CALCULATOR PROGRAM AND NOMOGRAPH FOR ON-SITE PREDICTION OF EPHEMERAL GULLY EROSION

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1. INTRODUCTION AND PURPOSE

Rill and interrill erosion in arable fields can be estimated quickly and simply using the Universal Soil Loss Equation (USLE). No similar approach to estimating soil loss due to ephemeral gullying is available. This is unfortunate, because ephemeral gully erosion may be comparable to the rill and interrill erosion. Under these circumstances, application of the USLE alone may result in soil loss estimates which are about half the true loss.

This report presents a preliminary attempt to develop a simple, easy-to-apply technique to estimate ephemeral gully erosion on the basis of a single field visit, consultation with the farmer, and practical experience. Either a hand held calculator (HP-41CV), or a Nomograph is used to aid calculations. The method is intended to predict ephemeral gully erosion for the first year of gully development--that is from gully initiation following seed bed preparation, to its eradication about one year later by annual tillage. The method cannot be used, with modification, to estimate ephemeral gully erosion in subsequent years, when the gully has not been eradicated at the end of the first year.

This method is intended for use by field personnel. It is hoped that whereever possible, the results will be tested against field data to test their realism. Comment and constructive criticism are invited, in order that the method can be developed for maximum utility with acceptable accuracy.

2. METHODOLOGY

The basis of the method is the analysis of field topography. Ephemeral gullies usually form in topographic lows (swales) in the field, where streamlines of surface and subsurface runoff converge to produce concentrated flow. This has long been recognized by researchers and conservationists, but the problem has been to convert this qualitative recognition into a quantitative erosion prediction technique, without introducing complex modeling of water and sediment processes.

In our method, a pragmatic approach is adopted, aimed at producing a technique which is reasonably easy to use, which does not require comprehensive data collected over extended periods, which can be applied by field personnel, but which maintains acceptable accuracy.

A Compound Topographic Index (CTI) is used to predict the intensity of concentrated surface runoff at any point in a swale. The CTI incorporates the upstream drainage area, the local slope, and the degree of flow convergence (planform curvature), at each point. A critical or threshold value of CTI is necessary for the concentrated flow to initiate ephemeral gully erosion. This value varies depending on the complex interaction of variables including climate, soil type, cropping, management and conservation practice. At present, the critical value cannot be calculated from basic principles. Instead, the critical value is calibrated in the field, using measurements of CTI at the known locations of critical conditions--that is around gully heads where erosion is initiated. The size of ephemeral gully likely to develop at a point in an average year is then predicted using an empirical equation linking gully cross-sectional area to local CTI value, where that value is greater than the critical CTI. The empirical equation is based on field data collected by the U.S. Army Corps of Engineers, Waterways Experiment Station, in central Mississippi. These data were supplied to the authors by Dr. Lawson Smith. The method is illustrated in this report using data collected in Maine by Tom Iivari, Soil Conservation Service. The authors are grateful to both researchers for their assistance.

The methodology developed at Colorado State University is described in much more detail in a report to the Agricultural Research and Soil Conservation Services, and interested individuals are referred to that report for further information. The full reference is:

Thorne, C. R., 1984. "Prediction of Soil Loss Due to Ephemeral Gullies in Arable Fields," Engineering Research Center, Colorado State University, Fort Collins, Colorado 80523, CER83-84CRT48.

This report is intended as a user's guide and only the data collection procedure and calculation methods are presented. First, the field data needed are outlined; second, the three methods of undertaking the necessary calculations are presented; and third, a worked example is given. Finally, the main points are summarized.

3. FIELD DATA COLLECTION

The procedure is straightforward and with experience the necessary field measurements and calculations can be completed in about one hour per acre (depending on gully intensity). The procedure may be broken down into a series of steps as follows:

3.1 Locating Ephemeral Gully or Gullies

Ephemeral gullies usually form in swales (topographic lows) in the field, where surface runoff concentrates due to ground surface convergence. Therefore, the first step in the procedure is to walk the field and pick out the significant swales. A scaled sketch map of the field, showing swales and drainage divides between swales, is then prepared (Fig. 1a). A particular swale may or may not contain an ephemeral gully at the time of the visit, depending on many factors such as the time of year in relation to cropping and tillage practices, and the severity of

