TECHNICAL NOTES

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Universal Soil Loss Equation - Example Solutions Designed for Self Training

Guidelines for becoming familiar with use of the USLE in California have been made available to SCS field office staff's through 2 references:

1. Guides for Erosion and Sediment Control, USDA, SCS, Davis, CA, January 1975.

2. Field Office Technical Guides, Section 2D.

Because numerical values have only recently been established for using the equation on the west coast, we need to make an early effort to devise methods of testing USLE to determine values for all factors that will make the equation predict average annual soil losses accurately. The purpose of this technical note is to propose some simple methods of testing the equation and provide a few sample problems to give SCS personnel practice in applying it during conservation planning activities.

Briefly, the basic equation is A or T = R K (LS) C P

A is the average annual predicted soil loss in tons per acre.

T replaces A when maximum tolerable soil loss is to be used in the equation to determine maximum permissible values for other variable factors. T is actually used more than A for applying the equation to conservation problems.

R is used to express the energy of precipitation. This value remains constant for given geographic locations but varies greatly as one moves to areas of more or less precipitation.

K is a numerical value used to indicate the susceptibility of a soil to erosion. It remains constant for a given soil. Susceptibility increases with numerical value.

(LS) is the range of numerical values applied to express differences in erodibility caused by changes in length and steepness of slope.

C is the value used to express differences in erodibility due to differences in condition of the soil surfaces receiving rainfall and runoff. The most erodible condition (a soil maintained continuously loose and barren of vegatation by tillage) is given a "C" value of 1.0. It is much less than 1.0 as an average value under most land uses, and is the primary factor that can be reduced by conservation practices to bring soil losses within tolerance "T".

P is a numerical expression of the erosion control value of conducting farming operations "across slope" or on the contour. When contouring is not applicable to a problem "P" is expressed as 1.0. When contouring or cross-slope farming is used to reduce erosion "P" becomes some value less than 1.0.

USLE predicts only sheet and rill erosion from rainfall. Other methods must be used to determine any additional erosion from an area (gully, wind, mass movement, irrigation, etc.).

Because "C" is the factor most often influenced by erosion control practices, the equation is most commonly applied to fields in the following form.

Maximum permissible "C" = T/RK (LS) P.

In this form the equation can be used to determine what type of soil surface condition must be maintained during periods of rainfall to keep soil loss within tolerance.

The range of variability table for various USLE factors in California is helpful for visualizing the effects of the variables encountered statewide on conservation treatments needed to provide effective erosion control. The user must keep in mind that for any given location in the state only the values for "C", "LS", and "P" can be altered by conservation treatment. Factors "T", "R", and "K" are site dependent and constant for individual sites.

Range of Variability for USLE Factors in California

T	=	R	X	K	X	(LS)	X	C	X	P
1-5 Ton		10-100		.17-.49		0-350		.001-.99		.25-1

Viewing the table above makes it easy to see how changing one value of the equation influences single other factors:

1. If we double the value of "T", we would need to double the value of "R" or "K" or "LS" or "C" or "P" to maintain equation balance.

2. If we double the value of "R", equation balance could be maintained by:

   a. Cutting the value of either K, LS, C or P in half. Or

   b. Doubling the value of T.

Noting that (LS), C, and P are the only factors that can be changed by conservation treatment;

1. List the Conservation Practices usable in your area to change (LS).

2. List the practices available for changing C.

3. List practices that change the value of P.

Based on your list, which factors appears most usable for reducing sheet and rill erosion in your area?

Example 1

Let us use a site that we feel has an adequate erosion control system on a young orchard because there has been no evidence of rilling on the lower slope, no evidence of sediment deposits in the diversion channel at the lower edge of the orchard and clear water has been observed running from the orchard following high intensity storms.

Length of the 12% slope is 1200 feet. From reference 1, p. 31, read (LS) = 3.5 1/

The Blando brome cover crop is disked in May after danger of rain has passed and the grass has matured seed.

1/ Guides for Erosion and Sediment Control, USDA, SCS, Davis, CA

The single disking is done across-slope giving an estimated "P" value of 0.9.

