^2 \Big/ \sum_{i=1}^{n} (O_i - \overline{O})^2\ , \qquad (10)$$

where O_i, S_i, i, and n are as previously defined and $\overline{O}$ is the mean observed runoff for the n events. The minimum NMSE value of 0 indicates that simulated values perfectly match observed runoff and an NMSE value of 1.0 means that the average observed value is as good a predictor of runoff as the simulated values are. NMSE values greater than 1 are possible.

Results and Discussion

Over the seven-year study period, there were 454 days with rainfall events that produced runoff events on at least one of the CvT plots and 312 days with rainfall events that produced runoff events on the ST plots, of 807 total days with rainfall. The primary source of water was rainfall; irrigation had been added to natural rainfall during 32 and 24 of the daily runoff events for CvT and ST, respectively. The number of rainfall-runoff data pairs used for each method is shown in table 2.

There were fewer runoff events from ST than from CvT for every threshold cut off except for 30 mm (1.18 in), the largest threshold tested, where the number of runoff events was equal at seven. For the data-censoring method, which used the ratio of P/S as the threshold, runoff event sizes ranged from 0.0 to 46.3 and 0.4 to 45.2 mm (0 to 1.82 in and 0.02 in to 1.78 in) and runoff occurrences were 60 and 37 for the CvT and ST data pairs, respectively. The data indicate less runoff for ST than for CvT and therefore greater infiltration and more plant available water, a conclusion reported by Bosch et al. (2005).

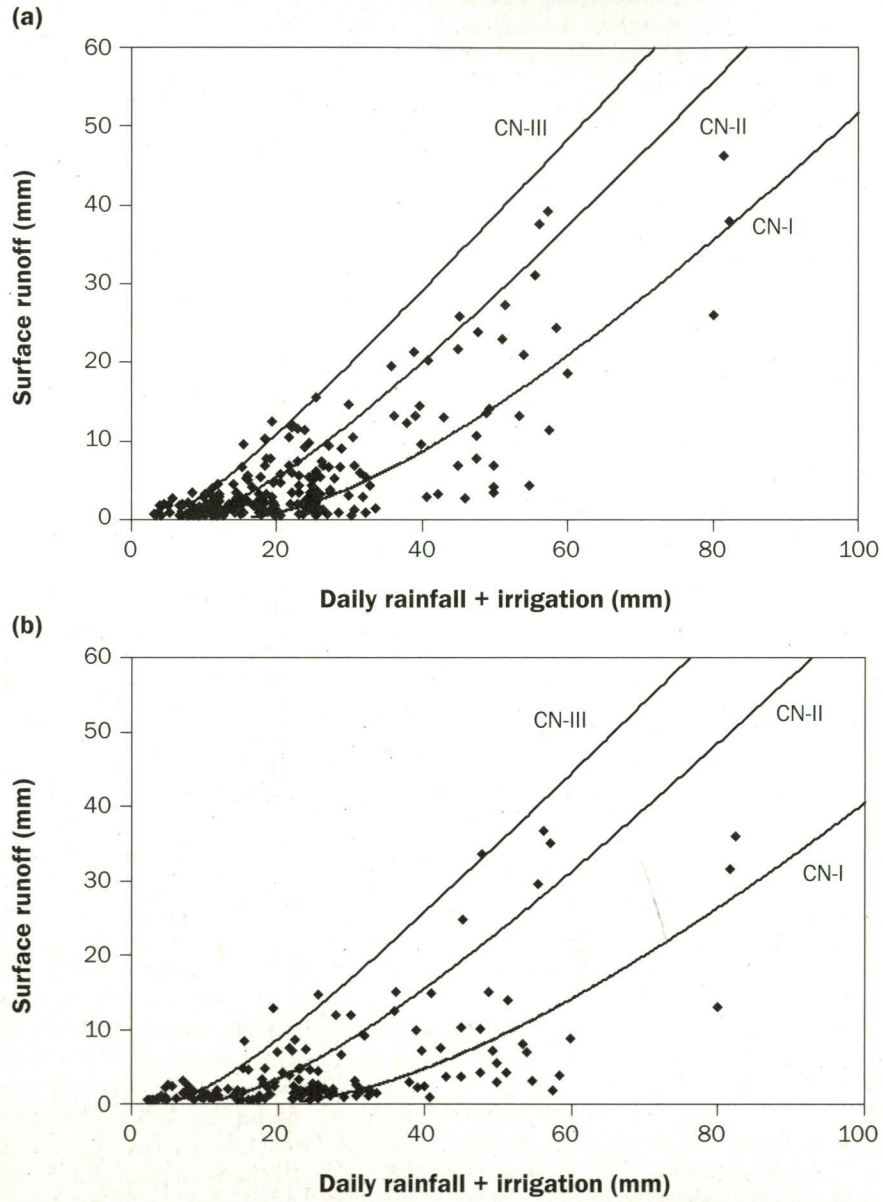
The plot of runoff versus rainfall plus irrigation pairs is shown in figure 2 with

