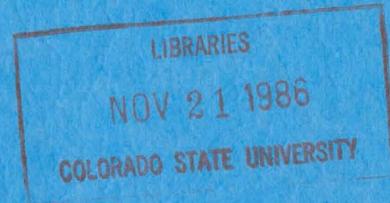


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ON-SITE PREDICTION OF EPHEMERAL GULLY EROSION



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ON-SITE PREDICTION OF EPHEMERAL GULLY EROSION

1. INTRODUCTION AND PURPOSE

Rill and inter-rill 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 gully erosion is available. This is unfortunate, because ephemeral gully erosion may be as much as 100% of the USLE soil loss.

This technique is a preliminary attempt to develop a simple, easily applied technique to estimate ephemeral gully erosion on the basis of a single field visit, consultation with the farmer, and practical experience.

It is intended that this approach be applied by field personnel and the results tested for realism. Comment and criticism are invited, in order that the method can be developed for maximum utility with acceptable accuracy.

2. PROCEDURE

The procedure is straightforward and with experience the necessary field measurements and calculations could 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.

2.1 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 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 head 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. 1(b)).

2.2 Selecting Representative Reaches

Between 2 and 10 further 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

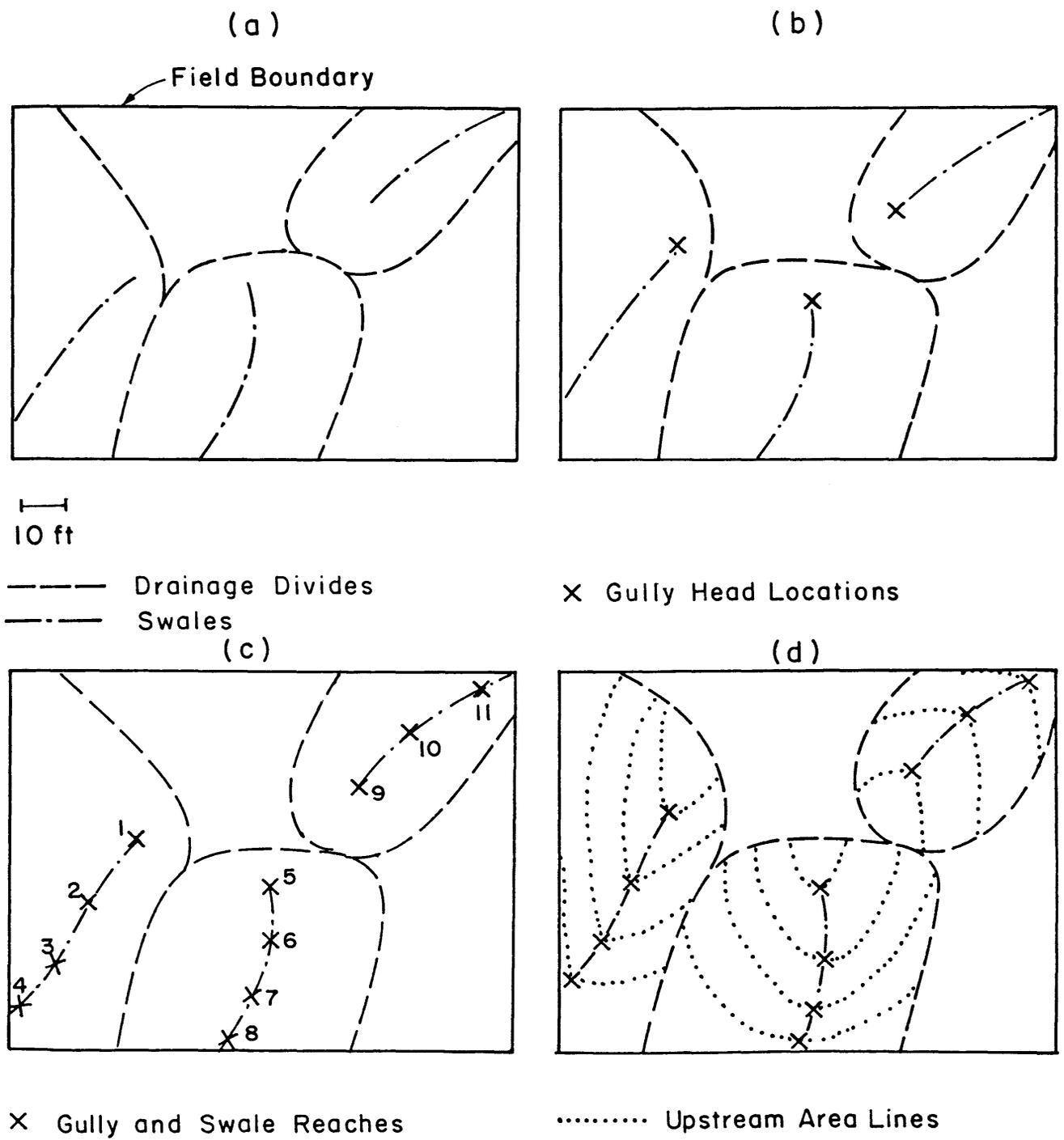


Figure 1. Sketch Map

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. 1(c)). Reach lengths between flags are measured by tape or rangefinder and noted in a table of results (see page 12 for an example).

2.3 Measuring Topographic Indices