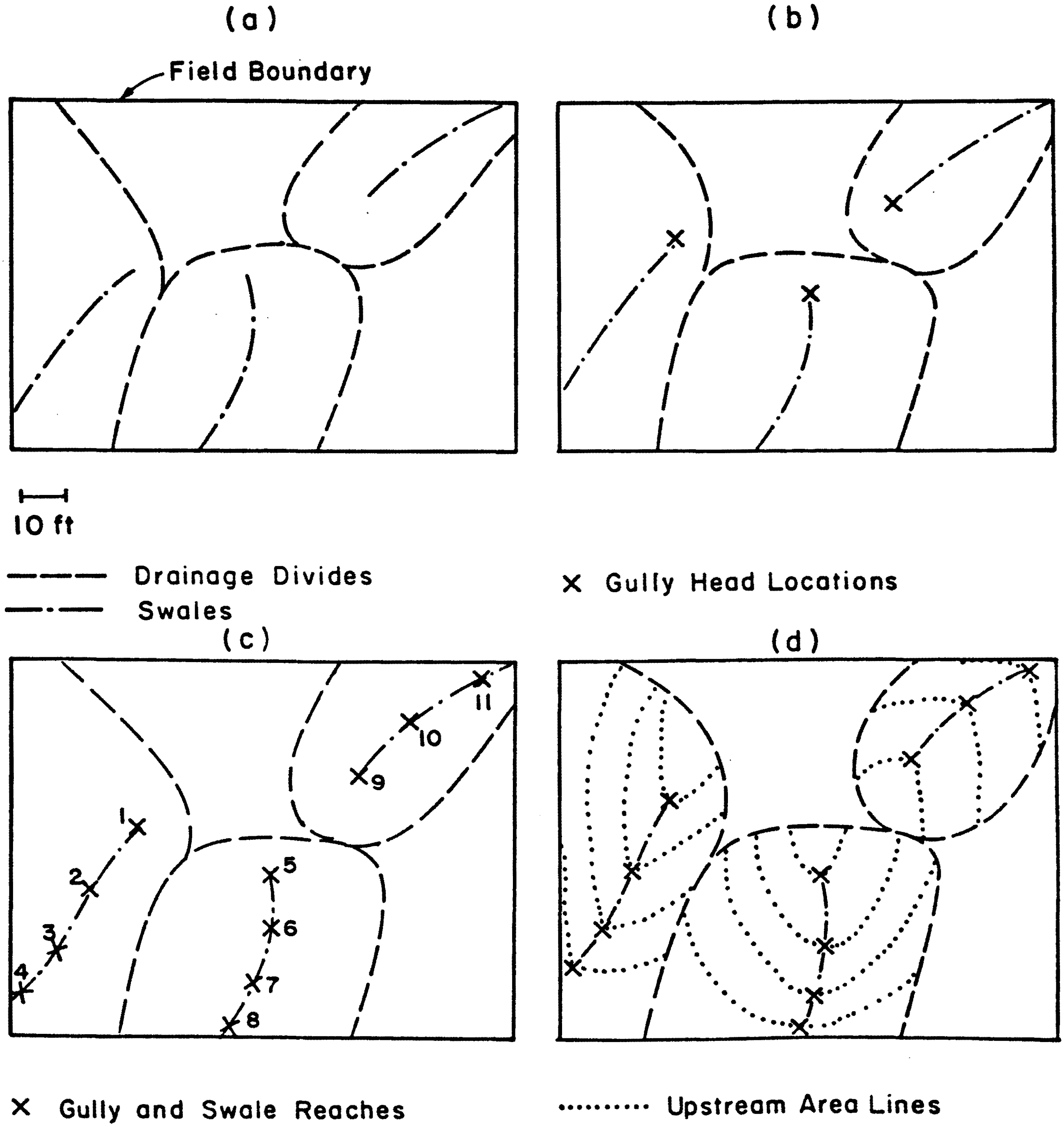


Figure 1. Sketch Map

rainfall events prior to the visit. Hence, unless the visit is made just prior to annual tillage, after an average year, it will not be possible to estimate the ephemeral gully erosion simply by measuring the volume of gullies present. Instead, the farmer is consulted as to the usual location of gullies and in particular the position of the gully heads just prior to tillage. Each gully head location is then identified with a survey flag and these points are marked on the sketch map (Fig. 1b). Gully head points are used to calibrate the critical CTI for the field.

3.2 Selecting Representative Reaches

Between 2 and 10 additional flags are used to mark the course of any ephemeral gullies present, from their heads to the point where they leave the field. Flags should be spaced so as to divide the length into characteristic reaches, so that within a reach the gully's size and shape are relatively constant. Any swales not containing a gully are similarly flagged, the spacing in this case being determined so as to divide the swale into characteristic reaches of slope, width and depth (Fig. 1c). The points are the locations for measurement of the topographic indices that go into the CTI.

3.3 Measuring Topographic Parameters

The required topographic parameters are:

(1) Stake height, H ft
(2) Left swale width, A ft
(3) Right swale width, B ft
(4) Local slope, S ft/ft
(5) Upstream area, AREA ft^2
(6) Distance downstream from gully or swale head, L ft.

These parameters are measured in the field at each flagged point, starting at each gully or swale head and working downstream. The values are recorded in a results table (Table 1). See Table 2 for an example. The measurement methods are as follows:

3.3.1 Stake Height (H) and Left and Right Swale Widths (A and B)

1) Insert a stake next to the flagged point, so that its top is 1 ft above the ground. Note: If an ephemeral gully is present, position the stake on the bank top, not the gully bed (Fig. 2).

2) Measure the horizontal distance across the swale, at right angles to the downstream direction, from the top of the stake to the ground on the left and right sides of the swale (A and B in Fig. 2). Note: It is not necessary for A and B to be equal to each other.

If either A or B is undesirably large and therefore difficult to measure, reduce the stake height to 0.5 ft. Record the values of H, A and B in the results table. The purpose of these measurements is to define the planform curvature (PLANC) of the swale, which controls the convergence of surface runoff. The calculation of PLANC is incorporated into the calculator program and the nomograph, and is also presented explicitly in section 4.1, on hand calculation.

3.3.2 Slope (S)

The local slope down the swale is measured in the field with a hand level, survey staff, and tape, or it may be estimated by eye by a person of great experience. It is expressed as a decimal (feet per foot) and noted in the results table. Slope is an important factor determining the erosivity of surface runoff.

3.3.3 Upstream Area (AREA)

The scaled sketch map is used to determine the upstream area draining to each point. On the basis of the field reconnaissance and

Table 1. Results Table

Swale Number (Length, ft)	Section Number (flag)	Dist. From Gully Head (ft)	H (ft)	A (ft)	B (ft)	Slope (ft/ft)	Upstream Area (ft^2)	CTI (Gully Head Only)	X-Area (ft^2)	Volume Voided (ft^3)

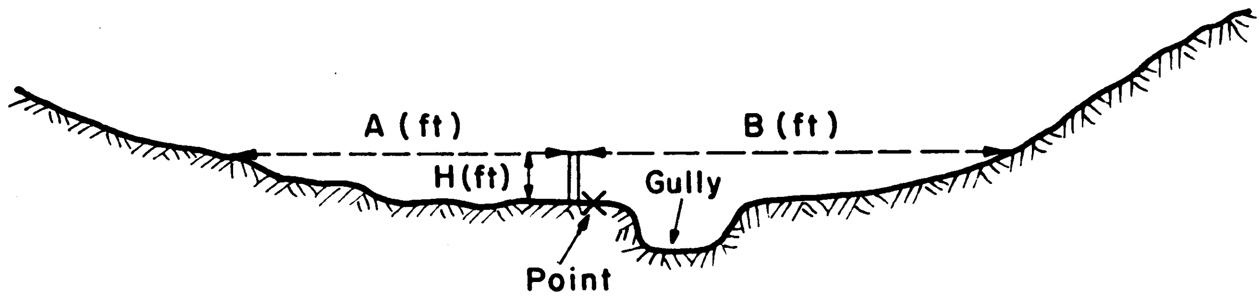


Figure 2. Field Measurement of A, B, and H.

interpretation of the drainage basin shape a line defining the drainage area for each point is sketched in (Fig. 1d). The area enclosed by the drainage divide and area lines is measured by planimeter, by counting the squares on graph paper, or by dot counting, and is recorded, in square feet, in the results table. Upstream drainage area is an important variable determining the volume of runoff at a point, which in turn affects gully size.