Assuming that the average annual soil loss from an orchard of the above description equals T, use the equation (C = T/R K (LS) P) to find maximum permissible C when:

(1) T = 1, R = 10, K = 0.15, C = ______
(2) T = 2, R = 20, K = 0.15, C = ______
(3) T = 3, R = 30, K = 0.15, C = ______
(4) T = 4, R = 40, K = 0.15, C = ______
(5) T = 5, R = 50, K = 0.15, C = ______

If your computations are correct solving for C in each case above will give a value of 0.21. Disked annual cover crops should provide C values ranging from about 0.2 with complete cover to about 0.3 when bare strips along tree rows occupy about 20% of the area. This assumes trees not large enough to provide significant canopy over the base areas. If trees provided 50% canopy, C values should improve to about 0.25 assuming 20% bare area along tree rows.

Example 2

Let us assume an orchard problem similar to example 1, except in this case the orchard is on 20% slopes and a mowed annual cover crops has been determined by experience to be the minimum treatment that keeps soil losses within tolerance.

Using 1200' of 20% slope (LS) = 6.5; assuming T = 1, R = 10, K =0.15 and P = 0.9 as in the first problem of example 1.

C = 1/10 x 0.15 x 6.5 x 0.9 = ______

Solving for combinations of "T" and "R" used in example 1 should all give Maximum Permissible C = 0.11 in this example. The estimated value of "C" for orchard annual strip cover crop, untilled, mowed is 0.10 as shown in Table 1, Reference 2.[1/] Thus our computation is in close agreement with the technical guide estimate.

1/ Field Office Technical Guide, Section II D

Example 3

If an orchard like that given in example 2 was moved into an area with "R" equal 50, a fivefold increase in rainfall energy but other factors remaining unchanged, it becomes obvious that the annual untilled, mowed cover crop would not keep soil erosion within tolerance (T). The maximum permissible "C" could be computed:

$$C = 0.11/5 = 0.022$$

Strips of perennial grass cover across slope would be needed to achieve the desired "C", assuming about 20% of the soil surface is maintained bare along the tree rows.

Example 4

In the above example, perennial grass may not be an acceptable alternative because of the difficulty of keeping the grass out of the bare strips without using herbicides that could injure the tree crop. A possible alternative would be use of terraces or diversions to shorten slope and bring potential soil losses within tolerance by using a mowed, untilled annual grass cover crop. The problem would then be "What is the maximum slope length between diversions that would be permissible when Maximum Permissible C = 0.11. Other conditions are T = 1; R = 50; K = 0.15; we could assume that supported by diversions, the erosion control value of "P" would increase to 0.8.

To determine maximum slope length between diversions, we use USLE as follows:

$$(LS) = T/R\ K\ C\ P = 1/50 \times 0.15 \times 0.11 \times 0.8 = 1/.66 = 1.5$$

Using Reference 1 "Guides for Erosion & Sediment Control", p. 31, we attempt to read across for L.S. Factor 1.5 to intercept the 20% slope line, and find that they do not intercept, indicating diversions cannot be used successfully. Note from the chart that diversions, even at 70 foot interval, on the 20% slope would require an L.S. Factor of not less than 2.75 in this instance.

We could anticipate that the diversions would not work on a soil so fragile that only an average annual loss of 1 T/Ac/year is permissible. Usually such soils are too shallow to consider diversions as an alternative.

Example 5

In example 4 it is important to note that on soils of 2 - ton soil loss tolerance or more, diversions with untilled mowed annual strip cover could be used to attain the required erosion control: with T = 2 ton, (LS) = 2/.66 = 3.0. From LS Chart read 90 feet for maximum distance between diversions.

For T = 3 Ton, (LS) = 3/.66 = 4.5. From LS Chart read 350 feet.

For T = 4 Ton, (LS) = 4/.66 = 6. From LS Chard read 900 feet.

For T = 5 Ton, (LS) = 5/.66 = 7.5. Note that up to 1800 feet slope would be protected without diversions.

Example 6

Let us use our 20% slope 1200 feet long with T = 1, R =10, (LS) = 6.5 and P = 0.9 to study effects of soil resistance to erosion "K" on Maximum Permissible "C".