Table 2
Number of rainfall-runoff pairs used in curve number (CN) calculation.

Method	CvT	ST
NEH Part 630, table 9-1 (USDA NRCS 2001)	NA	NA
Average CN	454	312
Lognormal, $Q > 0$	454	312
Lognormal, $Q > 1$ mm	180	121
Lognormal, $Q > 2$ mm	137	79
Lognormal, $Q > 3$ mm	109	58
Lognormal, $Q > 4$ mm	87	48
Lognormal, $Q > 5$ mm	76	38
Lognormal, $Q > 10$ mm	41	22
Lognormal, $Q > 20$ mm	17	10
Lognormal, $Q > 30$ mm	7	7
Data-censoring	60	37

Notes: CvT = conventional tillage. ST = strip tillage. NA = not applicable.

Figure 2
Daily rainfall plus irrigation and associated surface runoff for runoff events greater than 0.5 mm, 1999 to 2005, for (a) conventional tillage and (b) conservation strip tillage.



Note: Curve numbers (CNs) were calculated by the average curve number method.

graphic representation of the CNs for the three AMCs calculated by the average CN method. Table 3 contains the CN values for each of the four methods for the two treatments. The CN-IIs calculated by the average CN and lognormal methods were the same for CvT and within slightly more than one unit for ST. The two methods were within 1 to 4 units for CN-III; the results varied by 8 and 15 units for CvT and ST, respectively, for CN-I. The difference between the methods for the CN-I results can be in part attributed to the higher variability in runoff response for drier antecedent conditions, a point noted by Hjelmfelt (1991).

Results of the data-censoring method are the same as the NEH 630 table 9.1 values for a soil in hydrologic group B. Table 9-1 values were obtained by using an annual maximum event series. The data censoring method was intended to be used to determine CN from rainfall-runoff data using storms that had a 90% probability of measuring runoff.

The CN-IIs calculated from the Gibbs Farm data were higher for CvT than for ST for all methods of calculation, conforming to the relative order of handbook values and supporting our hypothesis. However, these results conflict with the order reported from research at another location in the southeastern United States (Yoo et al. 1993). The values for CN-II obtained by the average CN method, 91 and 88 for CvT and ST, respectively, were in reverse order to those obtained by the same method for CvT and conservation tillage, 85 and 89, respectively, in a six-year field experiment in northern Alabama. The rainfall-runoff data from Alabama were collected from a small watershed planted in cotton on a silt loam soil classified as soil hydrologic group B.

A notable item in table 3 is the discrepancy between the standard table CN values and those obtained by calculation using the field data. The CN-II values from the field data are 10 units greater than the table values for CvT and 13 to 14 units greater than for ST. The explanation for this discrepancy involves the nature of the data used for deriving the numbers. The NRCS method for obtaining curve number is based upon a maximum event annual series; only the rainfall-runoff data pair with the largest runoff is used for each year. Since larger events tend to lower CNs, including all smaller events in the calculation raises the CN. The average and lognormal methods used in the present research have included all rainfall-runoff data pairs, necessitated in part by the brevity of

Table 3
Curve numbers (CNs) calculated by four methods for conventional tillage (CvT) and conservation strip tillage (ST) for Gibbs farm plots.

