Assessing Soil Erosion on Trails: A Comparison of Techniques

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Abstract—Reports of trail degradation have been increasing in different wildernesses. This impact has become a common concern among managers. Deteriorating tread conditions of trails are increasing, as is concern at protected areas worldwide. In order to make objective and timely trail resource decisions, managers need to have effective and efficient methods of assessing trail erosion. Various approaches to assessing trail erosion, the limitations and utility of each and implications for management are discussed.

Trail deterioration, in the form of trail erosion, is a common problem in wilderness and other backcountry areas and is an impact indicator that warrants the attention of managers (Cole 1983). Trail erosion significantly affects ecological, social and managerial environments.

Ecological Significance

Erosion can result in aquatic system disturbance, excessively muddy trails, widening of trails, tread incision and braided or multiple trails and can lead to the creation of undesired trails (Hammitt and Cole 1998, Marion and others 1993). Unlike disturbed vegetation and compacted soil, soil erosion is the only trail degradation indicator, relatively speaking, that does *not* recover naturally over time. A study of 106 National Park Service units found that almost 50% of all park managers indicated that soil erosion on trails was a problem in many or most areas of the backcountry. Trail widening was cited by 31% of park managers, and 29% rated the formation of braided or multiple trails and the creation of undesired trails as serious problems (Marion and others 1993).

Social Significance

The impacts of soil erosion include undesirable trail conditions, which can adversely affect the recreational experience. Deeply eroded, muddy, multiple or undesired trails may lead to a variety of social problems. Trails that are severely eroded may have significant amounts of exposed roots, which can decrease the functional utility of the trail; the scars left by eroded trails may be considered a visual impact and adversely affect the visitors' experience. Braided trails commonly found in open meadows create a visual impact sometimes noticeable from miles away. These impacts and the decrease in the functional utility of trails due to factors of trail erosion have been found to affect the quality of recreational experiences (Vaske and others 1982).

Managerial Significance

Trail erosion caused by recreational use threatens the resource protection mandates of federal land managers. Managers of wilderness areas are legally mandated to assess recreational impacts. Management guidelines provide National Park Service managers with the most specific guidance in implementing legislation. The *Natural Resources Management Guideline* (National Park Service 1991) states that "park managers must know the nature and condition of the resources in their stewardship, have the means to detect and document changes in those resources, and understand the forces driving the changes" (chapter 5:20). A second *Natural Resources Inventory and Monitoring Guideline* (National Park Service 1992) states that it is the policy of the NPS to "assemble baseline inventory data describing the natural resources under its stewardship, and to monitor those resources forever [and] detect or predict changes that may require intervention" (chapter 1:1).

Several studies on trail conditions, specifically trail erosion, have been conducted (Bayfield and Lloyd 1973, Bratton and others 1979, Coleman 1977, Garland 1990, Helgath 1975, Rinehart and others 1978), from which valid assessment methods have been developed. This paper presents different approaches to assessing trail erosion and discusses the utility and management implications of each.

Literature Review

Assessment of trail erosion is fairly well-represented in the trail impact literature, which is to say that there have been numerous reported methods used to assess trail erosion. The literature presents nearly a dozen different terms related to methods of assessing trail erosion. They range from proactive estimations of potential soil loss to reactive methods that result in precise measurements of actual loss. The nine most widely applied methods are reviewed here.

Cole (1989) discusses the use of the *condition class* method. This rapid assessment method involves a series of condition descriptions determined by management objectives (fig. 1). The trail system is then systematically sampled, and trails/segments are classified according to the predetermined

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Trail Condition Classes

Class 0: Trail barely distinguishable; no or minimal disturbance of vegetation and/or organic litter.

Class 1: Trail distinguishable; slight loss of vegetation cover and/or minimal disturbance of organic litter.

Class 2: Trail obvious; vegetation cover lost and/or organic litter pulverized in primary use area.

Class 3: Vegetation cover lost and/or organic litter pulverized within the center of the tread, some bare soil exposed.

Class 4: Nearly complete or total loss of vegetation cover and organic litter within the tread, bare soil widespread.

Class 5: Soil erosion obvious, as indicated by exposed roots and rocks and/or gullying

Figure 1—Condition class descriptions used to assess trail conditions (source: Jeffrey L. Marion).

condition classes. Sampling has been done at differing intervals by various researchers. Bayfield and Lloyd (1973) every 50m, Bratton and others (1979) sampled every 500m, Marion and others (1997) every 300m, Root and Knapik (1972) every 152m.

