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COVER: Point Betsie Lighthouse on Lake Michigan. SCSA's Michigan Chapter will host the 35th annual meeting, August 3-6, in Dearborn. See pages 150-151 for the program. Photo courtesy Travel Bureau, Michigan Department of Commerce.

ing site index requires standing trees and site index curves, indirect estimates can be made from soil and site factors in prediction equations. This avoids damaging highly valuable walnut trees by boring the trunk to determine a tree's age.

Our "best" equation requires measuring both field factors and laboratory texture analysis. Although a little less accurate, the "easy-to-measure" equation should give adequate site evaluation information. Both equations make possible the evaluation of potential walnut growing sites on the western fringe of the tree's natural geographic range.

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Optimized runoff curve numbers for sugarcane and pineapple fields in Hawaii

Keith R. Cooley and Leonard J. Lane

ABSTRACT: Runoff curve numbers for Hawaiian sugarcane and pineapple fields were derived from actual rainfall-runoff data and used to adjust handbook values. These handbook values were based mainly on experience under mainland conditions and soils. The data-based curve numbers were slightly lower than previously used handbook values for sugarcane. They were considerably lower for pineapple fields where field roads occupied 11 to 20 percent of the area. Observations suggest that major portions of the runoff come from road areas and that more intensive conservation measures and maintenance programs for these roads would help reduce this runoff and subsequent erosion.

TO design soil conservation practices, it is helpful to know the runoff and erosion potential of an area under various field, soil, and precipitation conditions. Agencies assigned the task of helping farmers develop conservation measures must therefore develop or adapt methods to estimate the amount of runoff expected from given rainfall. One method of estimating direct runoff from storm rainfall, based on data from runoff plots and watersheds and on years of field experience, is the runoff curve number method developed by the Soil Conservation Service (*6*). In most parts of the United States an experienced conservationist can estimate quite accurately the runoff curve number associated with a given field or watershed using the tabulated relationship derived between these curve numbers and various hydrologic soil-cover complexes.

In some areas, such as Hawaii, where data from small watersheds were almost nonexistent, SCS personnel estimated runoff curve number relations on the basis of experience obtained under mainland conditions (*6*). In 1972 the Science and Education Administration—Agricultural Research initiated a study on five small agricultural watersheds in Hawaii to determine actual runoff and erosion relations on sugarcane and pineapple land. Our report compares calculated runoff curve numbers with handbook values. We present tables of adjusted curve numbers under all soil

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This study is part of a more inclusive study being conducted by SEA-AR personnel and the Department of Agronomy and Soil Science at the University of Hawaii (cooperative agreement no. 12-14-5001-320) on land owned by the Laupahoehoe Sugar Company, Honokaa Sugar Company, Waialua Sugar Company, Dole Company, and Del Monte Corporation.

conditions for both sugarcane and pineapple crops.

Description of study watersheds

We selected five small, nonirrigated agricultural watersheds for the study. Two of the watersheds, planted to sugarcane, were on the island of Hawaii (Figure 1). The other three, one in sugarcane and two in pineapple, were on the island of Oahu (Figure 2). Data collection started in early 1972 on all of the watersheds except one 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 (4). We visited each site weekly to maintain the recorders, take sediment samples, and record field crop and cover conditions.

Nonirrigated sugarcane in Hawaii normally requires 28 to 34 months from planting to harvest, depending mostly on rainfall availability at critical growth periods. Harvesting consists of cutting the stalks off at the soil surface, leaving only the roots. After harvest, the plants are allowed to come back, or ratoon, twice. Therefore, 6 to 8 years elapse between plowing, disking, and replanting operations (5).

Pineapple generally is harvested about 18 months after planting. In contrast to sugarcane harvest operations, 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 in plastic strips. This cycle takes about 3 years in most cases (1). The plastic strips control weed growth until the pineapple plants are established. The strips cover most of the bed area and about half of the total field. The pineapple shoots are placed through the plastic at designated points by hand.

Both crops provide a dense cover after 4 to 6 months of growth, thus providing the soil surface with considerable protection against rainfall impact. This dense cover affects surface sealing, runoff, and erosion.

A brief description and cropping history of each watershed follows. Table 1 summarizes the main characteristics of each site.

Laupahoehoe. This site was planted to sugarcane in March 1967, harvested in March 1971, ratooned, and harvested again in February 1974. Sugarcane was replanted in May 1974, the first crop harvested in August 1977, again ratooned, and scheduled for harvest in 1979. The watershed, which is 100 percent cultivated, is shaped like a clam shell, ending with a flat portion leading to the flume.