3.3.4 Distance Downstream from Gully or Swale Head (L)

This distance is measured by tape, by range finder, or by pacing, and is noted in the results table. Note: If the first point is located at the gully or swale head, the downstream distance is zero for that point. Subsequent points on the same gully or swale, have cumulative downstream distances. This completes the measurements for that flagged point.

The same measurements are made for the next flagged point and so on, to the last point in the first swale. If the last point is at the end of the gully or swale or where the gully leaves the field, then its downstream distance corresponds to the swale length (to be noted in column one of the results table). If the last point is not at the end of the swale, measure the distance to the end and add this to the downstream distance to obtain the swale length. That completes measurements for the first swale.

The whole process is repeated for the second swale, and so on until all swales in the field have been measured. When the last swale has been measured and the results recorded, the topographic parameters are complete and the ephemeral gully erosion can be calculated. Note: Calculation may be undertaken in the field or later in the office, but the former is recommended to allow checking of data which appear to be in error.

4. CALCULATIONS

The necessary calculations may be carried out most easily using a Hewlett-Packard HP-41CV or CX hand-held calculator, together with the program listed in Section 4.2. An HP-41C does not have sufficient memory, unless it is fitted with a quad memory module. If such calculators are not available, the nomograph supplied in Section 4.3 can be used. However, if desired, the basic equations may be used in hand calculation of the expected ephemeral gully erosion. Section 4.1 serves to illustrate how this is done, and also gives the background to the calculator program and nomograph approches. It is not essential to read 4.1 before proceeding to 4.2 or 4.3 if the reader is content to use the method as a "black box" model.

4.1 Basic Equations and Hand Calculation

4.1.1 Calculating the Compound Topographic Index (CTI)

The CTI incorporates the upstream area (A), slope (S), and planform curvature (PLANC) parameters and is defined by:

$$CTI = AREA\ S\ PLANC \tag{1}$$

where PLANC is given by:

$$PLANC = \frac{200H}{AB} \tag{2}$$

CTI is calculated for each point and the value noted in column 9 of the results table.

The critical or threshold value of CTI necessary for the initiation of ephemeral gully erosion in the field in question is calculated by averaging the gully head CTIs for that field. Mathematically:

$$CTI_{crit} = \frac{\Sigma_1^n [CTI_{gh}]}{n} \tag{3}$$

where,

CTI_{crit} = critical CTI n = number of gully heads

CTI_{gh} = gully head CTI

Points with CTI value less than the critical value, are excluded from the cross-sectional area calculations because they would not have an ephemeral gully in an average year. For swale head locations this suggests insufficient upstream area, slope or convergence to initiate erosion. For points lower down a swale, it indicates intermediate deposition of soil eroded upstream, due to flattening of slope or opening out of the swale (decreasing or zero convergence).

Mathematically, this test is written,

$$CTI < CTI_{crit}\ ?$$

At this stage all CTIs which fail the test are crossed through in the results sheet and excluded from further analysis.

4.1.2 Calculating Cross-Sectional Area (X-AREA)

Cross-sectional area (X-AREA) for the ephemeral gully at each point with a CTI greater than the critical value is found from the experimentally derived equation:

$$\text{X-AREA} = \frac{(\text{CTI})^{0.25}}{5}\ \text{ft}^2 \qquad (4)$$

The results are noted in column 10 of the results table.

4.1.3 Estimating Ephemeral Gully Erosion

Ephemeral gully erosion is calculated by multiplying the cross-sectional area for each point by the length of the reach which it represents. For the first point on a gully or swale:

$$\text{Volume Voided}_1 = (\text{X-AREA Pt. } 1)\left(\frac{\text{Downstream Distance to Pt. } 2}{2}\right) \qquad (5a)$$

For intermediate points:

$$\text{Volume Voided}_n = (\text{X-AREA Pt. } n)\left[\frac{(L_n - L_{n-1})}{2} + \frac{(L_{n+1} - L_n)}{2}\right] \qquad (5b)$$

For the last point (L):

$$\text{Volume Voided}_L = (\text{X-AREA Pt. Last})\left[\frac{(L_L - L_{L-1})}{2} + (SL - L_L)\right] \qquad (5c)$$

where: L_n = Downstream Distance to point in question

L_{n-1} = Downstream Distance to previous point

L_{n+1} = Downstram Distance to next point

L_L = Downstream Distance to last point

SL = Total Swale Length.

The results are recorded in column 11 of the results sheet.

The total volume eroded (in cubic feet) is found by summing the reach volumes for the whole field. If a weight of soil eroded is required, multiply this volume figure by the soil unit weight in pounds per cubic foot and divide by 2000 to obtain tons. If the weight per acre is required, divide by the total field area in acres, to obtain tons/acre.

4.2 Using the Calculator Program and HP-41CV or CX

4.2.1 Loading the Program

A. Manual loading

1) Turn on the calculator

2) Key in GTO . .

3) Put the calculator into Program Mode

4) Key in the Program exactly as listed in section 4.2.2. Keying in notes: i) All statements followed by either ARCL or PROMPT are entered in ALPHA mode. ii) Commands not found on the keyboard (for example; PROMPT, TONE) are entered by keying: XEQ, ALPHA, Command, ALPHA. iii) The symbol, ⊢, means APPEND, and is keyed in by: ALPHA, SHIFT (yellow key), K, ALPHA.

B. Magnetic Card Loading

If you have the program on magnetic cards and have a card reader, the program is loaded as follows:

1) Turn on the calculator

2) Key in GTO . .

3) Insert the cards into the card reader

4) When all the cards have been accepted, key in GTO . .

The program is now ready to be run.