Leonard and Whitney (1977) and Cole (1983) describe in detail the *cross-sectional area* method, in which once a sampling location is identified, a taught line, rope, cord, wire or rigid bar is placed across the trail and attached to two fixed points. These points should be permanent and far enough off the trail to allow for future erosion and or the development of multiple treads. At fixed intervals along the horizontal transect line, vertical measurements are taken to the tread surface. Care must be taken to keep the horizontal rope, wire or bar taut, level and elevated above vegetation. The cross-sectional area below the taut line or bar can then be calculated (fig. 2). Future measures will indicate the amount and rate of change that has occurred.

Published research indicates that the use of the *quadrat* assessment method on trails is limited. A quadrat is typically a square device made of varying materials, which is then made to look like a checkerboard by subdividing the frame with string. This device is placed on the tread surface, at sampling points determined by a sampling scheme, and conditions are then estimated on a percentage basis.

Census of active erosion, as described by Leung and others (1997) and Farrell and Marion (1999), is a subjective rapid assessment method, requiring experience and expertise in trail design and construction. Actively eroding trail segments is one type of erosional event, which will appear to develop constantly over present time, and a substantial loss may occur over a years time or a couple of months. The erosion is continuing its downward movement to the bedrock. An assessment of the trail system is done by walking the trail and tallying the actively eroding segments.

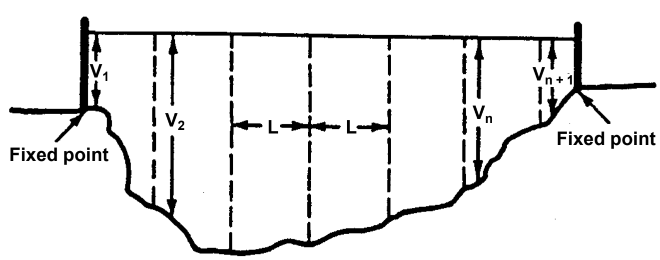
Census of erosional events, a rapid assessment method, is considered a subset of *active erosion,* described by Leung and others (1997), and Marion (1997a). The first step is to define in precise terms exactly what will be considered an erosional event (that is, at least 10 feet long and 1 foot deep). An erosional event is considered an inactive event that has stabilized as the downward erosional process hits the more resistant subsoil, regolith layer or bedrock. A census of the trail system is then conducted by tallying the number and length of erosional events while walking the trail.

Rinehart and others (1978) used *stereo photography* to assess trail conditions. This method involves taking stereoscopic pairs of photos at a sampling location determined by a sampling scheme. Trail transects are established following procedures similar to the cross-sectional method. However, instead of taking vertical measurements to the trail tread, stereo photos are taken and the cross-sectional area is computed with a digitized stereo plotter. Rinehart used a 2- x 2-inch camera mounted to a stereo board that accommodated various film sizes. Before each photo is taken, a target card is placed on the trail for scale, and the board is leveled and kept exactly 15 feet away from the trail transect.

Maximum tread incision, is a method in which a surveyor conducts incision measurements at a series of points along a trail, which is determined by a sampling scheme. One method of measuring incision is to identify the post-construction tread surface and take a vertical measurement to the deepest section of the current tread surface. A modification of the procedure is to identify the level of the current tread and take a vertical measurement to the deepest point of the tread surface.

Coleman (1977) used *aerial photographs* to evaluate trail conditions over a 19-year period. A 1953 photo of a popular trail was analyzed using a Hilger and Watts 5x Print Magnifier to measure path width, at a scale of approximately 1:10,000. This instrument is capable of measuring to 1/10mm. Trail sections were sampled from this photo and compared with a 1973 photo of the same trail segment.

Kuss and Morgan (1980; 1984) applied the *Univerisal Soil Loss Equation* (USLE) to assess soil loss. This method is a



$$A = \frac{V_1 + 2V_2 + \ldots + 2V_n + V_{n+1}}{2} \times L$$

Where A = cross-sectional area

$V_1 - V_{n+1}$ = Vertical distance measurements, starting V_1, the first fixed point, and ending at V_{n+1}, the last vertical measurement taken.

L = Interval on horizontal taut line.