The topographic indices required are: upstream area, local slope and planform curvature. These parameters can easily be measured in the field, with a little experience. All three parameters must be determined for each flagged point. The measurement methods are described next.

2.3.1 Upstream Area (A)

The scaled sketch map is used to determine the upstream area for each point. To do this a line defining the area draining to each point is drawn in, on the basis of the field reconnaissance and interpretation of the drainage basin shape (Fig. 1(d)). The upstream area (enclosed by the drainage divide and area lines) is measured by planimeter or by counting the squares on graph paper, and is tabulated, in square feet.

2.3.2 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 an operator of great experience. It is expressed as a decimal (feet per foot) and noted in the results table.

2.3.3 Planform Curvature (Planc)

This is a measure of topographic convergence and hence surface runoff concentration. It is measured as follows:

- 1) Insert a stake next to the flag point, so that the top of the stake is 1 foot above the ground (Note: if a gully is present, work on the bank top, not on the gully bed) (Fig. 2).

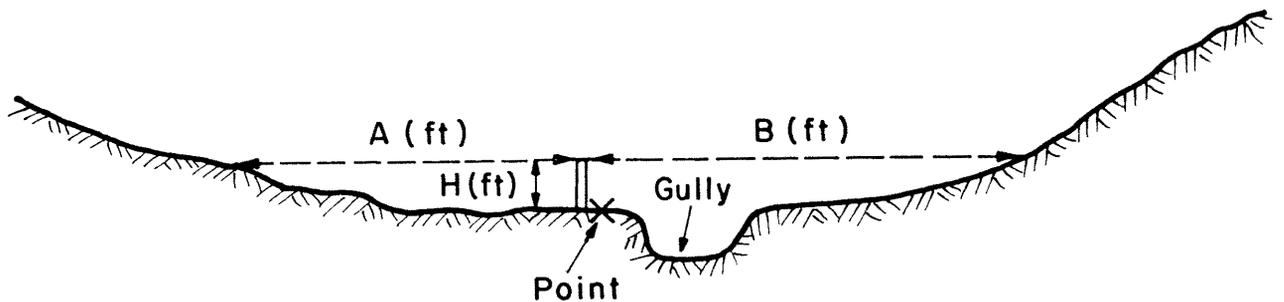


Figure 2. Field Measurement of A, B, and H for Planc Calculation.

- 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 (A & B in Fig. 2). If either length is undesirably small or large, adjust the height of the stake accordingly (i.e., if A and/or B are too large, lower stake; if they are too small, raise stake). If either A or B is very large, record that the planform curvature is zero. Planform curvature (planc) is then calculated by:

$$\text{planc} = \frac{200H}{AB} \quad (1)$$

where H = stake height (ft).

A = left horizontal distance to ground (ft).

B = right horizontal distance to ground (ft).

and recorded in the results table.