PROGRAM LISTING

```
1 LBL GULLY
2 CLRG
3 1
4 STO 02
5 STO 05
6 CTI CRIT?
7 PROMPT
8 STO 00
9 X=0?
10 GTO 07
11 NUM SWALE?
12 PROMPT
13 STO 01
14 LBL 01
15 FIX 0
16 START SWL_
17 ARCL 02
18 PROMPT
19 LTH SWL_
20 ARCL 02
21 ⊢?FT
22 PROMPT
23 STO 03
24 NUM SECT?
25 PROMPT
26 STO 04
27 LBL 02
28 FIX 0
29 DIST SEC_
30 ARCL 05
31 ⊢FT
32 PROMPT
33 STO 07
34 LBL 03
35 STK HT? FT
36 PROMPT
37 200
38 *
39 A? FT
40 PROMPT
41 /
42 B? FT
43 PROMPT
44 /
45 SLOPE? FT/FT
46 PROMPT
47 *
48 UPAREA? SQFT
49 PROMPT
50 *
51 STO 12
52 RCL 00
53 X=0?
54 GTO 08
55 X>Y?
56 GTO 04
57 X<>Y
58 .25
59 Y^X
60 5
61 /
62 STO 09
63 FIX 2
64 AREA=
65 ARCL .X
66 ⊢SQFT
67 PROMPT
68 GTO 05
69 LBL 04
70 CTI < CRIT
71 PROMPT
72 0
73 STO 09
74 LBL 05
75 1
76 RCL 05
77 X≠Y?
78 GTO 06
79 RCL 07
80 X=0?
81 GTO 06
82 RCL 09
83 STO 08
84 LBL 06
85 RCL 08
86 RCL 09
87 +
88 2
89 /
90 RCL 07
91 RCL 06
92 -
93 *
94 STO+ 10
95 RCL 07
96 STO 06
97 RCL 09
98 STO 08
99 1
100 STO+ 05
101 RCL 04
102 RCL 05
103 X<=Y?
104 GTO 02
105 RCL 03
106 RCL 07
107 -
108 RCL 09
109 *
110 STO+ 10
111 RCL 10
112 STO+ 11
113 TONE 5
114 FIX 0
115 VOL=
116 ARCL .X
117 ⊢CUFT
118 PROMPT
119 0
120 STO 10
121 STO 08
122 STO 06
123 1
124 STO+ 02
125 STO 05
126 RCL 01
127 RCL 02
128 X<=Y?
129 GTO 01
130 FIX 0
131 TVOL=
132 ARCL 11
133 ⊢CUFT
134 PROMPT
135 UNWT?LB/CUFT
136 PROMPT
137 2000
138 /
139 RCL 11
140 *
141 FIX 1
142 EROS=
143 ARCL .X
144 ⊢TNS
145 PROMPT
146 FLD A? ACRES
147 PROMPT
148 /
149 UERO=
150 ARCL .X
151 ⊢T/ACR
152 PROMPT
153 GTO GULLY
154 LBL 07
155 NUM GLY HDS?
156 PROMPT
157 STO 02
158 LBL 08
159 FIX 0
160 RCL 12
161 STO+ 04
162 1
163 STO+ 03
164 RCL 02
165 RCL 03
166 X>Y?
167 GTO 09
168 GULLY HEAD_
169 ARCL 03
170 PROMPT
171 GTO 03
172 LBL 09
173 RCL 04
174 RCL 02
175 /
176 CTI CRIT=
177 ARCL .X
178 PROMPT
179 GTO GULLY
180 GTO ..
```

4.2.3 Running the Program

After loading the program (and checking for keying errors if it was punched in), the program is initiated by keying: XEQ ALPHA GULLY ALPHA.

After that it is only necessary to press the RUN/STOP (R/S) key to proceed, entering data as prompted by the calculator.

The calculator first prompts the user for the critical CTI value for the field. This is the threshold value for the initiation of ephemeral gully erosion. If it is already known, the value is keyed in and R/S is keyed to proceed. If it is not known, zero is keyed in and the calculator moves to a subroutine to find CTI_{crit}. In the subroutine, the gully head data are keyed in and the program averages the gully head CTI values to estimate CIT_{crit}. The critical value is then displayed, and the program returns to the initial prompt when R/S is keyed. The known value of CTI_{crit} is keyed in and R/S pressed to proceed. The complete user instructions, with details of the displayed prompts, are shown in Section 4.2.4.

4.2.4 User Instructions: Running the Program

STEP	INSTRUCTIONS	INPUT	FUNCTION	DISPLAY
1	Begin execution		XEQ GULLY	CTI CRIT?
2	Prompt for critical CTI If known If not known go to step 2a*	CTI_{crit}	R/S	NUM SWALE?
3	Prompt for number of swales to be considered	n	R/S	START SWALE n
4	Displays swale number (1 .. n)		R/S	LTH SWL n? FT
5	Prompt for total length of swale n in ft	L_n	R/S	NUM SECT?
6	Prompt for number of places along this swale that calculations will be conducted	m	R/S	DIST SEC m, FT
7	Prompt for distance from gully head (or top of swale) to section m, ft	D_m	R/S	STK HT? FT

User Instructions (continued)

STEP	INSTRUCTIONS	INPUT	FUNCTION	DISPLAY
8	Prompt for the stake height (for PLANC) in ft	H	R/S	A? FT
9	Prompt for the distance A (for PLANC) in ft	A	R/S	B? FT
10	Prompt for the distance B (for PLANC) in ft	B	R/S	SLOPE? FT/FT
11	Prompt for local slope in decimal form	S	R/S	UPAREA? SQFT
12	Prompt for the upstream area to this point in ft^2	A_u	R/S	CTI<CRIT (if CTI is less than the critical value) or AREA=__SQFT
13	Informs you that CTI is less than the critical value or outputs the gully area in ft^2		R/S	Returns to step 7 or VOL=__CUFT
14	Outputs volume of eroded soil for gully n (ft^3)		R/S	Returns to step 4 or TVOL=__CUFT
15	Outputs volume of eroded soil for all gullies considered (ft^3)		R/S	UNWT?LB/CUFT
16	Prompts for soil unit weight in lb/ft^3	γ_s	R/S	EROS=__TNS
17	Outputs soil loss in tons		R/S	FLD A? ACRES
18	Prompts for the field area in acres	A_f	R/S	UERO=__T/ACR
19	Outputs soil loss in tons/acre		R/S	Returns to program beginning

*Steps 2a through 10a below.