Figure 2—Layout of trail transect and formula for calculating cross-sectional area (source: David N. Cole).

model and an estimation of potential soil loss, and it is useful in planning and designing trail systems. Its utility as a measure of real soil loss is limited and should be used with caution outside of Eastern agricultural lands in which the empirical relationships were developed. For these reasons, this method is not discussed further.

Wallin and Hardin (1996) estimated trail-related soil erosion in Ecuador and Costa Rica using an experimental design. Using a modified *McQueen rainfall simulator,* the study compared on- and off-trail infiltration rates and particle dispersion due to the simulated rainfall. Like Kuss and Morgan's method, this method is an estimation of potential erosion and therefore is not discussed further.

More comprehensive reviews of the trail impact literature are provided in Hammitt and Cole (1998), Cole (1981) and Hendee and others (1990). Table 1 summarizes the assessment methods previously discussed.

Methods

An analysis of published research resulted in the development of a trail erosion matrix, comparing methods of assessing trail erosion with evaluation criteria. Three scientists with expertise and experience in assessing recreation-based trail erosion were consulted. Each scientist independently rated each assessment method (1 = very low, 5 = very high) against five evaluative criteria. The five criteria were developed with the assistance of experts in the field (table 2). The average total assessment scores were computed using the formula Total = E+P+A+MU – LTR where (E=efficiency, P=precision, A=accuracy, MU=management utility and LTR=level of training required). The LTR criterion is reverse coded due to the negative aspects (time and cost) of training. Assessment scores were calculated and rank ordered.

Results

The range of possible scores are -1 to 19. The *condition class* method of assessing trail erosion was found to have the highest score of 11.68, while the *aerial photo appraisal* method had the lowest score of 6.0 (table 3). The condition class method, in addition to having the best overall ranking, also has the best score on level of training required (2.33, meaning a low level of training is required), but this method ranked the lowest on management utility (2.67).

Table 1—Summary of assessment methods by type, with corresponding selected references.

Assessment method	Description	Selected references
Condition Class Assessment		
Condition Class	Descriptive classes are defined and assigned to trails/segments.	Cole and others (1997)
Morphometric Assessments		
Cross-sectional Area	Sampling points are determined by a sampling scheme, then measurements are taking vertically from a horizontal datum, which is attached to fixed points on both sides of the trail.(1983)	Leonard and Whitney (1977) Cole
Maximum Tread Incision Post-construction (MIP)	Incision measurements are performed at a series of points along a trail that is determined by a sampling scheme, from Post-construction height to tread surface.	Marion (1997)
Maximum Tread Incision Current Tread (MIC)	Incision measurements are performed at a series of points along a trail segment.	Marion (1997)
Census/Tally Assessments		
Census of Erosional Events	Erosional events are defined, followed by a census of those problems.	Marion (1994)
Census of Active Erosion	"Active erosion" is defined, followed by a complete census of those problems.	Farrell and Marion (1999)
Quadrat Assessment		
Quadrat Measurement	Measurements are performed within quadrats at a series of points that is determined by a point-sampling scheme.	None (for assessing trail erosion)
Photographic Assessments		
Stereo Photography	On-the-ground photos are taken and evaluated against future photos using a digitized stereo plotter.	Rinehart and others (1978) Warner and Kvaerner (1998)
Aerial Photo Appraisal	Trails are identified and stereoscopically evaluated from aerial photos.	Coleman (1977) Price (1983)

Table 2—Evaluation criteria used to rate the utility of various trail erosion assessment methods.

Evaluation criteria	Description
Level of Training Required	Amount of time required to train a novice in the use of the method.
Efficiency	Amount of time and financial resources required to apply the method.
Precision	The ability to consistently replicate results. Will ten individuals using the same method report identical results?
Accuracy	How close to the "true" value can you get?
Management Utility	Will the results gathered from a particular method be relevant to resource management and planningdecisions?

These results differ from past research and hypotheses put forth in the literature. For example, it has been stated in the literature that the *cross-sectional area* method

> is probably the most useful measure for managers in that the technique is replicable, requires relatively little training, and provides results that are easy to use and interpret (Cole 1983).

Results reported here indicate that not only did the *cross-sectional area* method tie for third place with an overall score of 10.33, the individual scores on management utility and level of training required were 3.00 (neutral) and 3.67 (neutral-high), respectively. These data indicate 1) that individuals with experience and expertise with trail assessment methods are either not in agreement or 2) that there has been an evolution in thought regarding this particular method over the past 15 years.