Using USLE we note that maximum permissible "C" = 0.023 when K = 0.15 as follows:

$$C = T/R\ K\ (LS)\ P = 1/50 \times 0.15 \times 6.5 \times 0.9 = 0.023$$

What is Maximum Permissible "C" if "K" = 0.32 ______

What is Maximum Permissible "C" if "K" = 0.64 ______

If you performed the above computations correctly, your answers should be about 0.011 and 0.005 respectively. This shows the profound effect on "C" factor requirements as soil resistance to erosion decreases. In this example, continuous perennial grass (100% cover) would be needed on the most erosive "K" = 0.64 soil. Continuous annual grass would be barely adequate if "K" was 0.32.

The six examples given above show the profound differences in erosion control treatment required on California orchards and vineyards as rainfall, slope, and soil characteristics change.

TESTING RELIABILITY OF ASSIGNED FACTOR "R"

Each field office has been assigned computer print-outs for tabular solutions of Maximum Permissible "C", providing print-outs for only one "R" factor per field office. The "R" factors assigned were for use only on cropland. Usually these were the lowest R that the maps showed as going through the field office area because it was felt that most cropland would be in valley areas of lowest elevation and rainfall. No "R" values greater than 50 were assigned for use on cropland in the state because the WTSC hadn't prepared printouts above 50. Also because the TSC Agronomist felt that higher values were not realistic for use on California cropland, based on on his knowledge of the state.

Each field office staff will need to do some checking to determine if their assigned factor is about right. Some field offices may need to use higher "R" values to obtain accurate results.

On orchard and vineyard plantings checks can be run by selecting planted sites where management appears to be barely adequate to keep erosion in check as in example 1. Obtain or estimate all factors for the site except "R" as accurately as possible. Solve the equation for:

$$R = T / K (LS) C P$$

using the factors selected. If this procedure invariably shows a larger "R" than has been assigned to the field office it will suggest that "R" needs changing. The assumption that "R" needs changing is based on an assumption that we can estimate the actual average annual soil loss "A" in the field being tested and that "A" equals "T". Because we can't estimate sheet and rill losses in the 1 to 5 ton range with great accuracy, it takes computations from a number of test cases to establish evidence that "R" really needs changing and to indicate what it should be changed to.

Example 7

To illustrate a procedure for testing Factor R, let us assume a grain-fallow field that we have observed over five years without seeing evidence of erosion except for an occasional shallow rill one year of the 5 on the extreme lower slope, so we assume the system of management being followed keeps soil loss within the 5 T/Ac/yr shown by Soils Form 5 as permissible for this deep soil (T = 5, K = 0.32).

Field slope length and steepness is a uniform 500 feet and 20% (LS) (Reference 1, p. 31) = 5.0.

Tillage is done across the slope to form 4 alternate 125 foot strips of barley and fallow "P" (Reference 1, p. 11) = 0.67. Straw is not removed. Tillage is by chisels and sweeptype cultivator, operated slowly to keep residues on the soil surface. Nitrogen and phosphorus are applied each crop year to maintain high grain yields. Tillage is limited to operations necessary for weed control and seedbed preparation. "C" (Reference 2, Table 2) = 0.33.

Using the equation form R = T / K (LS) C P, determine the approximate value of "R". Your answer should be about 14. In this case, one would expect the round figure "R" assigned for use in the field office area to be either 10 or 20. Even though the assigned number was neither, tests on other fields would be needed to verify the correct "R" for the field office because of the relative unreliability of visual soil loss estimates.

AN EXERCISE ON APPLYING USLE TO DEVELOP ACCEPTABLE ALTERNATIVES

Let us assume that our criteria for solving example 7 is accurate enough that "R" = 15 would be the best for use on cropland in the field office area.

Questions

1. Should the same cropping system be adequate in another area where R = 10, other factors remaining the same?

2. Would it be adequate at a location where R = 20?

Using equation form A = R K (LS) C P, should indicate average annual soil losses less than "T" for question 1 and more than "T" for question 2 if the equation is solved correctly.

3. What cropping alternatives would keep "A" less than 5 in an area where "R" = 30?

   Trial Alternative 1. Wait until spring following harvest for first tillage, with other management left the same: (Note that Reference 2, p. 2 "example adjustments", suggests use of Table 3 to obtain "C" factors when field is not fall tilled following harvest. Table 3 shows C = 0.15, less than half the 0.33 shown by Table 2 used in example 7. Thus, A = R K (LS) C should equal a little less than 5 and be an acceptable alternative.)

