Modified runoff curve numbers for sugarcane and pineapple fields in Hawaii

Keith R. Cooley and Leonard J. Lane

ABSTRACT: Runoff curve numbers for sugarcane and pineapple fields in Hawaii were derived from rainfall and runoff data collected during a 7-year study between 1972 and 1979. The new curve number values were used to modify previously determined values based on 5 years of data and to adjust Soil Conservation Service handbook values. Handbook values were based mainly on experience obtained under mainland conditions and soils. The data-based curve numbers were slightly lower than previously used handbook values for sugarcane fields. The greatest differences were for porous A soils and complete cover conditions. The data-based curve numbers were considerably lower than handbook values for pineapple fields, where field roads occupied 11 to 20 percent of the area. The greatest differences were noted after pineapple had reached the partial or complete cover stage, indicating that pineapple provides more protection than expected once it covers at least 50 percent of the field surface. Observations suggest that major portions of the runoff comes from field roads, for which curve numbers are two to three times greater than those derived from the cropped area.

RUNOFF curve numbers for sugarcane and pineapple fields in Hawaii that we presented in a previous report (2) were based on data collected between 1972 to 1977. These numbers were urgently needed at the time by Soil Conservation Service personnel and others. All previously used numbers were based on mainland experience.

After publication of that report, the Agricultural Research Service small watershed project in Hawaii was discontinued. We were able to collect and analyze 2 additional years of data before the project's termination, however. Therefore, we are able to present here modified runoff curve numbers, determined from the 1972-1979 data base, for the same sugarcane and pineapple fields described previously. Also, we compared the new runoff curve numbers with the original values from the SCS handbook (8, 9) for all soil conditions using the same extrapolation method we used in our 5-year study.

Study watersheds

Our study involved five small (1.5 to 7 acres), nonirrigated agricultural watersheds. Two watersheds, planted to sugarcane, were on the island of Hawaii. The other three, one in sugarcane and two in pineapple, were on the island of Oahu.

We began collecting data in early 1972 on all of the watersheds but one, a pineapple site that was instrumented in 1975. Instrumentation on all sites consisted of a recording raingage, a water-stage recorder, a critical-depth flume, and a splitting and rotating sediment sampler (5). We visited each site weekly to maintain the recorders, take sediment samples, and record field crop and cover conditions.

Nonirrigated sugarcane production in Hawaii normally requires 28 to 45 months from planting to harvest, depending mostly upon rainfall at critical growth periods. At harvest, the stalks are cut off near the soil surface, leaving only the roots. After harvest, the plants are generally allowed to come back, or ratoon, twice. Therefore, 6 to 8 years elapse between plowing, disking, and replanting (6).

Pineapple generally is harvested about 18 months after planting. In contrast to sugarcane harvest, only the fruit is picked in the first pineapple harvest. Two more such harvests are normally completed at 9-month intervals before the crop is chopped, allowed to dry, and burned. The fields are then plowed, disked, and replanted between plastic strips. This cycle takes about three years in most cases (1). The plastic strips control weed growth until the pineapple plants are established. The strips cover most of the seedbed area and about half the total field. Pineapple shoots are placed through the plastic at designated points by hand.

Both crops provide a dense cover after 4

Keith R. Cooley and Leonard J. Lane are hydrologists with the Agricultural Research Service, U.S. Department of Agriculture, Boise, Idaho 83705, and Tucson, Arizona 85705, respectively. This article is a contribution from the Northwest Watershed Research Center, ARS, USDA. Initial research was done at the U.S. Water Conservation Laboratory, Phoenix, Arizona, and the Southwest Rangeland Watershed Research Center, Tucson, Arizona.

to 6 months of growth. This dense cover affects soil surface sealing and subsequent runoff and erosion.

Table 1 summarizes the main characteristics of each watershed. A brief description and cropping history of each watershed is contained in the original article (2).

