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To avoid excessive soil erosion and ensure the continued availability of U.S. military training lands, there must be a basis for estimating allowable levels of sustained tracked vehicle use. The allowable use management objective can be representative of each ecological response unit. The point-intercept method is employed along each line transect to determine botanical composition, amounts of ground and canopy cover for untracked and tracked points, and percent of the surface tracked and untracked. Soil samples are collected to determine soil erodibility. Slope lengths and gradients are measured. For each vehicle type, estimates are made of the average cross-country distance traveled per day (surface coverage is computed by adding the width of the tracks times distance traveled). Estimates are made of the average number of years for tracked areas to regrow vegetation cover equivalent in C-value for the universal soil loss equation to untraced areas and the average number of years that a track mark remains visible. With this information and using the USLE, maximum allowable use can be estimated for each ecological response unit. Allowable use is calculated in tracked vehicle days per year (TVDs/year) for military trainers and percent disturbance for land managers. Land managers verify that allowable use is not exceeded by measuring the percentage of the surface that appears tracked. Adjustments in allowable use are based on trends in the amount of ground cover (detected by short-term monitoring) and by observing changes in botanical composition (detected by long-term monitoring).

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FOREWORD

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Dr. R. K. Jain is Chief, USACERL-EN. Dr. L. R. Shaffer is Technical Director of USACERL, and COL Carl O. Magnell is Commander and Director.
A user’s guide for estimating allowable use of tracked vehicles on nonwooded military training lands

Victor E. Diersing, Robert B. Shaw, Steven D. Warren and Edward W. Novak

ABSTRACT: To avoid excessive soil erosion and insure the continued availability of U.S. military training lands, there must be a basis for estimating allowable levels of sustained tracked vehicle use. The allowable use management objective can be attained by establishing permanent line transects in areas representative of each ecological response unit. The point-intercept method is employed along each line transect to determine botanical composition, amounts of ground and canopy cover for tracked and untracked points, and percent of the surface tracked and untracked. Soil samples are collected to determine soil erodibility. Slope lengths and gradients are measured. For each vehicle type, estimates are made of the average cross-country distance traveled per day (surface coverage is computed by adding the width of the tracks times distance traveled). Estimates are made of the average number of years for tracked areas to regress vegetation cover equivalent in C-value for the universal soil loss equation to untracked areas and the average number of years that a track mark remains visible. With this information and using the USLE, maximum allowable use can be estimated for each ecological response unit. Allowable use is calculated in tracked vehicle days per year (TVDs/year) for military trainers and percent surface disturbance for land managers. Land managers certify that allowable use is not exceeded by measuring the percentage of the surface that appears tracked. Adjustments in allowable use are based on trends in the amount of ground cover (detected by short-term monitoring) and by observing changes in botanical composition (detected by long-term monitoring).

THE U.S. Army is responsible for managing about 12 million acres of land. Much of that land is available for tracked vehicle training, primarily tanks and armored personnel carriers. Passage of these tracked vehicles over the land disaggregates and compacts the soil, crushes the herbaceous and woody vegetation, and exposes the soil to the erosive forces of rain and overland flow. If vegetative loss is excessive, serious soil erosion may occur in a few years, leaving the land gullied and unusable for future training exercises. Adequate vegetative cover for soil protection is critical. Military land managers responsible for maintaining training lands must determine which ecological response units can support tracked vehicle training. But equally important, they must be able to predict how much training, measured in terms of percent surface disturbance, each training site can support. Any method of calculating allowable use for a site must be capable of translating percent surface disturbance into the allowable number and kind of tracked vehicles that the site can support on a sustained basis. Also, for the purposes of rehabilitation, a manager should be able to determine how much of an increase in vegetative cover is needed on a marginal site before it is used again in training exercises.

Currently, there are no methods to estimate allowable levels of tracked vehicle use on nonwooded Army land. Herein, we describe a method for surveying vegetative cover as it relates to sheet and rill erosion. The method will allow military land managers to estimate existing soil erosion rates on ecological response units and predict changes in soil erosion rates under varying levels of tracked vehicle use.