Further investigation revealed that, when controlling for research-oriented criteria, precision and accuracy (table 4), the cross-sectional area method dropped in ranking from third to eighth, while condition class and census of erosional events continued to rank one and two, respectively.

Discussion

Monitoring of trail conditions can be useful for many reasons. Trail conditions, rate of change and trends can be identified. This information can be used to evaluate the acceptability of current conditions and whether or not trail

Table 3—Comparison of trail erosion assessment methods based on evaluation criteria, and summary of ratings showing individual rater scores and their average, (1 = very low to 5 = very high).

	Level of training required	Efficiency	Precision	Accuracy	Management utility	Average total* score	Kruskal-Wallis** mean rank
Condition Class	1 3 3 2.3	5 5 4 4.7	3 2 4 3.0	3 5 3 3.7	2 2 4 2.7	11.3	23.7
Census of Erosional Events	3 4 4 3.7	4 4 4 4.0	3 3 2 2.7	3 4 3 3.3	5 5 4 4.7	11.0	22.0
Cross-sectional Area	4 4 2 3.7	1 2 1 1.3	5 4 5 4.7	5 5 5 5.0	3 4 2 3.0	10.3	18.0
Maximum Incision Post-construction (MIP)	3 3 3 3.00	4 4 2 3.33	2 3 4 3.00	2 3 4 3.00	4 4 4 4.00	10.3	17.2
Census of Active Erosion	5 4 4 4.3	4 3 4 3.7	2 3 2 2.3	3 3 3 3.0	5 5 4 4.7	9.3	11.8
Quadrat Measurement	3 4 3 3.3	2 2 2 2.0	4 3 4 3.7	4 4 4 4.0	3 4 2 3.0	9.3	11.8
Maximum Incision Current Tread (MIC)	3 4 3 3.3	4 2 2 2.7	3 2 4 3.0	3 2 4 3.0	4 3 2 3.0	8.3	11.2
Stereo Photography	5 5 3 4.3	1 1 3 1.7	3 4 3 3.3	3 5 2 3.3	2 4 3 3.0	7.0	5.5
Aerial Photo Appraisal	4 4 5 4.3	3 3 3 3.0	1 3 3 2.3	1 3 2 2.0	2 4 3 3.0	6.0	4.8

*Average total score = (Efficiency + Precision + Accuracy + Management Utility) - (Level of Training Required)
** Kruskal-Wallis c^2 = 17.643; p= .024.

Table 4—Summary of survey results comparing trail erosion assessment methods based on evaluation criteria, while controlling for accuracy and precision (1 = very low to 5 = very high).

	Level of training required	Efficiency	Management utility	Average total* score
Condition Class	2.3	4.7	2.7	5.0
Census of Erosional Events	3.7	4.0	4.7	5.0
Maximum Tread Incision Post-construction (MIP)	3.0	3.3	4.0	4.3
Census of Active Erosion	4.3	3.7	4.7	4.0
Maximum Tread Incision Current Tread (MIC)	3.3	2.7	3.0	2.3
Quadrat Measurement	3.3	2.0	3.0	1.7
Aerial Photo Appraisal	4.3	3.0	3.0	1.7
Cross-sectional Area	3.7	1.3	3.0	0.7
Stereo Photography	4.3	1.7	3.0	0.3

* Average total score = (efficiency + management utility)—(level of training required).

management programs, including maintenance and reconstruction, have been effective.

Condition Class Method

In many areas, field assessments of impact are desirable, but it is not feasible to spend more than a couple of minutes at each sampling location. This is usually the case in large, dispersed recreation areas. The first step is to define, in precise terms, exactly what the condition class ratings will be. Defining condition class ratings is a subjective, time-consuming process, however, results are useful but limited. A major limiting factor in the utility of the condition class method is that it relies on a single qualitative measure. However, the *condition class* method of assessing trail erosion requires little training and is a rapid, accurate, efficient method that results in somewhat limited data as to the character of the trail system. The utility of these data for managers is questionable and should be considered a second or third alternative to methods with greater management usefulness.