Study methods

SCS officials estimate runoff due to rainfall using the equation

$$Q = \begin{cases} 0 & , P \leq 0.2\,S \\ \dfrac{(P-0.2S)^2}{(P+0.8S)} & , P > 0.2\,S \end{cases} \qquad [1]$$

where Q is the runoff volume in inches, P is the storm rainfall in inches, and S is the retention parameter in inches.

From S in equation 1 a runoff curve number, CN, is defined as:

$$CN = \frac{1,000}{10+S} \qquad [2]$$

with values between 0 (no runoff) and 100 (all rainfall becomes runoff).

This procedure incorporates four soil classifications, three antecedent moisture classifications, and various cover complexes. The soil classification is broken into four hydrologic soil groups, A, B, C, and D, varying from relatively low runoff potential (A) to high runoff potential (D). Antecedent moisture condition I represents a relatively dry condition; II represents an average or normal condition; and III represents a wet antecedent condition. Runoff curve numbers also reflect land use, such as fallow, row crops, and pasture, as well as treatments or practices, such as straight-row cultivation, contour farming, and terracing (8). The usual SCS procedure is to determine runoff curve numbers from the handbook for the given soil and cover complexes and antecedent moisture classification II. The curve number for condition II is then adjusted for the existing moisture condition (8).

However, because observed rainfall and runoff data are available, S (or CN) can be determined in equation 1 by optimization. The objective function, G, is defined as

$$G = \sum_{i=1}^{n} (Q_i - \hat{Q}_i)^2 \qquad [3]$$

where Q_i is an observed runoff volume, $\hat{Q}_i$ is a computed runoff volume using equation 1, and n is the number of storms. The optimal CN is that value, when used with observed P and Q in equations 1 and 2, that minimizes G in equation 3. Associated with the "best" or least squares estimate of CN is a coefficient of determination, R^2. Values of R^2 near zero would indicate that fitting the SCS model, equation 1, was little better than using the mean runoff volume as a predictor. Values of R^2 near one would indicate nearly perfect fit.

The curve numbers also were distributed or weighted (2), based upon the percentages of watershed area in roads and in crops. Although our study included all storms with runoff, in contrast to the SCS recommendation of using only the larger events (8), the least squares procedure tended to give more weight to the larger storms. The curve numbers calculated using all events compared closely with curve numbers using only storms of 2 inches or more precipitation.

Results

Sugarcane. We used observed rainfall and runoff data from two small watersheds without roads and from one with roads covering 5 percent of the watershed area to determine optimal CNs for sugarcane cultivation (Table 2). The optimized curve numbers for the 1972-1979 period varied only slightly from those obtained using 1972-1977 data (0 to 10 units), although the number of events increased from 1.3 to 3 times (2). The coefficients of determination, R^2, for the seven conditions shown in table 2, remained essentially the same or increased considerably, indicating an overall improvement in the relationship.

The variability in curve numbers for the two watersheds with type A soils indicates that for a given crop cover condition and hydrologic soil group a range of conditions exists. The data-based curve numbers for the two watersheds under bare soil were 53 and 60. The complete cover values were 46 and 28, respectively. Composite values determined were 54 and 39 in these two cases. The greater (18-unit) difference between values under a complete crop cover indicates that the crop cover causes more difference than the 7-unit difference noted for the bare soil condition. A series of watersheds on a given soil type and with a given crop cover condition would be required to determine the range of variability one might expect within a given class.

When the values presented in table 2 were weighted according to number of events, plotted, extrapolated, and adjusted using the SCS "curve number aligner," values for all hydrologic soil groups and cover conditions were obtained (Table 3). The data-based curve numbers shown in table 3 varied by only 0 to 5 units from those derived from the 1972-1977 data. Also shown in table 3 are original SCS handbook values for comparison. The differences between data-based and handbook values were greatest for the bare or limited cover conditions on A soils and the complete cover conditions on B, C, and D soils. The indication here is that infiltration

Table 1. Description of study watersheds.