2.4 Calculating Compound Topographic Index (CTI)

The cross-sectional area predicted for a fully developed ephemeral gully is based on a combined topographic index (CTI) found by:

$$CTI = AS \text{ Planc} \quad (2)$$

If the CTI is larger than a critical value, a gully will form in most years. The critical value is the result of complex interactions between climate, soils, cropping and management and no universal value can be used. Instead the critical CTI for the field in question is taken to be the average gully head CTI for the field. Points with CTI's lower than the gully head average are not used in the X-AREA calculations, because they would not have a gully in an average year.

2.5 Calculating Cross-Sectional Area (X-AREA)

Cross-sectional area (X-AREA) is then found by an experimentally based relation:

$$X\text{-AREA} = \frac{(CTI)^{\frac{1}{4}}}{5} \text{ ft}^2 \quad (3)$$

for CTI's larger than CTI_{crit} .

2.6 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:

$$\text{Volume Voided}_1 = (\text{X-AREA Point 1}) \left(\frac{\text{Dist. to Pt. 2}}{2} \right) \quad (4a)$$

For intermediate points:

$$\text{Volume Voided}_n = (\text{X-AREA Pt. n}) \left(\frac{\text{Dist. to Pt. (n-1)}}{2} + \frac{\text{Dist to Pt. (n+1)}}{2} \right) \quad (4b)$$

For the last point (L):

$$\text{Volume Voided}_L = (\text{X-AREA Pt. Last}) \left(\frac{\text{Dist. to Pt. (L-1)}}{2} \right) \quad (4c)$$

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 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 field area in acres to obtain tons/acre.

3. EXAMPLE

The method for onsite prediction can be based on analysis of a topographic map of 1 foot contour interval, as well as a site visit. This example was based on such an analysis of the map shown in Fig. 3, 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. 4a). For the field shown 3 ephemeral gullies were indicated and a possible fourth was suggested by a weak line. 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. Distances between points are measured on the map. For each point, lines defining the upstream drainage area are sketched (Fig. 4b). 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. 5).

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.