Census of Erosional Events

The census of erosional events method can accurately assess trail systems. Terminology must be identified and defined in terms of exactly what will be considered an erosional event. This method is applied using a systematic sampling scheme, and it is accurate, and efficient, and the results are relevant to managers who must make appropriate and timely trail resource decisions. Limitations include the need for a high level of training due to the qualitative nature of an erosional event and the potential lack of inter-rater reliability. However, this method allows relatively rapid assessment of a trail system and produces information on the frequency, extent and distribution of erosional event problems; this would explain the high score received on management utility. The data in this paper suggest that trail system monitoring be most effectively done using a combination of methods.

Maximum Incision Post-Construction (MIP)

This method is increasing in use as indicated by its mention in recent theses, dissertations and journal publications. Measuring incision from the post-construction height is an effective method of monitoring system-wide trail erosion. This point measurement technique allows prompt assessment of trail conditions and their spatial variations. The data collected provide information that managers can use to make trail resource decisions.

This method is limited due to the subjectivity of identifying the post-construction tread height, measurement error and inter-rater variability. The time required to train technicians remains a concern of managers. This method was rated relatively neutral (3.0) across all five criteria and yet resulted in the third highest overall rating. It should be noted that of all nine methods, the MIP method is the only one that received perfect inter-rater reliability of 4.0 on management utility. This seems to suggest that there is more agreement about the usefulness of data collected using the MIP method than any other method.

Cross-Sectional Area Method

Soil erosion is the single most important, managerially significant trail degradation indicator. The *cross-sectional method* is probably the most frequently used, replicable method for monitoring purposefully located trail segments. This method may also be applied to systematically sampled locations for monitoring entire trail systems. The erosion or deposition of soil can be measured with very high precision and accuracy with this method. The data collected using this method are adequate for managers making trail management decisions. However, there are a number of limitations to the *cross-sectional method*. First, the training required is high, and the method is extremely time-consuming and therefore an inefficient method for monitoring trail systems. When monitoring a trail system with a systematically sampled scheme, this method becomes inefficient in terms of time (equipment is often heavy and difficult to transport) and financial resources. In addition, it involves a number of assumptions, including ability to relocate the fix points precisely, reference line elevated above surrounding vegetation, the line is kept taut, a level is used for the vertical measurements, the taut line is repositioned the same height above the fixed points, vertical measurements are taken at the same interval, and the vertical measurements are taken starting from the same side. For these reasons, training is the single most important factor in the proper application of this method. Adequate training is costly and thus a major limiting factor for managers.

Certain wilderness areas, however, may have only a few problem locations within their trail system. Monitoring of these locations using the *cross-sectional method* would be quite appropriate with the proper training and experience. This method is accurate, precise, gives managers relevant information about amount of soil loss/deposition and rate of loss, and identifies any trends that may be developing. Furthermore, a well-trained surveyor should be able to make management suggestions about how to mitigate the continued soil loss.

Census of Active Erosion

This problem assessment method is efficient and results in data useful to managers. Before this method can be implemented, managers must determine what constitutes "active erosion." This step is crucial to the effectiveness of this method. Defining in precise terms what exactly is to be considered active erosion is a considerable task and a limitation of this method. The subjective distinction between active and inactive erosion can be mitigated with precise definitions developed before the method is implemented. The qualitative definition of "active erosion" leads to inter-rater variability. This is a major concern for managers who have to deal with high employee turnover. Furthermore, extensive employee training is required to ensure accuracy. The *census of active erosion* method has its benefits however. The method is efficient, in terms of time and financial resources and accurate, and it results in information on the frequency, extent and distribution of active erosion problems. Trail data relevant to managers can be obtained using this method and should be considered as a trail monitoring method.

Quadrat Measurement

Published research indicates that the use of quadrats to assess trail conditions is limited. The use of the quadrat method may become more widespread as indicated by its overall score of 9.34 (table 3). Relocation of sampling points, measurement error and field/training time limit the efficiency of this method. However, our results indicate that the quadrat method is accurate and precise, and the results are managerially significant. This method has significant management utility, and the results are adaptable to an indicator/standards-based management framework.

Maximum Incision Current Tread (MIC)

The current tread incision measurement is a variation of the MIP method. This rapid assessment method is more subjective, in that identification of the current tread height is, often times, more difficult than identifying the post-construction height. This would explain the lower efficiency rating of MIC as compared to MIP. This lower efficiency rating caused a decrease in the management utility rating, which adversely affected the overall rating. Although this method is similar to MIP and has comparable limitations and usefulness, MIC ranked eighth overall compared to a third place ranking of MIP. This method, along with MIP, can be effectively used in an indicator/standards-based management framework, and it is an effective method of monitoring trail erosion and should be considered for monitoring trail systems.