	Watershed				
	Laupahoehoe	*Honokaa*	*Waialua*	*Mililani*	*Kunia*
Island	Hawaii	Hawaii	Oahu	Oahu	Oahu
Crop	Sugarcane*	Sugarcane*	Sugarcane*	Pineapple	Pineapple
Size (acres)	2.05 (2-72, 4-74) 1.52 (4-74, 79)	5.17	5.97	5.09 (2-72, 4-73) 3.80 (4-73, 79)	7.02
Average annual precipitation (inches)	150-200	70-100	60-90	40-60	24-50
Soil classification (*4, 8*)					
Order	-	-	Ultisols	Oxisols	Inceptisols
Subgroup	Typic Hydrandepts	Hydric Dystrandepts	Humoxic Tropohumults	Tropeptic Eutrustox	Ostoxic Humitropepts
Family	Thixotropic, isothermic	Thixotropic, isothermic	Clayey, oxidic isothermic	Clayey, kaolinitic, isothermic	Fine, oxidic, isothermic
Series	Kaiwiki	Kukaiau	Paaloa	Wahiawa	Kolekole
Field texture	Silty clay loam	Silty clay loam	Silty clay	Silty clay	Silty clay loam
General soil slope (percent)	16	17	10	5	7
Hydrologic soil group	A	A	B	B	C
Percent roads	0	0	5	15	11†

*All sugarcane watersheds cropped in nearly straight-row cultivation; runoff curve number for roads taken as 90 (*3*).
†Some data were recorded from an earlier planting where roads occupied 20 percent and pineapple 80 percent of the area.

capacities were greater than anticipated for the A soil, and the complete sugarcane cover provided more protection and greater resistance than estimated.

Pineapple. We used observed rainfall and runoff data from two small watersheds with field roads covering 11 to 20 percent of the watershed area to determine optimized curve numbers for pineapple cultivation (Table 4). Both of these watersheds had reached the complete cover stage by the end of 1977, and all data collected between then and the end of the project were for this cover condition. Therefore, the only changes between the 1972-1977 values and those obtained using the 1972-1979 data base were for the complete cover condition.

The curve number for the Kunia site changed by only 1 unit, and R^2 remained the same, although the number of events increased 1.6 times. For the Mililani site, the curve number declined from 47 to 38, as the number of events increased from 15 to 53 (3.5 times). The coefficient of determination dropped from 0.93 to 0.83 but still indicated good correlation. When the optimized values in table 4 were subjected to the same extrapolation procedures described previously for sugarcane, curve numbers for all hydrologic soil groups and cover conditions were developed (Table 5).

The runoff curve numbers for pineapple presented in table 5 changed by 2 to 18 units from those obtained using the 1972-1977 data. These changes were due entirely to the change in cover condition noted. The values obtained using the 1972-1977 data were based on relatively few events, and weighting was essentially uniform. With the increased number of events for the complete cover condition, and the high values of R^2, these curve numbers were given more weight when adjustments and extrapolations were made. The values in table 5 also correspond more closely to the trends indicated by the handbook values (*9*) than did the values based on 1972-1977 data. The greatest changes occurred on the tighter soils with partial or complete cover.

Discussion and conclusions

Comparison of the new runoff curve numbers obtained using actual rainfall-runoff data and those published in SCS handbooks indicated that data-based values were generally lower for sugarcane than handbook values. The greatest differences were associated with the porous A soils and greater cover conditions. Sugarcane apparently provides more protection because of its dense cover than expected. The porous A soils seemingly have the ca-

Table 2. Summary of optimized runoff curve numbers (CNs) for small sugarcane watersheds in Hawaii.

Watershed (soil series)	*Study Runoff Curve Numbers and Statistics for Various Cover conditions**										
	Bare Condition			*Limited Cover*		*Partial Cover*			*Complete Cover*		
	CN	*R²*	*N*	*CN*	*R²*	*CN*	*R²*	*N*	*CN*	*R²*	*N*
Laupahoehoe (Kaiwiki)	53	.77	46	-	-	-	-	-	46	.62	150
Honokaa (Kukaiau)	60	.33	12	-	-	-	-	-	28	.76	63
Waialua (Paaloa)	80	.86	28	-	-	61	.83	21	49	.65	62

*Bare condition: no vegetative cover. Limited cover: cane new or ratooned with less than 50 percent canopy cover. Partial cover: transition from limited to complete cover with more than 50 percent canopy cover. Complete cover: full canopy provided until time to harvest.