Figure 1. Locations and survey maps for watersheds on the island of Hawaii: (1) Laupahoehoe and (2) Honokaa. Contours shown are 5-foot intervals.

Figure 2. Locations and survey maps for watersheds on the island of Oahu: (3) Waialua, (4) Mililani, and (5) Kunia. Contours shown are 5-foot intervals.

Honokaa. This site was planted to sugarcane in May 1968, harvested in March 1971, ratooned, and again harvested in May 1974. Sugarcane was replanted in June 1974, the first crop harvested in October 1976, followed by a ratoon crop that was scheduled for harvest in 1979. The watershed, which is 100 percent cultivated, is somewhat elongated with alternating slopes of different gradients, the flattest being the area near the flume.

Waialua. This site was planted to sugarcane in December 1966, ratooned in August 1968, September 1970, August 1972, November 1974, and again in May 1977. The field was re-worked at least twice before replanting in March 1978. The watershed surface is convex, flat on the upper portion and steep on the lower site adjacent to the road. The road accounts for about 5 percent of the watershed area and forms the lower boundary.

Mililani. This site was planted to pineapple in late 1968. After the final harvest in mid-1972, weeds and grass were allowed to grow until the spring of 1973 when the site was tilled and planted to Irish potatoes. This cropping, often sparse and intermixed with weeds, lasted until mid-1976 when the field was again prepared for pineapple. Because of the limitation imposed by harvesting equipment, a road is needed at least every 100 feet in pineapple culture; thus, roads cover 15

Table 1. Description of study watersheds.

	Watershed				
Characteristic	*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 series	Kaiwiki	Kukaiau	Paaloa	Wahiawa	Kolekole
Field texture	Silty clay loam	Silty clay loam	Silty clay	Silty clay	Silty clay loam
General soil slope (%)	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.

percent of the watershed area.

Kunia. This site has been planted to pineapple for nearly 50 years. The field was planted in May 1974, harvested in December 1975, and again in December 1976. A new crop was planted in May 1977. This watershed, the largest, has the most complex drainage pattern and the highest percentage of roads (17%) before the May 1977 planting. It also contained a waterway representing 3 percent of the area prior to the 1977 planting. In 1977 the road and waterway area were reduced to 11 percent of the watershed by eliminating most of the with-slope roads and planting across most of the waterway.

Rainfall on the watersheds ranges from a high of 150 to 200 inches at Laupahoehoe to 30 to 50 inches at Kunia. Most storms are of relatively low intensity, although they may last for rather long durations, and fit into the Type IA or I storm category defined by SCS (*7*). Higher intensity storms of Type II and IIA do occur on the islands occasionally (*2*), and very large storms of even low to medium intensity can cause considerable runoff and erosion. The winter months, November through March, are generally the wettest; June and July are the driest, although rainfall can occur at any time. In some areas it rains almost every day (*8, 9*).

Study procedures

The SCS procedure for estimating runoff volume due to rainfall uses the equation:

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

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:

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

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, as described in the National Engineering Handbook (*6*). The usual SCS procedure, which we followed here, is to determine runoff curve numbers for the given soil and cover complexes for antecedent moisture classification II. In actual practice, the curve number for condition II is selected and then adjusted for the existing moisture condition (*6*).

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

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

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 in the data set. The optimal CN is that value that minimizes C in equation 1. Associated with the "best" or least squares estimate of CN from equation 3 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.

When a watershed consists of heterogeneous land use, a common procedure is to average the curve numbers associated with each land use to form a composite curve number. However, under Hawaiian conditions of sugarcane and pineapple cultivation, where access roads have very high curve numbers and cultivated areas have low curve numbers, this procedure did not seem appropriate. Therefore, we decided to distribute the curve numbers based upon the percentages of watershed area in roads and in crops. With this distribution, the runoff equation becomes:

$$Q = \frac{A_1(P - 0.2S_1)^2}{(P + 0.8S_1)} + \frac{A_2(P - 0.2S_2)^2}{(P + 0.8S_2)} \quad [4]$$

where, A_1 is the proportion of the total watershed area in roads and A_2 is the proportion of the total watershed area in crops. In equation 4, $A_1 + A_2 = 1.0$ and $Q = 0$ unless $P > 0.2S_1$ (rainfall must exceed the smaller initial abstraction that occurs on the roads in this case). Again, given A_1 and A_2, it is possible to determine the optimal S_2 value (or CN) for the second term in equation 4 using an objective function described by equation 3. Thus we specified curve numbers for the roads (*3*) and derived optimal curve numbers for the cultivated areas. For relatively large values of A_1, the contribution of the roads to total runoff can be significant. Under conditions such as those described above, where almost all sediment comes from the roads, even small values of A_1 can be significant in calculating runoff and sediment yield.