Data collection

Several (usually 3 to 5) permanent, 200-m line transects are established in areas representative of each ecological response unit. An ecological response unit is an area of land with similar topography, soils, and range types that will respond similarly throughout to treatment or management.

The number of transects required per ecological response unit depends upon available resources, site size, and degree of data resolution required. Botanical composition and cover data are collected by the point-intercept method at 1-m intervals along each 200-m transect. Ground cover, defined as that cover in contact with the surface of the ground, is recorded as gravel, rock, litter, deadwood, plant basal cover (by species), or bare ground. Canopy cover is recorded by species at 1-dm height intervals where vegetation touches a narrow, 6-mm diameter, vertically positioned measuring rod.

The percentage of the surface that is tracked and untracked is documented by the point-intercept method, and all cover data (ground and canopy) are separated into tracked and untracked categories. Soil samples are collected to a depth of 15 cm at four equally spaced intervals along each line transect (25, 75, 125, and 175 m). Slope length is measured as the straight-line distance of overland flow, from point of origin to a defined channel or point of significant slope change, that would cross each of the four points noted above on a line transect. Slope gradient is measured with a clinometer.

All cover, soil, and topographic data are averaged among all transects of an ecological response unit. Large, discontinuous areas of the same ecological response unit may have a different history of use and, thus, may be in a different condition. These areas are best treated separately.

Calculating RKLSCP

The universal soil loss equation (A = R x K x LS x C x P) was developed to predict average rates of soil loss from sheet
and rill erosion by water (6). Computed soil loss, A, is expressed in tons/acre/year. The equation's parameters represent erosivity of rainfall and runoff (R), soil erodibility (K), slope length and gradient (LS), vegetative and other soil protecting cover (C), and erosion control support practices (P). The P factor on many military training lands is nearly 1.0 and is, therefore, omitted here.

**R factor.** General values of R are available in figure 1 of Wischmeier and Smith (6). Some state Soil Conservation Service offices now have more detailed R-factor maps.

**K factor.** For most areas, soil surveys are available from SCS; these usually contain estimated soil erodibility values (K values) for each soil series. If these data are not available, soil samples collected along the line transects can be analyzed for texture, organic matter, structure, and permeability. These data are entered into the soil erodibility nomograph [Figure 3 of Wischmeier and Smith (6)] to determine the K values.

**LS factor.** The LS factor is determined directly from the slope length and gradient information collected on the permanent transects. LS values are available in figure 4 of Wischmeier and Smith (6).

**C factor.** In open habitats, such as prairies, shrublands, deserts, and open savannas, the movement of tracked vehicles is independent of the vegetative cover and botanical composition. Therefore, the difference in cover and composition between untracked and tracked areas is due to track effects. The point-intercept method of measuring vegetation along a randomly selected line transect allows for the unbiased segregation of ground and canopy cover in tracked versus untracked areas. This makes it possible to calculate changes in C on a site for any percentage of surface disturbance.

For the untracked portion of a site, C values (Cm denotes the untracked condition) are calculated using table 10 from Wischmeier and Smith for permanent pasture, range, and idle land (6). For the tracked portion of a site, however, C values (C2 denotes the tracked condition) cannot be calculated from this table because surface crusts are broken, soil aggregates are disaggregated, surface roots are killed, and soils are compacted. All of these changes increase soil erosion. Many of these physical changes in the soil from an untracked to a tracked condition can be accounted for in table 12 from Wischmeier and Smith for mechanically prepared woodland sites (6). Forests are botanically and structurally different from prairies, but whether harvesting a forest or tracking a prairie with a tank, the net effect is canopy loss, litter removal, root destruction, increased surface roughness, and various combinations of soil disaggregation and compaction. Table 1 shows an interpolated expansion of Wischmeier and Smith's table 12 for C values on mechanically prepared sites (6). To account for increases in surface roughness from an untracked condition, all listed values in table 12 of Wischmeier and Smith were multiplied by 0.75 and their products entered into our table 1 (6). We recognize that scientific data are lacking to support this application of the USLE. Hopefully, our research will stimulate further research, the findings of which will replace our judgment. Application of the USLE to range-lands has been discussed by several authors (3, 4).