Table 3. Runoff curve numbers for sugarcane cover—hydrologic soil groups on small Hawaiian watersheds. All curve numbers for nearly straight row cultivation.

*Cover**	*Runoff Curve Numbers for Sugarcane Cover — Hydrologic Soil Group†*			
	A	*B*	*C*	*D*
Bare	**54** (77)‡	**80** (86)	89 (91)	92 (94)
Limited cover	50 (67)	71 (78)	81 (85)	86 (89)
Partial cover	45 (49)	**61** (69)	72 (79)	78 (84)
Complete cover	**39** (39)	**49** (61)	58 (74)	64 (80)

*Bare: no vegetative cover. Limited cover: cane new or ratooned with less than 50 percent canopy cover. Partial cover: transition from limited to complete cover with over 50 percent canopy cover. Complete cover: full canopy provided until time of harvest.
†Curve number for hydrologic soil group C and D extrapolated.
‡Values in boldface type are optimized curve numbers from observed data. Values in parentheses are from SCS Handbook (*8*). Handbook values for bare soil are those listed under fallow conditions in Table 9-1 from the SCS national engineering handbook (*8*).

Table 4. Summary of optimized runoff curve numbers (CNs) for small pineapple watersheds in Hawaii.

Watershed (soil series)	*Study Runoff Curve Numbers and Statistics for Various Cover conditions**											
	Bare Condition			*Limited Cover*			*Partial Cover*			*Complete Cover*		
	CN	*R²*	*N*	*CN*	*R²*	*N*	*CN*	*R²*	*N*	*CN*	*R²*	*N*
Mililani (Wahiawa)	78	.37	20	61†	.93	24	-	-	-	38	.83	53
Kunia (Kokekole)	87	.74	9	74	.88	7	64	.85	7	48	.83	52

*Field roads were considered separately and assigned CNs of 90 for Mililani and 92 for Kunia (*3*).
†Values computed from mixed cover of crops and weeds rather than pineapple.

Table 5. Runoff curve numbers for pineapple cover—hydrologic soil groups on small Hawaiian watersheds. All curve numbers are for nearly cross-sloped row cultivation.

*Cover**	*Runoff Curve Numbers for Hydrologic Soil Group†*			
	A	*B*	*C*	*D*
Bare	67 (77)	**80** (86)‡	**87** (91)	90 (94)
Limited cover	49 -	**61** -	**71** -	76 -
Partial cover	39 (67)	50 (78)	**60** (85)	66 (89)
Complete cover	28 (49)	**38** (69)	**48** (79)	55 (84)

*Bare: no vegetative cover. Limited cover: stage of cover from planting until plants extend beyond plastic strips (provide ≈ 50% cover). This stage is not used by SCS, but is included in the partial cover stage. Partial cover: from 50 percent cover to initial closing in (greater than 80% cover). Complete cover: stage of growth when crop is completely closed in.
†Curve number for hydrologic soil group A and D extrapolated.
‡Values in boldface type are optimized curve numbers from observed data. Values in parentheses are from SCS Handbook (*9*). Handbook values for bare soil are those listed under fallow conditions in Table 9-1 from the SCS national engineering handbook (*8*).

pacity to absorb most rainfall events also. Therefore, little runoff occurs. These slightly lower curve numbers for sugarcane probably would not change design criteria significantly.

Data-based curve numbers for pineapple fields under bare soil conditions were similar to handbook values. But, data-based values for partial and complete pineapple cover were 20 to 30 units lower than handbook values, indicating that pineapple provides considerably more soil protection than expected because of its dense cover, once it covers at least 50 percent of the soil surface. Also, the curve numbers presented are for the pineapple-covered portion of the watershed only. The 10 to 20 percent area covered by roads was considered separately. Thus, considerable runoff may still occur, but it would be produced mainly from the road area, for which the curve number (on the order of 90 to 92) is much higher than for the field areas.

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