STEP	INSTRUCTIONS	INPUT	FUNCTION	DISPLAY
2a	If CTI C_{RIT} is not known	0(zero)	R/S	NUM GLY HDS?
3a	Prompt for the number of gully heads for CTI_{crit} determination	n	R/S	GULLY HEAD n
4a	Displays gully head number		R/S	STK HT? FT
5a	Prompt for the stake height (for PLANC) in ft	H	R/S	A? FT
6a	Prompt for the distance A in ft	A	R/S	B? FT

User Instructions (continued)

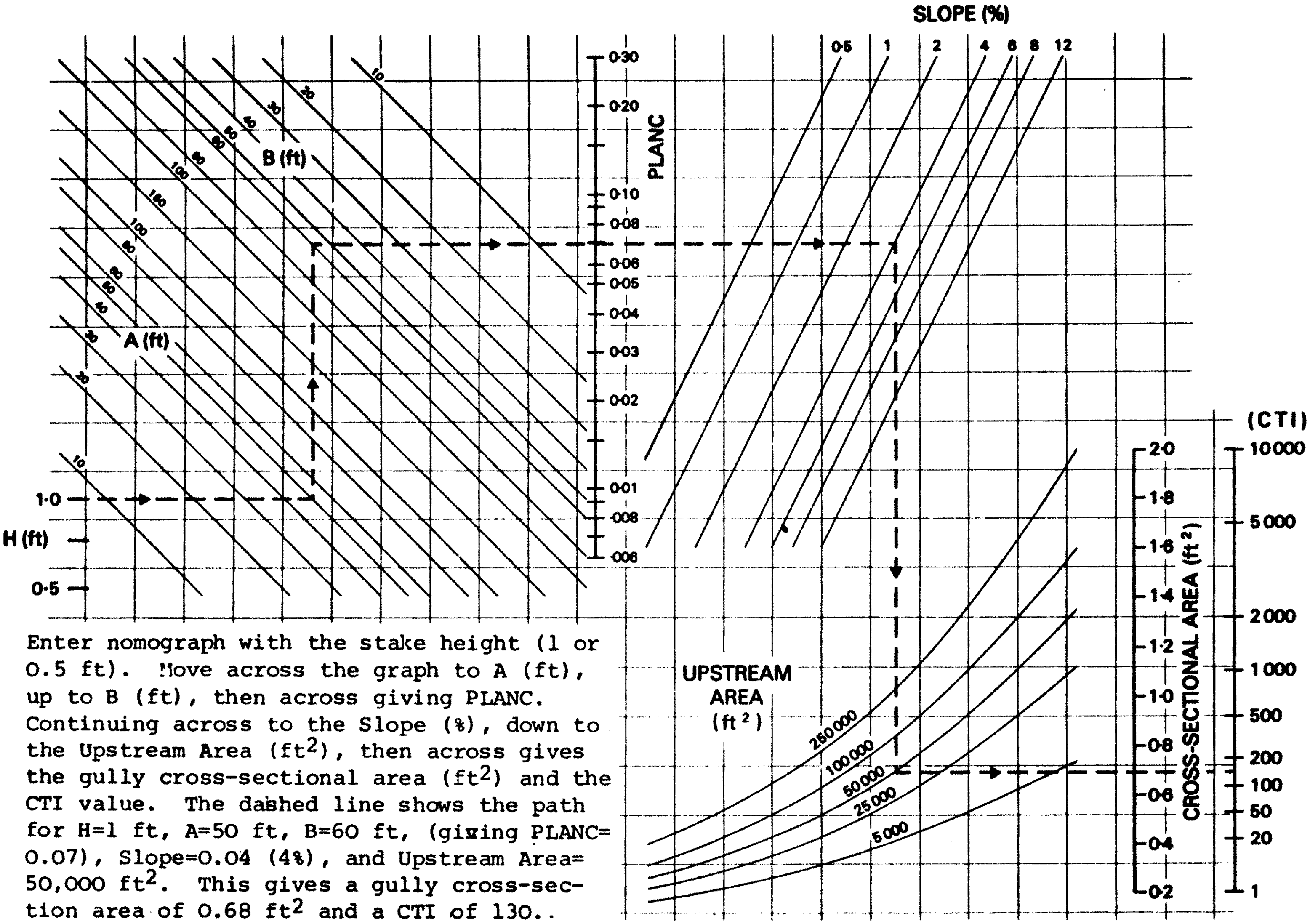
STEP	INSTRUCTIONS	INPUT	FUNCTION	DISPLAY
7a	Prompt for the distance B in ft	B	R/S	SLOPE? FT/FT
8a	Prompt for slope in decimal form	S	R/S	UPAREA? SQFT
9a	Prompt for upstream area in ft^2	A_u	R/S	Returns to step 4a or CTI CRIT=__
10a	Displays the critical CTI value (note this value)		R/S	Returns to program beginning

4.3 Using the Nomograph

If no calculator is available, the nomograph shown in Fig. 3 can be used to speed up the calculation procedure. The nomograph is entered on the left scale of stake height (0.5, 0.75 or 1.0 ft). Then the A and B distances are used to find PLANC. Next the Local Slope (%) and Upstream Area are used to determine cross-sectional area and CTI (Compound Topographic Index). When the area and CTI have been determined for all points, the gully head CTI values are averaged to estimate the critical value for the field. The method is given in Section 4.1.1. Any points with CTIs less than the critical value are given zero cross-sectional area because for the field in question, they would not be expected to have an ephemeral gully in an average year, as explained in Section 4.1.1. The ephemeral gully erosion is calculated using the method outlined in Section 4.1.3.