Trial Altervative 2. R = 30 may provide sufficient moisture to make continuous grain feasible. Would continuous grain provide sufficient erosion control? (Reference 1, Table 2 shows C = 0.16 which is about 50% of 0.33 but we lose strip-cropping, increasing P from 0.67 to 0.95. Thus your solution should show "A" exceeding the 5 tons allowable soil loss.

Trial Alternative 3. Would terraces make continuous grain acceptable, other conditions remaining the same? If so what would be the maximum allowable spacing using (LS) = T / R K C P = 5 / 30 x .32 x .16 x .95 = 3.4.
(From Reference 1, p. 31, for S = 20%, Read L = 140 feet)
Dividing the 500' slope with 3 evenly spaced terraces would give 125' slope lengths.

From Reference 1, p. 11, what is the value of "P" with contour farming between terraces?

Solve average annual soil loss:

A = R K (LS) C P = 30 x .32 x 3.4 x .16 x .9 = ____

Does Trial Alternative 3 provide an acceptable level of erosion control?

Leaving our field of example 7 relocated to "R" = 30, assume that the land is acquired by a municipal water district and a reservoir is to be constructed in the lower watershed. Land use will be limited to avoid sheet and rill erosion rates exceeding 0.5 Ton per acre per year. What land uses would meet this goal? (Use Reference 2, Table 1, with equation form

"C" (Maximum Permissible) = "T" (use 0.5) / R K (LS) C P

to determine acceptable alternatives, if any.) Remember that in any management system not involving contour farming, cross-slope farming, or strip cropping, "P" = 1.0.

POLLUTANTS OTHER THAN SEDIMENT

In the municipal water supply watershed example above, if we conclude the water district has acquired all of the land within the watershed and is managing it primarily for municipal water production, it follows that intensive agricultural use of the watershed lands would not be permitted because agricultural chemicals could pollute the runoff sufficiently that it would not meet chemical standards for human consumption. This would tend to limit land use to grassland or woodland for livestock production, wildlife habitat and light recreational use.

If the water supply was for less restrictive uses such as recreation or irrigation we could visualize more intensive agricultural uses that could keep soil losses within the annual 0.5 T per acre limit. Properly managed irrigated pasture of perennial grasses and legumes for example would give a "C" value of about 0.003.

Compute A = R x K x (LS) x C x P

= 30 x .32 x 5 x .003 x 1

A = _____Tons per acre per year

Let us assume that the 3 terraces discussed previously are in place at 125 foot interval and the water district wants to consider contour planted orchard with perennial grass cover crop strip-planted between the tree rows, such that 80% of the field has grass cover and 20% is tilled bare strips on the tree rows.

Estimating a 25-year life span for the proposed orchard, and that the orchard will mature to 50% canopy in 10 years, can you use USLE to predict that average annual soil losses during the 25 years from sheet and rill erosion will be 0.5 T/A or less?

In working on this problem consult Reference 2, p. 13, Table 4. Using grass, 80% ground cover should give a reliable "C" value for our proposed orchard.

The value of "P" should be greatly enhanced because of the wide grass strips and narrow bare soil strips. From Reference 2, p. 11, Table 1, note that for conventional 50% - 50% grain contour strips for 20% slope the "P" value listed is 0.45. For our 80% grass and 20% bare untilled strips, a slope "P" value should be:

"P" = 0.45 x 20/80 = 0.11

If the bare strips are tilled consider

"P" = 0.9 x 20/80 = 0.23

Also consider keeping bare strips mulched with clippings from the grass strips to give

"P" = 0.9 x 50% (value of the mulch) x 20/80 = 0.11

Considering all factors for our orchard computation for average annual soil loss prediction during the 25 years would be

$$A = R \times K \times (LS) \times C \times P$$

$$= 30 \times .32 \times 3.4 \times .012 \times .23$$

A = ______ Tons per acre per year

If all your computations are correct they should suggest that the orchard, protected by perennial grass strips, terraces, contouring and strip cropping would hold soil in place even better than irrigated pasture.

I believe most conservationists would agree that the orchard wouldn't be a good option where the primary objective of watershed management is water yield. In an "R" = 30 belt, only the most intense storms would produce much from the grassed, terraced and contoured orchard even with soils of moderately slow to slow infiltration rate.