Results

Sugarcane. We used observed rainfall and runoff data from two small watersheds without roads and from one watershed

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

	SCS Runoff Curve Numbers and Statistics for Various Cover Conditions*										
	Bare Condition			Limited Cover		Partial Cover			Complete Cover		
Watershed	CN	R^2	N	CN	R^2	CN	R^2	N	CN	R^2	N
Laupahoehoe	50	.83	33	-	-	-	-	-	36	.34	50
Honokaa	60	.20	6	-	-	-	-	-	20	.05	44
Waialua	80	.89	16	-	-	62	.87	16	49	.64	34

*Cover condition classifications: 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.

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

	Hydrologic Soil Group†			
Cover*	A	B	C	D
Bare	*50* (77)‡	*80* (86)	89 (91)	92 (94)
Limited cover	45 (67)	71 (78)	82 (85)	87 (89)
Partial cover	40 (49)	*62* (69)	75 (79)	81 (84)
Complete cover	*36* (39)	*49* (61)	60 (74)	66 (80)

*Cover conditions: 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 numbers for Hydrologic Soil Group C and D extrapolated from figure 5.
‡Italic values are optimized curve numbers from observed data. Values in parentheses are from handbook (*6*).

with roads covering 5 percent of the watershed area to determine optimal CNs for sugarcane cultivation (Table 2). Curve numbers decrease as the cover conditions change from bare to full. Also, there is a great deal of variability among watersheds, and the curve numbers are greater for the soils in hydrologic soil group B than for those soils in group A. Figures 3 and 4 show the data for the A and B soils, respectively. Also shown in these figures are curve numbers taken from the SCS National Engineering Handbook (6). The handbook values are generally higher than corresponding optimized curve numbers for straight-row cultivation of sugarcane.

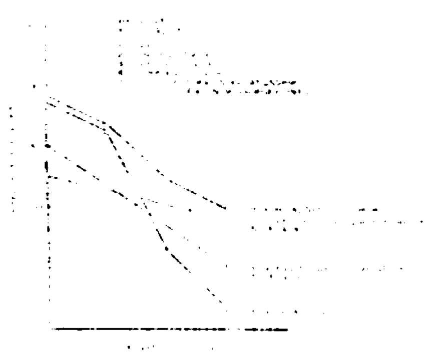

Figure 3. Relation between cover condition and runoff curve number for sugarcane, A soils.

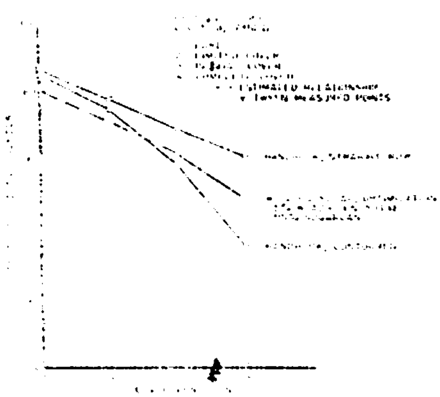

Figure 4. Relation between cover condition and runoff curve number for sugarcane, B soils.

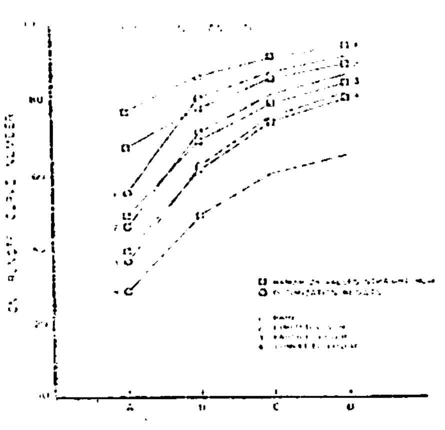

Figure 5. Variation in curve numbers with soil groups for various cover conditions, sugarcane.