	CN-I		CN-II		CN-III	
Method	**CvT**	**ST**	**CvT**	**ST**	**CvT**	**ST**
NEH Part 630 (USDA URCS 2001)	60* 64*	57*	78† 81‡	75§	90* 92*	88*
Average CN	80	75	x 91	y 88	96	94
Lognormal, $Q > 0$ mm	72	60	x 91	y 89	97	98
Data-censoring	65	57	x 81	y 75	90	87

Note: The letters *x* and *y* indicate CN-II differences within a row for $\alpha = 0.05$.

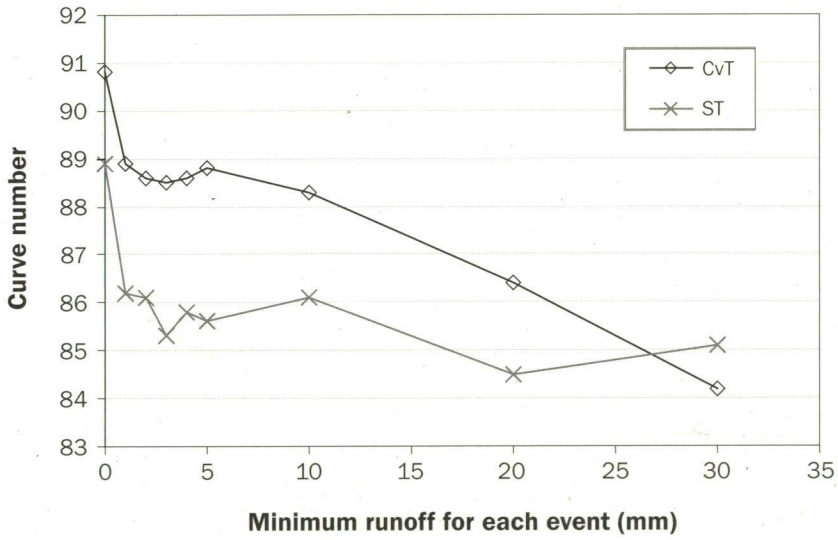
* Table 10.1.

† Table 9.1. Soil hydrologic group B, straight row, good.

‡ Table 9.1. Soil hydrologic group B, straight row, poor.

§ Table 9.1. Soil hydrologic group B, straight row + crop residue, good.

Figure 3
Curve number calculated with rainfall-runoff data pairs for which runoff events were larger than the value on the x-axis for conventional tillage and conservation strip tillage.



Notes: CvT = conventional tillage. ST = strip tillage.

the record. Hjelmfelt (1991) noted the tendency for CNs calculated from a few years' of field data to be higher than table values and suggested truncation of the record based upon rainfall, citing the work of Hawkins et al. (1985).

In order to demonstrate the effect of including smaller events in the data set used to calculate CN, we have plotted CN versus the minimum runoff event included in the rainfall-runoff pairs (figure 3), using the lognormal method to determine CN. When runoff events of 20 mm (0.79 in) or less are included in the CN calculation, CN is consistently two to three units less for ST than for CvT, a result that agrees with the prior research that led to the addition of separate CNs to NEH 630 table 9-1 for conservation tillage and supports our hypothesis. However, when only the rainfall events were used that produced runoff events greater than 30 mm (1.18 in), CN for ST exceeded that for CvT.