Stereo Photography

"Stereo photographs taken with an ordinary camera mounted on a shop-made tripod attachment proved valuable in studying trail entrenchment…" (Rinehart and others 1978). The use of stereo photography to monitor trail systems is questionable, although it does have advantages. Backcountry areas with short seasons may be well-suited for this method. Spending the short season in the field taking photos and leaving the more time-consuming and tedious plotting of trails until later would be an efficient use of time. Also, stereo photographs illustrate current conditions and trends, a feature that is especially useful in orienting and training new personnel (Rinehart and others 1978). Stereo photographs identify actual change in tread conditions rather than forcing one to interpret numerical measurements that can conceal compensating changes. For example, "if a trail becomes wider and also fills in with material eroded elsewhere and deposited in the transect… the transect area might remain unchanged (Rinehart and others 1978). Other methods would interpret this as an unchanged condition, and stereo photos would accurately identify the dynamic process of trail erosion.

However, the utility of this method to managers is questionable. Disadvantages of stereo photographs include vegetation occasionally obscuring the view of the transect, field limitations due to inclement weather and relocating transects. Rinehart and others (1978) suggest measuring from the trailhead using a calibrated bicycle wheel to relocate transects. However, the inter-rater reliability of using measuring wheels should be of concern. In unpublished field tests Marion (1997b) demonstrated the significant lack of inter-rater reliability using various diameter measuring wheels.

Although the stereo photography method is relatively accurate and precise, it lacks efficiency and requires a high level of training. Managers should be versed in numerous assessment methods before implementing stereo photography as a method of monitoring trail systems.

Aerial Photo Appraisal

If suitable coverage is available over a sufficient period of time, aerial photography can be an efficient method of measuring trail erosion. As implied, this method has potentially significant limitations. Coleman (1977) suggests that identifying real trends from mere fluctuations can be done effectively with this method. Using aerial photography on a popular path in England, she documented a level of accuracy much greater than that required for defining paths. However, due to limitations such as varying weather conditions and canopy cover, aerial photography is typically an ineffective method in most of the United States. When interpreting aerial photographs, the distinction between trampled, dying, dead or damaged vegetation and eroded segments is far from obvious (Coleman 1977). This limits the interpretation to the visible extent of change and therefore, may vary seasonally in some types of vegetation. Visible extent of trail alterations may be extremely relevant to managers. In contrast, lack of accuracy, precision and efficiency significantly detracts from the utility of this method. Furthermore, the financial commitment and high level of training necessary to interpret photos raises serious concern about its utility. This method should not be implemented as a single monitoring method. However, in combination with other methods, aerial photography may enhance the data that managers use to make trail resource decisions.

Conclusions

This study looked at nine different methods of assessing trail erosion. When determining which method to implement, resource managers must first identify their resource standards. Human judgments, in the form of standards and indicators, are needed before the appropriate method can be determined. Thoughtful and timely development of those standards and indicators are of fundamental importance to proper management of trail systems in the backcountry.

Managers often lack adequate information on the nature, severity and causes of erosion- related problems and on the management approaches (assessment methods) that have successfully reduced such problems (Manning and others 1996). Moreover, little or no formal effort or few if any programs exist that are specifically designed to foster communication among natural resource managers. Consequently, information about trail erosion and alternative solutions are not effectively gathered, analyzed and shared (Manning and others 1996). This lack of information sharing results in considerable confusion and inefficiency.

We believe that natural resource managers can use these findings for improving impact assessment and monitoring programs. First, the extensive, systematic list of erosion assessment methods developed in this paper can be a useful guide. Understanding and awareness of the methods available can help managers make better trail resource decisions and result in more effective management. Moreover, the table of assessment methods should help stimulate managers' thinking about alternative solutions to managing trail erosion-related problems. Typically, a number of potential management practices can be applied to assess trail erosion, and these management practices vary in their strategic purpose and directness. Managers should be aware of and give serious consideration to all potential trail erosion assessment methods before implementing a trail-monitoring program. It is our hope that this paper assists managers in recognizing the assessment methods available for measuring soil erosion, and that we have provided some order to the confusion.

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