Discussion of Reference 1, p. 13, Table 4, "C" Values for Permanent Pasture, Rangeland, and Idle Land

Table 4 can be of great value to conservationists in California for applying USLE to untilled land with various combinations of shrub, grass and weed covers, including nontilled orchard and vineyard. The table can be misleading for use in California because it was developed to fit conditions of the great plains and eastern states where the grasses are dominantly perennials and annual covers tend to have a dominance of broad leaf weeds. In California Mediterranean climate, nonirrigated grass stands are dominantly annuals and actually have less ability to control erosion than the Table 4 "C" values for grass indicate. I would suggest that "C" values for annual grass stands be estimated from the table by averaging the table values for grass and weeds. This would give a more reliable value than if taken directly from the table.

Example, "C" value for 95 - 100% ground cover with no appreciable canopy:

grass "C" value 0.003
weed "C" value 0.011
Annual grass "C" value 0.007

In addition to providing "C" factors for grass and shrub lands, Table 1 should provide reliable "C" factors for similar nontilled systems where canopy and cover can be estimated. Typical examples would be nontilled orchards, vineyards, and christmas tree plantings. The table should not be used on areas where tillage will be practiced because loose soil surface greatly increases potential for sheet and rill erosion, giving a much larger "C".

Using the Computer Print-Outs in Technical Guide Section II-D

The print-outs are designed to solve USLE directly for maximum permissible "C", but almost any form of the equation can be solved tabularly from the print-outs with a little practice.

As indicated previously "print-outs" for only one "R" factor have been provided to each field office. A collection of sets for all "R" factors becomes too bulky to be pratical.

Because Maximum Permissiable "C" values vary inversely with "R" it is easy to obtain corrected "C" values for any "R" from a single set of print-outs. Just keep in mind that Maximum Permissible "C" is doubled by cutting "R" in half; conversely, doubling "R" cuts the permissible "C" in half.

The best way to master the print-outs is to practice using them. For practice, try solving examples from this exercise using the print-outs. If you derive approximately the same answers as from the mathematical solution, it will indicate you have learned to use them correctly.

Estimating Values for "C" When Cropping Systems Include Row Crops Such as Corn, Sorghum and Vegetables.

To a limited extent row crops are grown on California soils with sufficient slope to make sheet and rill erosion a problem. In other states where USLE has been in use for a long time values for an average annual "C" have been estimated for entire cropping sequences or rotations. In most parts of California, cropping sequences are changed too frequently for such a long term "C" to have much value on cultivated land.

Because cropping sequences can be so variable in our irrigated agriculture, it appears advisable to use a system of estimating "C" values for individual crops, based on the soil surface condition left during our 6 month season of rainfall.

For example an irrigated corn field left over winter untilled with stalks shredded and distributed evenly should have a "C" value of about 0.12 for the corn year. Similar procedure with grain sorghum should give about 0.18, larger than corn because it has less residues. Corn or sorghum removed for silage but left untilled will be nearly bare with a "C" of about 0.45. If the field is fall disked or chiseled following ensilage harvest, "C" for the silage crop year will be about 0.65 unless a winter cover crop is seeded. A good cover crop will reduce the "C" to about 0.3, assuming that soil loss will occur during some years before the crop grew enough to provide cover. Irrigating the crop up ahead of fall rains should give a "C" of about 0.2.

Winter vegetable crops grown without residues on the soil surface will have "C" values ranging between about 0.7 and 0.4, depending on how much soil cover the crop itself provides over the rainy season.

Realizing that the rate of soil loss to sheet and rill erosion varies directly with "C" during each crop year should help conservationists visualize the soil management systems needed to keep soil loss within tolerance for each crop. It can be seen that any system that leaves the soil on other than gentle slopes loose and/or exposed during any part of the rainy season will probably require special practices such as terraces, contoured rows, or strip farming to avoid excessive sheet and rill erosion. For terrain with long slopes averaging 5% or more, only systems that provide soil cover during the rainy season should be designated as Conservation Cropping Systems.

Summary The preceding material has been prepared to provide California conservation specialists with a self training tool for becoming proficient in using the Universal Soil Loss equation to predict sheet and rill erosion from agricultural land. The problems presented attempt to reveal how the equation can be used to compare the effects of various land management alternatives on soil loss. Use of USLE to calculate maximum permissible terrace spacings is demonstrated. The effect of various soil management systems on the equation factor "C" is demonstrated and discussed. Answers are provided for most of the problems presented.

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