5. EXAMPLE

The method for on-site prediction can be based on analysis of a topographic map of 1 foot contour interval, as well as a site visit. This example is based on such an analysis of the map shown in Fig. 4,



Enter nomograph with the stake height (1 or 0.5 ft). Move across the graph to A (ft), up to B (ft), then across giving PLANC. Continuing across to the Slope (%), down to the Upstream Area (ft^2), then across gives the gully cross-sectional area (ft^2) and the CTI value. The dashed line shows the path for H=1 ft, A=50 ft, B=60 ft, (giving PLANC= 0.07), Slope=0.04 (4%), and Upstream Area= 50,000 ft^2. This gives a gully cross-section area of 0.68 ft^2 and a CTI of 130..

NOMOGRAPH FOR DETERMINATION OF EPHEMERAL GULLY CROSS-SECTION AREA AND CTI VALUE

Figure 3.

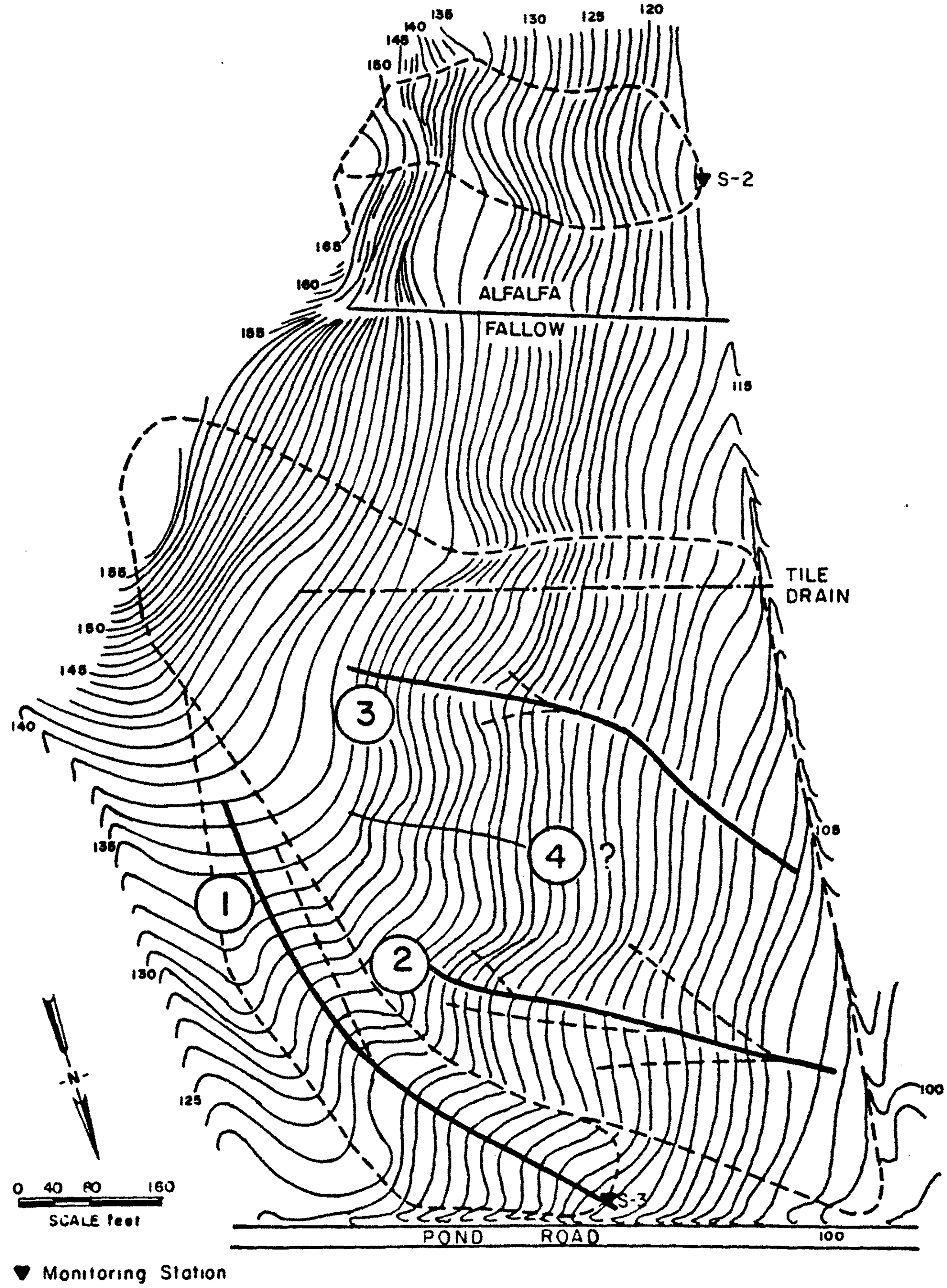


Figure 4. Map of Research Watersheds

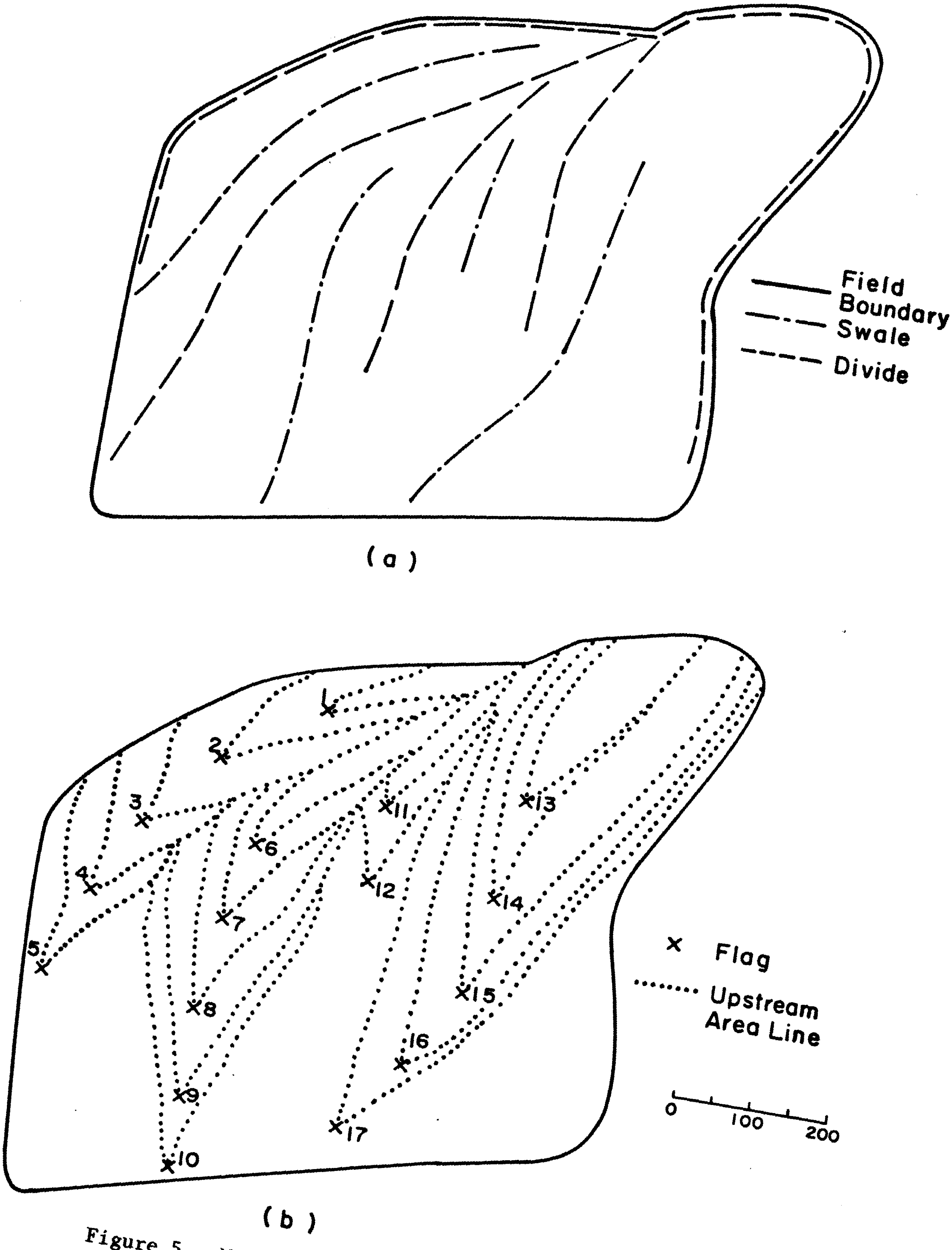


Figure 5. Map of Drainage Divides, Swales, and Known Ephemeral Gullies

which shows a small watershed in New Hampshire. The map was kindly supplied by Tom Iivari, SCS, Chester, Pa.

The drainage divides, swales, and known ephemeral gullies are sketched from the map (Fig. 5a). For the field shown, three ephemeral gullies were indicated and a possible fourth was suggested by a weak line on the site map. For each of the gullies and the swale containing the possible fourth gully, topographically similar reaches are identified and points selected to be representative of the gully head, gully end or exit from the field, and intermediate reaches between. Distance downstream from the swale or gully head is measured for each point, and lines defining