For practical application, we assumed that if there are no visible imprints of tracks in the soil then it is untracked. If the imprints of tracks are readily visible in the soil, then it is tracked. All roads and trails are considered tracked. Gravel and rocks are considered part of the ground cover (5). Compared with straw and bark chips, however, rocks and gravel do not control erosion as effectively (2).

**Estimating allowable vehicle use**

The following five steps outline in condensed form the fundamentals necessary to estimate allowable levels of tracked vehicle use on military lands:

1. **Step I.** Calculate D = erosion rate when not tracked. Calculate E = erosion rate when partially tracked. Calculate F = erosion rate when totally tracked.

2. **Step II.** Using the method of data collection previously described, determine the average R, K, LS, and C (C1 and C2) values for each ecological response unit. Use the point-intercept observations to calculate the percentage of the site tracked and untracked. Then calculate an average C-value for untracked and tracked cover. Calculate the site erosion rate (Figure 1), assuming the site is (D) not tracked, (E) partially tracked (current percent of surface that is tracked and untracked), and (F) totally tracked. Calculations for D and F are necessary before going to step 2.

3. **Step II.** Calculate G = maximum one-time surface use (%); without exceeding T.

4. **Step IV.** This calculation determines the maximum percentage of the surface of an ecological response unit that could be tracked on a one-time basis without losing too much cover and exceeding soil loss tolerance (T). If the site erosion rate when totally tracked (F) is less than or equal to T, then the maximum one-time surface use (C) is 100%. Typically, however, F exceeds T, in which case G is calculated as follows:

   \[ G = \frac{T - D}{F - D} \times 100 \]

5. **Values of T** (maximum limit of satisfactory erosion control) are available for most soil series in SCS-published soil surveys.

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**Table 1. Factor C** for the visibly tracked portion of an ecological response unit. 

<table>
<thead>
<tr>
<th>Ground Cover (%)</th>
<th>Canopy Cover (%)</th>
<th>Canopy Cover (%)</th>
<th>Canopy Cover (%)</th>
<th>Canopy Cover (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>20</td>
<td>40</td>
<td>60</td>
</tr>
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</tr>
<tr>
<td>80</td>
<td>.04</td>
<td>.03</td>
<td>.03</td>
<td>.01</td>
</tr>
</tbody>
</table>

*Interpolated from table 12 in Wischmeier and Smith (6). All values were multiplied by 0.75 to account for surface roughness (page 34 of Wischmeier and Smith). 

**Soil Condition**

192 Journal of Soil and Water Conservation
Calculations in the previous step are for estimating the maximum portion of a site that can be tracked on a one-time basis without exceeding T. After that, years of rest would be required to replace the lost cover. To calculate allowable use on a sustained basis, as opposed to a one-time basis, it is necessary to estimate the number of years required to replace (grow) an equivalent amount of soil-protecting cover (same C-factor value) after being tracked. This time frame for recovery is the recovery period. The maximum one-time surface use (G) must be divided by the recovery period in years to approximate H. The length of the recovery period is not equal to the amount of time for a tracked area to appear untracked. Track marks often become obliterated before the vegetative cover has returned to its previous C-value. The recovery period must be measured.

\[
H = \frac{G}{C 	ext{-factor recovery period (years)}}
\]

To translate allowable surface tracking/year (H) to usable acres/year (I), multiply site size in acres by H.

\[
I = (\text{Site size in acres}) \times (H)
\]