Because our observed data were limited to watersheds with A and B soils, we needed a method to extrapolate the results to C and D soils. The square points with solid lines in figure 5 illustrate changes in curve numbers for the four hydrologic soil groups with various cover conditions, as given in the SCS Handbook (6). We used these same trends with soil groups to extrapolate the optimized curve numbers for C and D soils, as shown by the dashed lines with the circled points in figure 5.

We used the optimized curve numbers (Table 2) and the extrapolated curve numbers (Figure 5), along with curve number values obtained using the SCS "Curve Number Aligner," to derive the curve numbers in table 3. Because of the extreme scatter of data from the Honokaa site (poor R^2 in table 2), we gave little weight to these data. Three of the curve numbers for A and B soils (Table 3) are interpolated from figures 3 and 4 and all curve numbers for C and D soils are extrapolated from figure 5. However, these curve numbers represent the best available information from observed data and from trends established in the SCS handbook (6). Also shown in table 3 are handbook curve numbers presently used in Hawaii for comparison.

Pineapple. We used observed rainfall and runoff data from two small watersheds with 11 to 20 percent of the area occupied by field roads and the remainder planted to pineapple to determine curve numbers. Table 4 summerizes the optimized curve numbers for these two watersheds. The curve numbers decrease as crop cover increases, and they are greater for the C soils than for the B soils. Figures 6 and 7 show the data for the B and C soils, respectively. Also shown are curve numbers from the SCS handbook. The handbook values are higher than corresponding optimized curve numbers for cultivated pineapple. The magnitude of the difference is much greater than is the difference for sugarcane, suggesting that the pineapple crop provides a much better cover than originally postulated. The optimized values for sugarcane generally fall between the straight-row and contoured handbook values, whereas the optimized values for pineapple are 20 to 30 percent lower than the lowest (contoured and terraced) handbook values for both B and C soils.

Because the observed data were limited

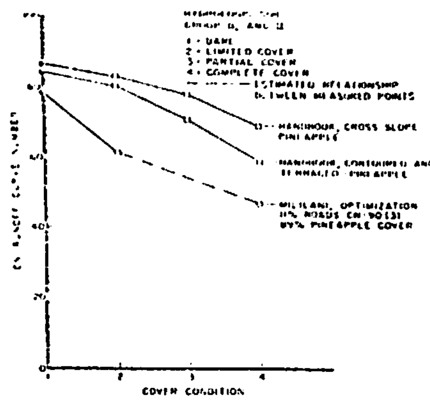

Figure 6. Relation between cover condition and runoff curve number for pineapple, B soils.

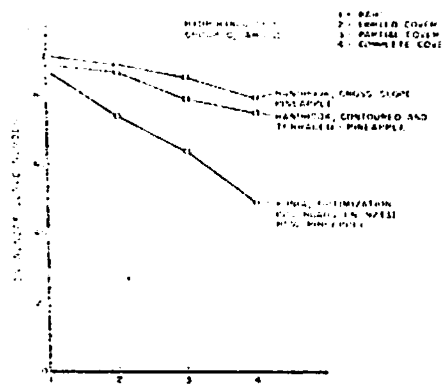

Figure 7. Relation between cover condition and runoff curve number for pineapple, C soils.

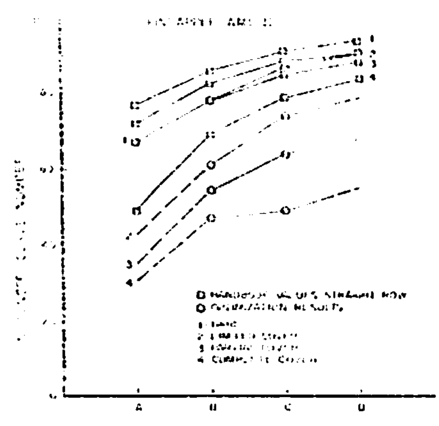

Figure 8. Variation in curve numbers with soil groups for various cover conditions, pineapple.

to watersheds with B and C soil types, the method described previously for sugarcane was used to extrapolate values for A and D soils. The square points with solid lines (Figure 8) illustrate changes in curve numbers for the four hydrologic soil groups with various cover conditions, as given in the SCS handbook (6). We used these same general trends with soil groups and those obtained using the curve number aligner to extrapolate the optimized curve numbers for A and D soils. We did not use the data for mixed cover of various crops and weeds to develop the values in table 4, but used them as reference values only. In developing the values in table 4, we observed that the C soil at Kunia may respond more like a B soil under full cover conditions, but insufficient data were available to verify this observation or change soil groupings.