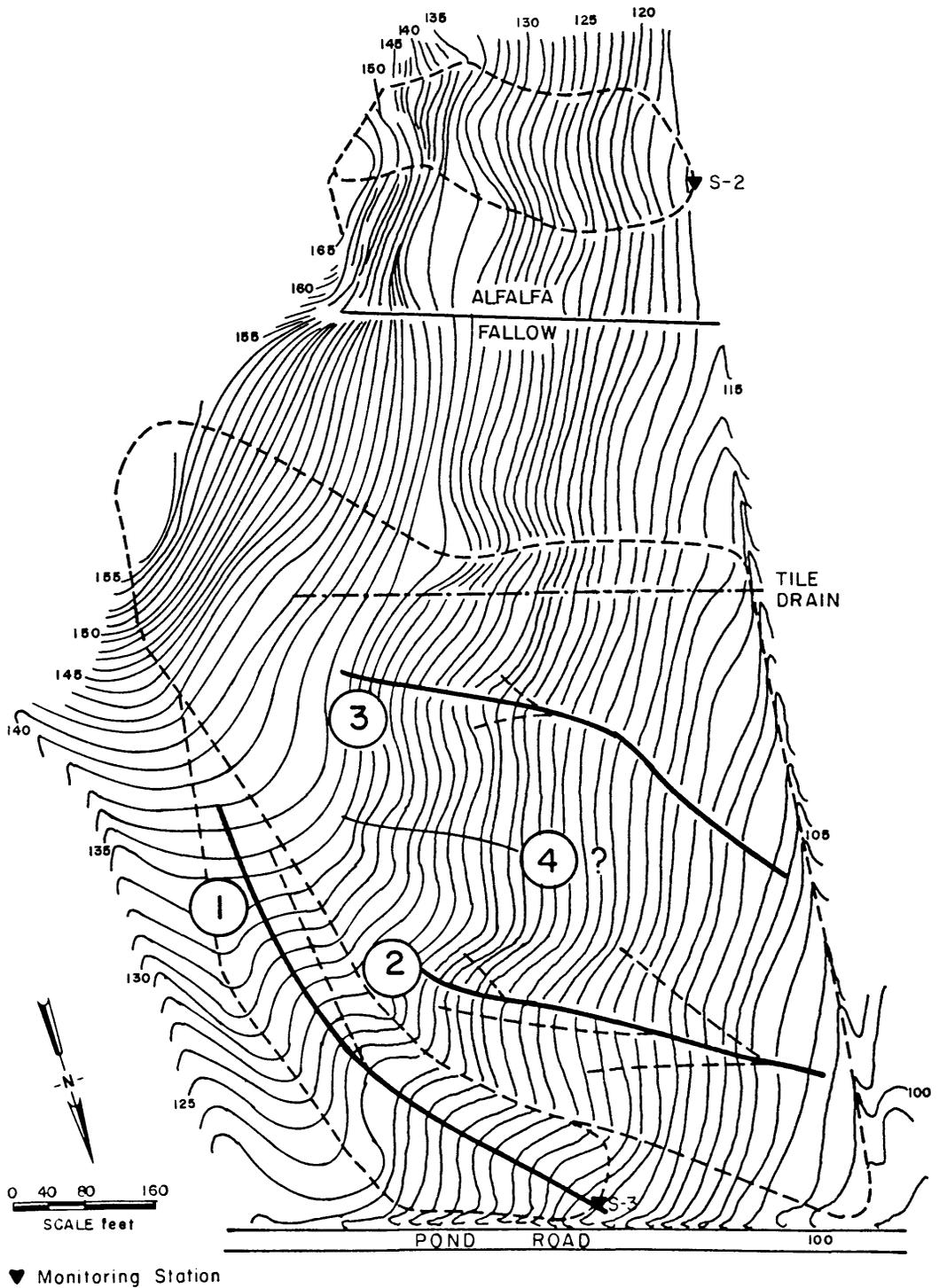
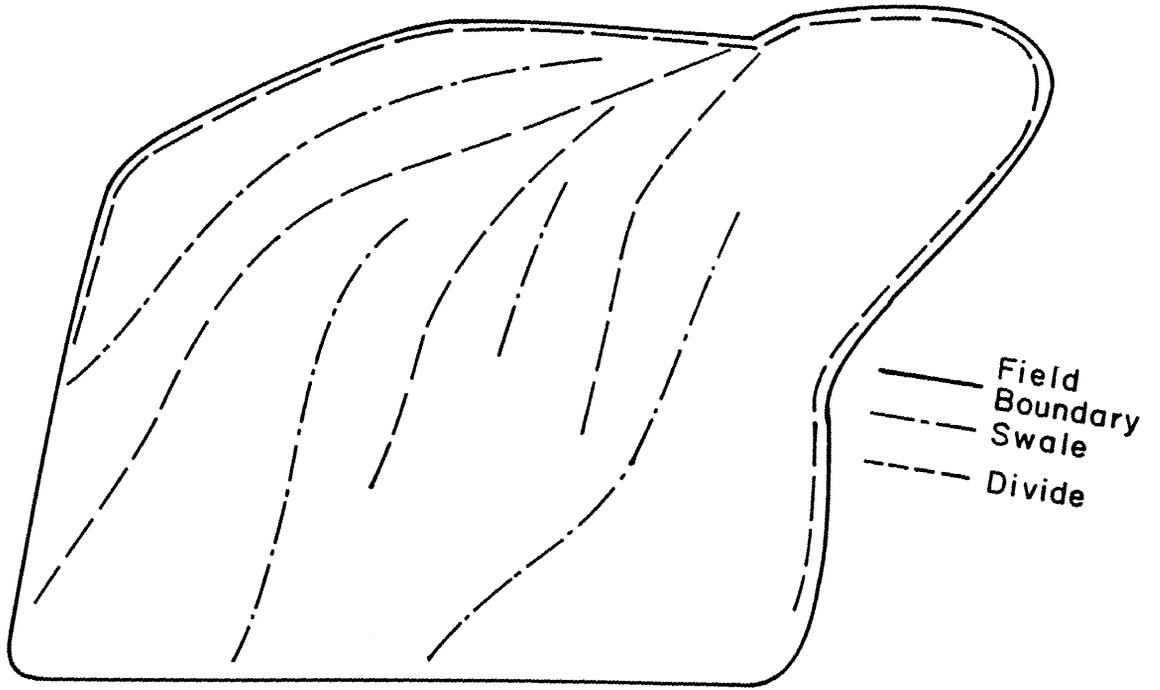