Step 5. Calculate J = allowable tracked vehicle days/year (TVD/year).
This step yields the information necessary for the military trainer and land manager to determine allowable vehicle numbers, kinds, and days of use on each site. A tracked vehicle day (TVD) is defined as the average off-road distance traveled by an M60 tank during maneuver exercises in one day. The assumption is that the average off-road distance traveled is 6 miles and the combined track width is 3.25 feet. An M60 tank then disturbs 2.36 acres/maneuver day. Convert usable acres/year (I) into allowable tracked vehicle days/year (J) with the following equation:

\[
J = I \times 2.36 \text{ acres}
\]

Other tracked vehicles have tracks of different widths, and these travel, on the average, different distances. Based on these two variables, Table 2 lists the conversion factors used for other tracked vehicles. The footprint weight of all these vehicles is comparable. On smaller military installations, or installations where there is no maneuver training, one TVD is probably less than 2.36 acres/day for an M60 tank and should be recalculated. The conversion factor relationship with other vehicles should remain about the same.

Step 5. Calculate M = maximum allowable visible track coverage.
This step is required for the land manager to verify the use (surface tracking in percent) a site receives. This is done by estimating the percentage of the surface that appears tracked. Before this can be calculated, however, the average time that tracks remain visible must be estimated. Track marks generally are obliterated more quickly as B of the USLE increases, soil aggregation decreases, and wind increases. The average obliteration period for tracks can be easily determined by marking tracks of known age and observing the average number of years they remain visible. Typically, at least in arid and semiarid regions, the obliteration period for vehicle tracks is shorter than the vegetation recovery period (C-factor equivalent). Maximum allowable visible track coverage on a site is determined by the equation:

\[
M = H \times \text{Track obliteration in years}
\]

### Example calculations

Table 3 shows allowable use estimates for four ecological response units, two in central Colorado and two in central Texas. The ecological response units selected are about equal in size (about 4,000 acres) to demonstrate how factors other than size affect allowable use estimates. One site in Colorado is dominated by blue grama (Bouteloua curtipendula) and the other site is dominated by Indian ricegrass (Oryzopsis hymenoides) and fourwing saltbush (Atriplex canescens). One Texas site is dominated by little bluestem (Schizachyrium scoparium); the other site is dominated by Texas wintergrass (Stipa leucotricha) and annual broomweed (Xanthocephalum dracunculoides).

Table 3 also shows the data required to calculate allowable use. The rainfall and runoff factor (R) is much greater for the Texas sites (290) than the Colorado sites (80). Soil erodibility (K) among the four sites ranges from 0.17 to 0.34. There are only slight differences among the LS values (0.35-0.50). The untracked portion of the Colorado sites (blue grama prairie and fourwing saltbush/Indian ricegrass shrubland sites) provided more effective soil cover (C' of 0.03 and 0.06, respectively) than the cover on the Texas sites (Texas wintergrass/annual broomweed and little bluestem prairies, C' of 0.07 and 0.09, respectively). The reduction in soil-protecting cover in tracked areas resulted in an increase in C, especially on the fourwing saltbrush/Indian ricegrass shrubland site in Colorado (increase from C' of 0.06 to C' of 0.22).

The portion of each site that was visibly tracked ranged from 3% on the little bluestem site to 29% on the Texas wintergrass/annual broomweed site. Definitive data are not available on the average time (in years) required for the vegetative cover of the various ecological response unit's to grow cover equivalent in C to the untracked cover (recovery period). However, 3 years of observation on these four sites indicates that recovery of the fourwing saltbush/Indian wintergrass shrubland site is complete.
ricegrass shrubland is longest, about 15 years. This is largely because of the slow regrowth of the woody species. The blue grama prairie is second slowed, about 10 years for recovery. Most blue grama survives the impacts of tracked vehicles, but that which is killed is not typically replaced by seed; instead, the blue grama slowly reestablishes itself in the bare area by tillering.

The two Texas sites appear to recover more rapidly (4 to 5 years). The track obliteration period on the four sites averages 1 to 2 years. Soil loss tolerance on the sites ranges from 1 ton/acre/year (fourwing saltbush/indian ricegrass shrubland site) to 5 tons/acre/year (blue grama prairie).