Evidence for a storm threshold, above which the soil profile fills sooner for ST than for CvT and therefore produces more runoff, can be seen in a graph showing annual maximum runoff event for CvT and ST for the years 1999 to 2005 (figure 4). The annual maximum runoff event for CvT and ST occurred during the same rainfall event in five of the seven study years. In 2000 and 2005, separate rainfall events caused the annual maximum runoff events for the two tillages and both events for each of those years are included in the graph. For the two largest rainfall events, 122 and 115 mm (4.8 and 4.5 in), of the nine charted, surface runoff from ST was greater than from CvT. One of the events occurred September 27, 2004 and was a seasonal tropical event in an otherwise drier-than-normal year. The other of the largest events occurred during 2005, which was wetter than the area long-term annual average. The four smallest rainfall events charted in figure 4, each measuring just over 50 mm (2.0 in), had split results in terms of relative runoff between CvT and ST. The results appear to be a function of season of the year and/or residual soil moisture from prior events. Runoff from the CvT plots was greater than from the ST plots for the events of July 22 and September 5, 2000, which both occurred during the growing season. Rainfall the 14 d prior to each event was 63 mm (2.5 in). On the other hand, runoff for the dormant season events of November 12, 2002, and March 20, 2003, were nearly equal for the CvT and ST treatments, and rainfall the previous 14 d was 105 and 102 mm (4.1 and 4.0 in), respectively. Thus, when the soil moisture is high, the rainfall-runoff relationships for CvT and ST appear to be similar, a point emphasized in the following analysis of growing season vs. dormant season CN calculation.

The concept of a larger storm threshold at which point CN for ST exceeds that for CvT apparently did not prove true in the case of the Alabama study (Yoo et al. 1993). Curve number for conservation tillage was greater than for CvT, even when all events (runoff threshold = 0) were used in the determination of CN. Thus, the results from the loamy sand soils of the Little River Experimental Watershed are not representative of all locations and soil types.

Table 4 contains CNs for CvT and ST calculated by the lognormal method for the growing and dormant seasons for the years 1999 to 2005. Values for dry (CN-I), average (CN-II), and wet (CN-III) antecedent moisture conditions are included. We chose to include runoff events greater than 5 mm (0.20 in) for the calculation because the previous analysis showed that CNs were stable

Figure 4
Maximum annual surface runoff events for conventional tillage (CvT) and conservation strip tillage (ST) (1999 to 2005).

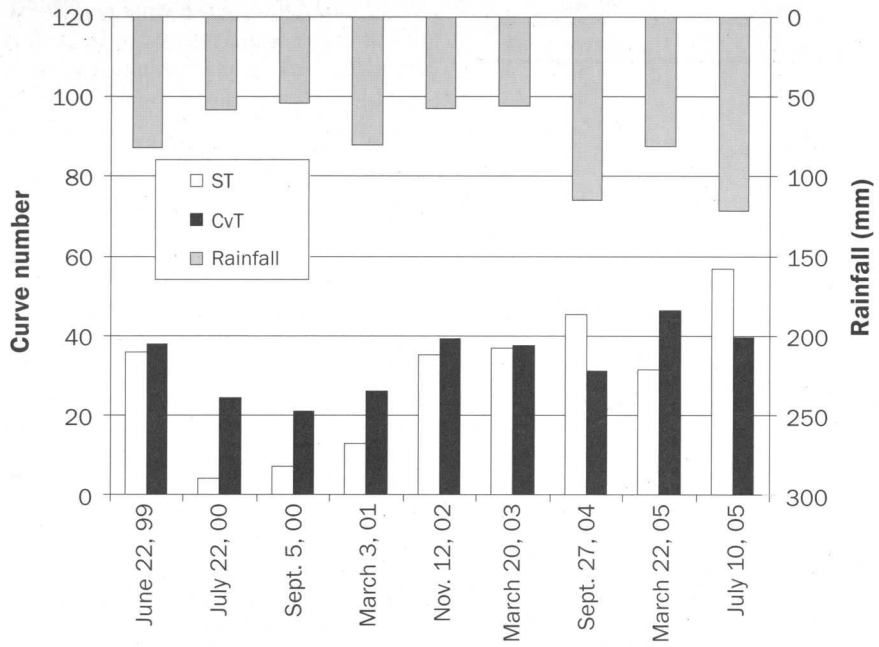


Table 4
Curve numbers (CNs) calculated by the lognormal method for runoff events > 5 mm for growing season and dormant season by tillage type for Gibbs Farm plots.