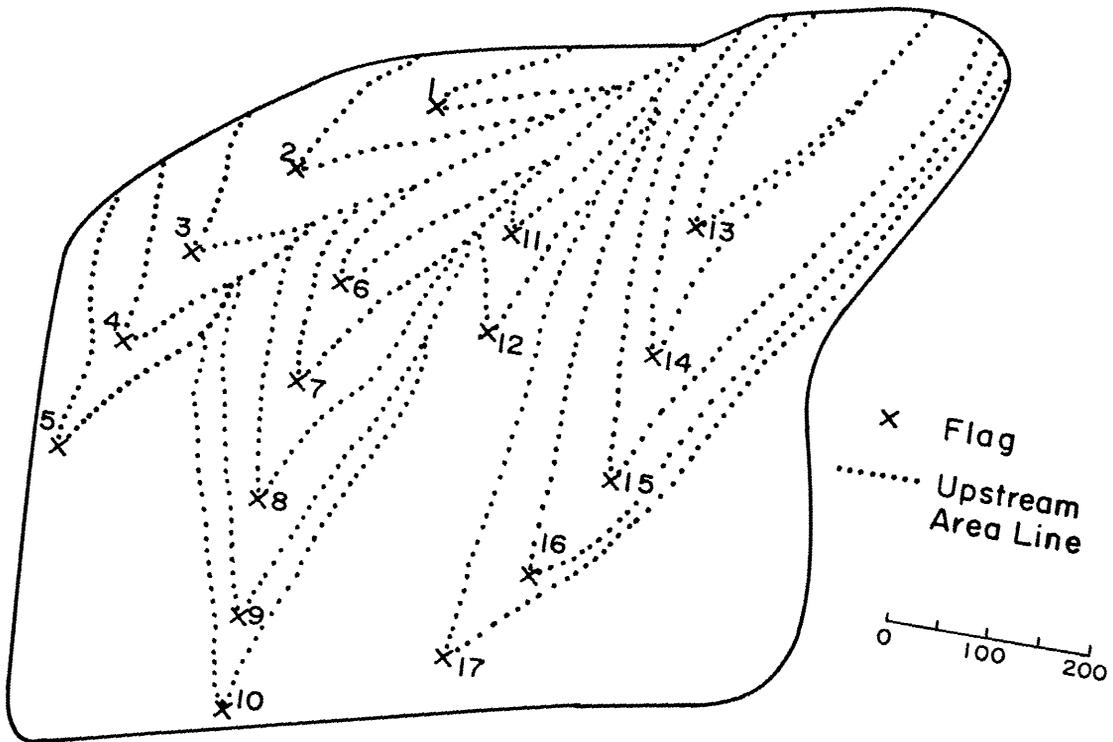