Allowable use estimates for each of these sites (Table 3) vary greatly, based on the data values for each site. Soil loss tolerances are being exceeded on the fourwing saltbush/indian ricegrass shrubland site in Colorado and the Texas wintergrass/common broomweed site in Texas. Both of the sites can, however, be used on a limited basis for training. Surface use per year on the fourwing saltbush/indian ricegrass shrubland site needs to be reduced by only 1% /year to be within acceptable limits. Surface use on the Texas wintergrass/common broomweed site should be reduced from 25% to 2%.

Maximum one-time surface use varies from 11% to 100%. However, when the cover recovery period is taken into account, allowable surface use/year for the sites ranges from 25% for the little bluestem prairie to 1% for the fourwing saltbush/indian ricegrass shrubland. Based on the track obliteration period, a land manager should visually observe no more than 20% surface use/year for the sites. For the little bluestem site, 1% on the fourwing saltbush/indian ricegrass shrubland, and 2% on the Texas wintergrass/common broomweed site. To allow land managers to communicate to trainers, allowable use for each site is estimated in allowable tracked vehicle days/year (MOO tank equivalents). The little bluestem prairie site can receive 424 TVDs/year without exceeding T; blue grama prairie, 169 TVDs/year; Texas wintergrass/common broomweed prairie, 34 TVDs/year; and fourwing saltbush/indian ricegrass shrubland, 17 TVDs/year.

**Short-term monitoring**

When a site is to be inventoried, data are collected entirely from the permanent transects. These data are used primarily to determine the average cover in tracked and untracked areas, document botanical composition, and determine the portion of a site that appears tracked and untracked. In comparison, short-term monitoring is directed toward documenting changes in the portion of a site being tracked and to substantiate that a site is being used within acceptable limits (the threshold being established during the inventory).

Our short-term monitoring program consists of using a metric measuring wheel with an attached counter and two finger counters. The measuring wheel is pushed along each line transect (200 observations/transect). Each time the small pin on the wheel that advances the number on the counter is at its lowest point adjacent to the ground, a visual determination is made if the pin tip falls over a tracked or untracked area if the pin falls over ground cover or bare ground. One finger counter is used for recording the tracked observations. Untracked observations are calculated by subtracting the tracked observations from the total observations on the wheel counter. The other is used for recording the ground cover. Bare ground is calculated by subtracting ground cover observations from the total observations on the counter.

Alternatively, a surveyor can conduct a walking survey. A pencil mark is made on the front tip of each shoe sole, and with each step, the surveyor records what the shoe tip falls over (tracked or untracked and ground cover or bare ground). After 100 steps are taken, the percentage of surface tracking and the percentage of ground cover can be calculated.

If the portion of each transect that is tracked differs greatly among transects on a site, additional areas on the site can be surveyed to estimate more accurately the portion of the site that is tracked. If this is done, however, the route taken by the surveyor should be documented so the same area can be resurveyed, along with the transects, in future years.

There is no fixed time interval for conducting resurveys (monitoring). However, the short-term monitoring techniques discussed above should, in general, be conducted annually or biannually on training land receiving moderate to heavy use. Land receiving little or no use may only require monitoring on a 2- to 4-year basis.

The basic philosophy for choosing this short-term monitoring program is based on two premises. First, if the monitoring program selected is too labor intensive or requires large monetary resources, land managers may be reluctant to conduct the inventory. Second, the monitoring program should, in general, quantify the intensity of land use and the effect of that use on the land resource. The amount of tracked vehicle use is quantified, and the effect of that use on cover is quantified.