the upstream drainage area are sketched (Fig. 5b). The upstream area is then measured by planimeter. The slope at each point is measured from the contour spacing on the original topographic map. The planform curvature is measured from the contours also. The method is identical to that used in the field, except that H is the contour interval and A and B are measured as the straight line distances left and right at right angles to the gully from the point, to the next higher contour (Fig. 6).

For example, at point (6), the planform curvature is found by:

$$\text{PLANC} = \frac{200(1.0)}{50 \cdot 50} = 0.08$$

If A and B are too large, an intermediate contour is sketched in (say, 90.5) and H becomes 0.5 ft. The data are listed in Table 1. PLANC is obtained from Eq. (2).

The Compound Topographic Index for each point is then calculated using Eq. (1). For point (6):

$$\text{CTI} = A \cdot S \cdot \text{Planc} = 9000 \cdot 0.06 \cdot 0.08 = 43$$

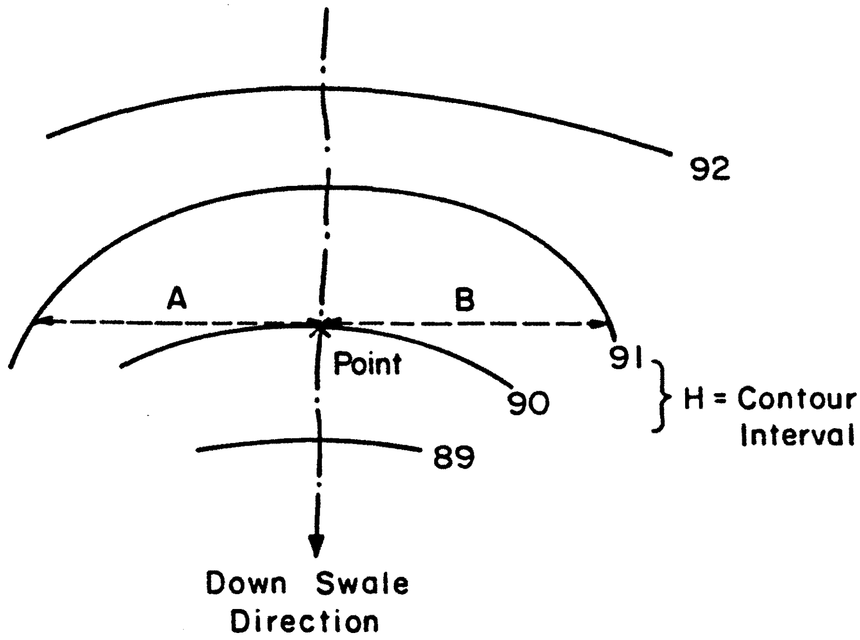


Figure 6. Measurement of H, A and B from Contours for Calculation of Planform Curvature

The critical CTI value for gully formation in the field in question is estimated by averaging the CTI values for the gully heads (points 1, 6, 13). In this case:

$$CTI_{crit} = \frac{14 + 43 + 42}{3} = 33$$

The CTI value for each point is compared to the critical value to test whether an ephemeral gully would be expected to form at that point in most years. For example, data points 1 and 10 fall below the critical value and are excluded from further analysis. The points for the swale at the center of the field are retained, because they do exceed the CTI_{crit}.