	CN-I		CN-II		CN-III	
Tillage type	**Growing**	**Dormant**	**Growing**	**Dormant**	**Growing**	**Dormant**
Convential tillage	77	75	*x* 89a	*x* 89a	95	95
Strip tillage	64	74	*x* 83b	*y** 88a	93	95

Notes: The letters a and b indicate differences within a column for $\alpha = 0.05$. The letters *x* and *y* indicate differences within a row for $\alpha = 0.05$.

* $p < 0.08$.

at that threshold. Also, eliminating smaller events removes those that are more prone to measurement error.

For ST, there is a statistically significant difference of five units at average antecedent moisture conditions between the growing and dormant seasons; however, the difference between seasons is less than one unit for CvT and is statistically insignificant. In both cases, CN for the dormant season is greater. Our hypothesis that CN for the dormant season would be greater than for the growing season was based upon the idea that higher evapotranspiration during the summer growing season increases soil moisture storage capacity, thus increasing infiltration, reducing runoff, and hence lowering CNs. The hypothesis was supported for ST but not for CvT. The infiltration-runoff dynamics under CvT are likely controlled by the soil at the surface since it is not shielded by litter. The surface likely seals somewhat and this dominates infiltration throughout the year. For the Tifton loamy sand on the Gibbs plots, CN-II was 6 units less for ST than for CvT during the growing season; however, the gap was reduced to one unit during the dormant season. The reduction in runoff due to ST diminished to 2 units in the growing season under wet antecedent moisture conditions. During the dormant season, CN-IIIs were identical for ST and CvT. Thus, under above-normal AMCs during the dormant season (e.g., figure 4, November 12, 2002, and March 20, 2003), equivalent runoff can be expected between the two tillage types. Under dry antecedent moisture conditions, CN-I for ST is 13 and 1 unit(s) lower than for CvT for the growing and dormant seasons, respectively, due in part to a lower CN-II, but also an indication that rainfall-runoff relationships are more variable under ST than under CvT, especially during the growing season.

For ST there is a difference of 5 and 2 units between growing and dormant seasons for AMC-II and AMC-III conditions, respectively, while for CvT there is little to no appreciable difference between the seasons for these two conditions (table 4). The results indicate that during the growing season, CNs for ST, compared to CvT, were lower by 13, 6, and 2 units for dry, average, and wet antecedent moisture conditions, respectively. The CN reductions indicate increased infiltration and reduced surface runoff, erosion, and associated nutrient and chemical loss for agricultural fields managed by ST. The CN differences between the tillage types are less pronounced for the dormant season. During this period of the year when the main crop is not growing, the ST curve numbers were 1, 1, and 0 units less than the CvT curve numbers for dry, average, and wet antecedent moisture conditions, respectively, and the differences were statistically insignificant.

The data-censoring method was also used to estimate CNs for the growing and dormant seasons (table 5). The CN values were generally lower for the data-censoring method for reasons previously discussed. For CvT, the growing and dormant season CN-IIs were statistically different ($p < 0.08$). The variability in CN from CN-I to CN-III for ST–growing season is less when calculated by the data-censoring method than by the lognormal method, evidently a result of the way that storms are included in the analysis by the P/S ratio. The spread in CNs from CN-I to CN-III is much greater for ST–dormant season (33) than for ST–growing season (16). This is somewhat counterintuitive in that one could expect there to be a wider range of soil moisture antecedent conditions during the growing season.

Comparisons of RMSE and NMSE of runoff estimates based upon CN-IIs derived by the lognormal and data-censoring methods are shown in table 6. The errors are shown for CvT vs. ST and for one annual CN vs. separate CNs for growing and dormant seasons. For each of the four tillage–temporal regime cases, the data-censoring method errors were less than the lognor-

Table 5
Curve numbers (CNs) calculated by the data-censoring method for growing season and dormant season by tillage type for Gibbs Farm plots.