One of the curve numbers for the B soils (Table 5) is interpolated from figure 6, and all of the curve numbers for A and D soils are extrapolated from figure 8 and the curve number aligner. However, these curve numbers represent the best available information from observed data and from trends established in the SCS handbook (*6*). Table 5 also shows handbook curve number values in parentheses presently used by SCS in Hawaii. Handbook values are not included for the limited cover stage because SCS does not use this breakdown. The agency includes everything between the time when a crop is planted until initial closing in, in the partial cover stage.

Discussion and conclusions

The runoff curve numbers we developed are slightly lower than previously used handbook values for sugarcane and considerably lower for pineapple. Although a considerable amount of extrapolation was needed to obtain values for all conditions, these curve numbers represent the best available information.

The slightly lower curve number values obtained for sugarcane would probably not change design criteria significantly. However, the considerably lower values obtained for pineapple indicate that the pineapple offers much more protection than was anticipated. It could well be that, except for very large storms, all runoff comes from field roads. If this is the case (and the data indicate that it is, but the watersheds were not instrumented to provide proof), perhaps present conservation design procedures need modification. At present, roads and fields are apparently treated similarly. Field roads are periodically graded, which aggravates the situation and eliminates in many cases the runoff checks and collection ditches originally installed. The results of this study indicate that the most intensive conservation measures should be applied to the roads and that present field practices may be adequate, especially once the pineapple is established. Maintenance of the conservation measures on road areas would be possible at all times, whereas field measures cannot be easily repaired or changed once the crop has been planted until after final harvest and cultivation.

Reducing runoff from the road areas could significantly reduce erosion from pineapple fields because the soil on the road areas is generally fine and unstable due to effects of vehicle traffic. In this condition, it is susceptible to erosion from even small runoff events.

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

	SCS Runoff Curve Numbers and Statistics for Various Cover Conditions*											
	Bare Condition			Limited Cover			Partial Cover			Complete Cover		
Watershed	*CN*	R^2	*N*	*CN*	R^2	*N*	*CN*	R^2	*N*	*CN*	R^2	*N*
Mililani	78	.37	20	61†	.93	24	·	·	·	47	.93	15
Kunia	87	.74	11	74	.88	7	64	.85	7	49	.83	33

*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 for nearly cross-sloped row cultivation.

	Hydrologic Soil Group†			
*Cover**	*A*	*B*	*C*	*D*
Bare	74 (77)	*84* (86)‡	*89* (91)	92 (94)
Limited cover	58 --	*74* --	*82* --	87 --
Partial cover	43 (67)	64 (78)	*76* (85)	81 (89)
Complete cover	18 (49)	*48* (69)	*65* (79)	73 (84)

*Cover conditions: Bare, no vegetative cover; limited cover, stage of cover between time of planting until plants extend beyond plastic strips (provide about 50% cover)—this stage is not used by SCS, but is included in 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 numbers for Hydrologic Soil Groups A and D extrapolated from figure 8.
‡Italic values are optimal curve numbers from observed data. Values in parentheses are from handbook (*6*).

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Dates to remember

July 16-18, Natonal Association of Conservation Districts North Central Region Meeting
Chicago, Illinois
Write: NACD, 1025 Vermont Avenue, N.W., Washington, D.C. 20005

July 20-28, National Association of Conservation Districts Southeastern Region Meeting
Richmond, Virginia
Write: NACD, 1025 Vermont Avenue, N.W., Washington, D.C. 20005

July 21-23, Symosium on Watershed Management
Boise, Idaho
Write: Richard Hawkins, UMC 52, Utah State University, Logan, 84322, or Clifton W. Johnson, SEA-USDA, 1175 South Orchard, Boise, Idaho 83705

July 21-25, International Conference on Soil Conservation
Silsoe, Bedford, England
Write: National College of Agricultural Engineering, Silsoe, Bedford, England MK45 4DT

July 23-25, Irrigation and Drainage—Today's Challenges
Boise, Idaho
Write: American Society of Civil Engineers, 345 East 47th Street, New York, N.Y. 10017

July 26-30, Toxic and Hazardous Substances Annual Educational Conference
Milwaukee, Wisconsin
Write: National Environmental Health Association, 1200 Lincoln Street, Denver, Colorado 80203