The cross-sectional areas for each point above CTI_{crit} are calculated using Eq. (4). For point (6), for example:

Table 1. Results Table

Swale Number (Length, ft)	Section Number (flag)	Dist. from Gully Head (ft)	H (ft)	A (ft)	B (ft)	Slope (ft/ft)	Upstream Area (ft^2)	PLANC (1/100 ft)	CTI (ft/100)	X AREA (ft^2)	Length (ft)	Volume Voided (ft^3)
1	1 (1)	0	0.5	40	40	0.04	6,000	0.06	14	Below CTI_{crit} Value		
(540)	2 (2)	80	1.0	70	50	0.04	25,000	0.06	60	0.56	150	84
	3 (3)	300	1.0	38	35	0.05	42,000	0.15	315	0.84	130	109
	4 (4)	340	1.0	50	50	0.04	65,000	0.08	208	0.76	120	91
	5 (5)	540	1.0	40	60	0.04	82,000	0.08	262	0.80	100	80
2	1 (6)	0	1.0	50	50	0.06	9,000	0.08	43	0.51	60	31
(480)	2 (7)	120	1.0	45	40	0.05	20,000	0.11	110	0.65	130	85
	3 (8)	260	1.0	60	50	0.05	40,000	0.07	140	0.69	130	90
	4 (9)	380	1.0	80	70	0.05	65,000	0.04	130	0.68	110	75
	5 (10)	480	0.5	120	100	0.03	83,000	0.01	25	Below CTI_{crit} Value		
3	1 (11)	40	0.5	30	30	0.07	5,000	0.11	39	0.50	100	50
(200)	2 (12)	160	1.0	70	30	0.06	11,000	0.10	66	0.57	100	57
4	1 (13)	0	1.0	70	70	0.05	21,000	0.04	42	0.51	70	36
(520)	2 (14)	140	1.0	40	30	0.07	40,000	0.17	476	0.93	140	130
	3 (15)	280	1.0	80	60	0.05	85,000	0.09	170	0.72	130	94
	4 (16)	400	0.5	80	60	0.05	120,000	0.02	120	0.66	120	79
	5 (17)	520	0.5	70	120	0.03	160,000	0.01	48	0.53	60	32
												1123

$$\text{X-AREA}_6 = \frac{(43)^{1/4}}{5} = 0.51 \text{ ft}^2$$

The volume voided in each reach is calculated from the cross-sectional area and the reach length, using eq. (5), a, b, or c as appropriate. For example, point (6) is a gully head, so eq. (5a) is used:

$$\text{Vol. Voided}_6 = (0.51)(\frac{120}{2}) = 31 \text{ ft}^3$$

For an intermediate point, point (7), eq. (5b) gives:

$$\text{Vol. Voided}_7 = 0.65\ [(\frac{120 - 0}{2} + \frac{(260 - 120}{2})] = 85 \text{ ft}^3$$

and for a gully end point, point (17), eq. (5c) gives:

$$\text{Vol. Voided}_{17} = (0.53)[\frac{(520 - 400)}{2} + (520 - 520)] = 32 \text{ ft}^3$$

The ephemeral gully erosion for the field is found by summing the erosion in each swale:

$$\text{Total Volume Voided} = \Sigma \text{ Volume Voided in Each Swale}$$

For the example shown,

$$\text{Total Volume Eroded} = 1123 \text{ ft}^3 = 41.6 \text{ yds}^3$$

The weight of soil is found by multiplying by a representative unit weight, for this field 120 pounds per cubic foot:

$$\text{Weight eroded} = \frac{1123 \cdot 120}{2000} = 67 \text{ tons}$$

The area of the field is about 11 acres, yielding a unit soil erosion rate of:

$$\text{Weight eroded per acre} = \frac{67}{11} = 6.1 \text{ tons/acre.}$$

This erosion is additional to the erosion by rill and interrill erosion, which would be estimated using the USLE.

6. SUMMARY AND CONCLUSIONS

It has been recognized that ephemeral gully erosion is not accounted for in Universal Soil Loss Equation estimates of erosion in arable fields. A simple, on-site method to estimate the additional soil erosion due to ephemeral gullies has been developed. It is based on the following inputs:

1) A site visit by a field scientist.
2) Consultation with the farmer.
3) Professional experience and judgment.

The procedure is straightforward and can be completed in about 1 hour per acre of field area. In summary, the steps are:

1) Walk the field noting the locations of swales, drainage divides and ephemeral gullies.
2) Consult the farmer as to the usual location of gullies and particularly the location of the gully head in each swale. Flag each gully head location.
3) Make a sketch map, to scale, of the field, showing the swales, drainage divides, ephemeral gullies and gully head locations.
4) Select representative reaches of each swale based on local topography and the size of any gully present. Flag intermediate points in each reach. Measure the distance downstream from the gully or swale head to each flag and note this on the results table.
5) Determine the upstream drainage area, local slope and planform convergence for each point. Area is measured on the sketch map, slope measured or estimated in the field, and planform convergence measured in the field, as described in sections 3.3.1 to 3.3.3.

If hand calculation is being undertaken:

6) Calculate the Compound Topographic Index for each point using eq. (1).

7) Calibrate the CTI_{crit} by calculating the average the CTI value for the gully head points. Point CTI values less than the critical value are excluded from further analysis.

8) Calculate the gully cross-sectional area from eq. (4), based on the CTI.

9) Calculate the eroded volume for each reach from the cross-sectional area and the reach length using eq. (5).

10) Determine the total annual ephemeral gully erosion for the field by summing the volume eroded in each reach. This may be expressed in cubic feet, cubic yards, tons or tons per acre as desired.

If the HP-41CV program is to be used:

6) Load the program as described in Section 4.2.1.

7) Follow the User Instructions listed in Sections 4.2.3 and 4.2.4.

If using the Nomograph:

6) Find the CTI and Cuilly cross-sectional area for each point using Fig. 3.

7) Calibrate the Critical CTI by calculating the average gully head value, as described in Section 4.1.1.

8) Give zero cross-sectional area to all points with CTIs less than the critical value.

9) Calculate the ephemeral gully erosion using the method outlined in Section 4.1.3.

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