	CN-I		CN-II		CN-III	
Tillage type	**Growing**	**Dormant**	**Growing**	**Dormant**	**Growing**	**Dormant**
Conventional tillage	71	62	x 82a	y* 79a	90	90
Strip tillage	62	58	x 71b	y† 79a	78	91

Notes: The letters a and b indicate differences within a column for $\alpha = 0.05$.
* $p < 0.08$.
† $p < 0.16$.

Table 6
Root mean square error and normalized mean square error of runoff estimates based upon curve numbers derived by the lognormal ($Q > 5$ mm) and data-censoring methods.

		Root mean square error		Normalized mean square error	
Tillage type	**Temporal regime**	**Lognormal (mm)**	**Data-censoring (mm)**	**Lognormal**	**Data-censoring**
CvT	Annual	4.93	3.57	0.97	0.53
	Seasonal	4.91	3.61	0.96	0.54
ST	Annual	4.12	2.67	0.84	0.37
	Seasonal	4.19	2.62	0.87	0.35

Notes: CvT = conventional tillage. ST = conservation strip tillage.

mal method errors. The NMSE differences between the methods were pronounced. Using the NRCS curve number method to estimate runoff for the 836 rainfall and/or irrigation events with CN-IIs from the lognormal method yielded results that would be only slightly better than simply estimating the average runoff depth for each event. Because the data-censoring method yielded better runoff estimates, we recommend that this method be used to calculate CN with experimental plot rainfall-runoff data pairs. Since the data set will be truncated by the $P/S > 0.46$ criteria when using the data-censoring method, several years of data may be required to reduce uncertainty of values calculated by the method. The method results also appear to correspond well with published CN values, which is a benefit in that hydrologic models and SWAT in particular use an initial CN based on the standard NEH 630 table.

Comparisons of RMSE and NMSE for cases using one annual CN vs. separate CNs for growing and dormant seasons showed no appreciable differences between the two for either CvT or ST treatments (table 6). Because there were significant differences between growing and dormant season CNs, we expected to see an improvement in accuracy of runoff estimates when separate growing and dormant CNs were used. We used the NRCS curve number equation (equation (1) and CN-II only for estimating runoff. The use of CN-I or CN-III, or other adjustment of CN-II based upon soil moisture content (e.g. hydrologic models such as SWAT) have the potential to improve runoff estimates by accounting for the influence of soil moisture on CN at the time of the rainfall. However, the results of this study indicate that separate CNs for different seasons do not improve runoff estimates.

Summary and Conclusions

Curve numbers were calculated from field rainfall-runoff data pairs measured on six 0.2 ha (0.5 ac) plots in South Georgia for two tillage treatments, CvT and ST, under a cotton-peanut crop rotation on a Tifton series loamy sand. The CN under average antecedent moisture conditions, CN-II, calculated by the average CN and the lognormal methods on an annual basis, was identical for CvT, 91, and varied by one unit, 88 and 89, respectively, for ST; however, these results were substantially above the NEH Part 630 table 9.1 values for CvT and ST, 81 and 75, respectively. The values for CN-II obtained by a data-censoring method proposed by Hawkins et al. (1985) matched the NEH Part 630 table 9.1 values. All methods indicated higher variability in runoff from ST compared with CvT as evidenced by larger variation between CN-I and CN-III for ST. In order to reflect in hydrologic simulation exercises the impact that conservation ST has on runoff and total water yield, hydrologic models that use a CN approach to calculating runoff will need to be parameterized with separate sets of curve numbers for CvT and ST.

Although statistical differences were seen between growing and dormant season CN-IIs for ST by the lognormal method and for CvT and ST by the data-censoring method, there were no differences in runoff estimates when using one annual CN-II vs. separate CN-IIs for growing and dormant seasons, based upon the errors of estimates. The data-censoring method CNs yielded lower runoff estimate errors than did the CNs obtained by the lognormal method. The data-censoring method is recommended for determining CNs from plot rainfall-runoff data pairs.

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