Figure 3. Map of Research Watersheds.



(a)



(b)

Figure 4. Map of Drainage Divides, Swales, and Known Ephemeral Gullies.

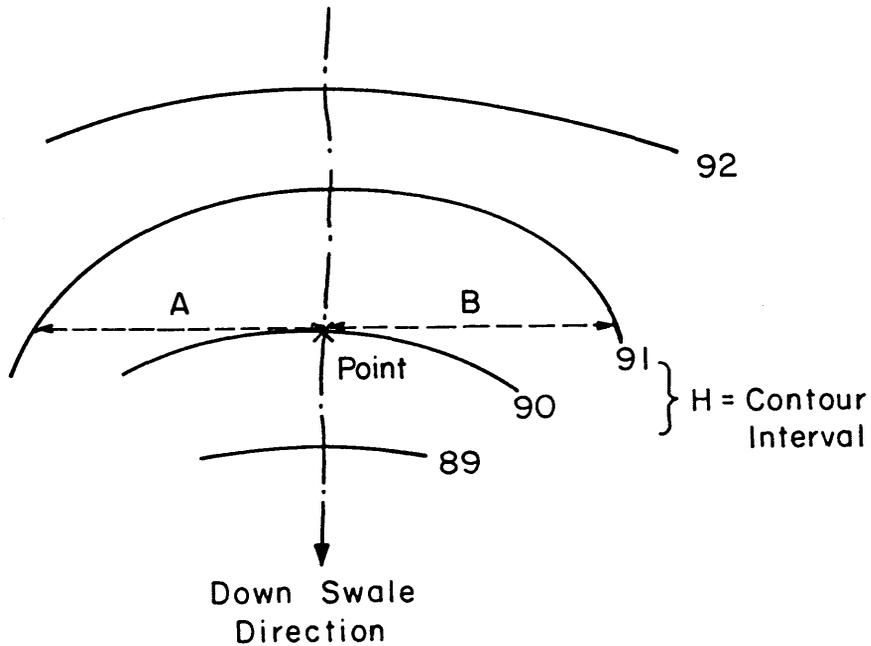


Figure 5. Measurement of H, A and B from Contours for Calculation of Planform Curvature.

Plan_c is obtained from Eq. (1).

The Compound Topographic Index for each point is then calculated using Eq. (2). For point (6):

$$CTI = A \cdot S \cdot Plan_c = 9000 \cdot 0.06 \cdot 0.08 = 43$$

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} .

Table 1

Flag	Upstream Area (ft ²)	Slope (ft/ft)	A (ft)	B (ft)	H (ft)	Planc (1/100 ft)	CTI (ft/100)	X-AREA (ft ²)	Length (ft)	Volume Voided (ft ³)
1	6,000	0.04	40	40	0.5	0.06	14	Below CTI _{crit} Value		
2	25,000	0.04	70	50	1.0	0.06	60	0.56	150	84
3	42,000	0.05	38	35	1.0	0.15	315	0.84	130	109
4	65,000	0.04	50	50	1.0	0.08	208	0.76	120	91
5	82,000	0.04	40	60	1.0	0.08	262	0.80	100	80
6	9,000	0.06	50	50	1.0	0.08	43	0.51	60	31
7	20,000	0.05	45	40	1.0	0.11	110	0.65	130	85
8	40,000	0.05	60	50	1.0	0.07	140	0.69	130	90
9	65,000	0.05	80	70	1.0	0.04	130	0.68	110	75
10	83,000	0.03	120	100	0.5	0.01	25	Below CTI _{crit} Value		
11	5,000	0.07	30	30	0.5	0.11	39	0.50	100	50
12	11,000	0.06	70	30	1.0	0.10	66	0.57	100	57
13	21,000	0.05	70	70	1.0	0.04	42	0.51	70	36
14	40,000	0.07	40	30	1.0	0.17	476	0.93	140	130
15	85,000	0.05	80	60	1.0	0.04	170	0.72	130	94
16	120,000	0.05	80	60	0.5	0.02	120	0.66	120	79
17	160,000	0.03	70	120	0.5	0.01	48	0.53	60	32

The cross-sectional areas for each point above CTI_{crit} are calculated using Eq. (3). For point (6), for example:

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

The volume voided in each reach is calculated from the cross-sectional area and the reach length, using eq. (4), a, b, or c as appropriate. For example, point (6) is a gully head, so eq. (4a) is used:

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

For an intermediate point, point (7), eq. (4b) gives:

$$\text{Vol. Voided}_7 = 0.65 \left(\frac{120}{2} + \frac{140}{2}\right) = 85 \text{ ft}^3$$

and for a gully end point, point (17), eq. (4c) gives:

$$\text{Vol. Voided}_{17} = (0.53)\left(\frac{120}{2}\right) = 32 \text{ ft}^3$$

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

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

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.

4. 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 distances between flags and note these on the sketch map.
- 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 2.3.1 to 2.3.3.

- 6) Calculate the Compound Topographic Index for each point using eq. (2).
- 7) Calculate the average CTI_{crit} by averaging the CTI values 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. (3), based on the CTI.
- 9) Calculate the eroded volume for each reach from the cross-sectional area and the reach length using eq. (4).
- 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.

5. ACKNOWLEDGMENTS

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