**Long-term monitoring**

Long-term monitoring is conducted like the inventory. It reestablishes the amount of cover in tracked and untracked areas, quantifies botanical composition, and yields a

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**Table 3. Example of data requirements and allowable use estimates for four ecological response units, each about 4,000 acres in size.**

<table>
<thead>
<tr>
<th>Data Requirements</th>
<th>Blue Grama Prairie (Colorado)</th>
<th>Four-wing Saltbush Indian Ricegrass Shrubland (Colorado)</th>
<th>Texas Wintergrass Common Broomweed Prairie (Texas)</th>
<th>Little Bluestem Prairie (Texas)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rainfall and runoff factor (R)</td>
<td>60</td>
<td>80</td>
<td>290</td>
<td>290</td>
</tr>
<tr>
<td>Soil erodibility factor (K)</td>
<td>.28</td>
<td>.34</td>
<td>.28</td>
<td>.17</td>
</tr>
<tr>
<td>Average slope length and gradient factor (LS)</td>
<td>.47</td>
<td>.49</td>
<td>.50</td>
<td>.35</td>
</tr>
<tr>
<td>Average cover in tracked areas (Tracked C)</td>
<td>.11</td>
<td>.22</td>
<td>.17</td>
<td>.10</td>
</tr>
<tr>
<td>Average cover in untracked areas (Untracked C)</td>
<td>.03</td>
<td>.06</td>
<td>.09</td>
<td>.07</td>
</tr>
<tr>
<td>Site size (acres)</td>
<td>4,000</td>
<td>4,000</td>
<td>4,000</td>
<td>4,000</td>
</tr>
<tr>
<td>Portion of site tracked/untracked (%)</td>
<td>10/90</td>
<td>29/79</td>
<td>29/71</td>
<td>39/79</td>
</tr>
<tr>
<td>C-factor recovery period (years)</td>
<td>10</td>
<td>15</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>Track obliteration period (years)</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>(T) Maximum allowable soil loss (tons/acre/year)</td>
<td>5</td>
<td>1</td>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>

**Allowable use estimates (without exceeding T)**

<table>
<thead>
<tr>
<th>% T being exceeded</th>
<th>No</th>
<th>Yes</th>
<th>Yes</th>
<th>No</th>
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<tbody>
<tr>
<td>Maximum allowable tracked vehicle days/year (MOO tank equivalents)</td>
<td>100</td>
<td>9</td>
<td>11</td>
<td>100</td>
</tr>
<tr>
<td>Maximum allowable surface use/acre/year (Ha)</td>
<td>10</td>
<td>1</td>
<td>2</td>
<td>25</td>
</tr>
<tr>
<td>Maximum allowable track coverage (%)</td>
<td>20</td>
<td>1</td>
<td>2</td>
<td>25</td>
</tr>
<tr>
<td>Maximum allowable tracked vehicle days/year (TVDs/year)</td>
<td>169</td>
<td>17</td>
<td>34</td>
<td>424</td>
</tr>
</tbody>
</table>
new estimate of allowable tracked vehicle use on the site. In general, long-term monitoring procedures are required only on a 5- to 10-year basis unless the short-term monitoring data indicates that cover has declined substantially.

Long-term surveys, in their documentation of botanical composition, yield important information for documenting trends on a site. For example, a perennial cover may decline and weedy annuals increase — an indication that the site has received too much use. Accordingly, allowable use estimates should be reduced. Typically, however, a perennial-to-annual shift in cover would be detected indirectly by the short-term monitoring procedures; for example, total ground cover often decreases as perennial vegetation is replaced by annuals.

**Conclusions**

This method provides a framework for calculating reasonable estimates of allowable levels of sustained tracked vehicle use based upon physical properties of the soil and biological attributes of the vegetation. The system also incorporates a safety feature in case the allowable-use estimates are either miscalculated or do not accurately reflect the ability of a site to withstand vehicle impacts. This safety feature involves documentation of changes in ground cover (short-term monitoring) and shifts in botanical composition (long-term monitoring). Currently, no other method is available for estimating allowable levels of sustained tracked vehicle use on a site-by-site basis. Also, this method provides a mechanism for military trainers and land managers to communicate by translating the percentage of surface disturbance into vehicle kinds and numbers. Use of this method will serve as a mechanism for regulating or better distributing tracked vehicle use on military training lands.

**REFERENCES CITED**