11 Monitoring Recreational Impacts

In the last chapter we discussed the importance of inventory and monitoring within a planning framework. Inventory provides a means of evaluating the current condition of a resource in relation to management objectives so that problems can be identified. Over time, monitoring allows trends in condition to be recognized. Information about current conditions and trends aids in the selection of limits of acceptable change. It also permits the effectiveness of management programs to be assessed and suggests places where changes in management are needed. Lessons can be learned—from both successes and failures. Places where problems are particularly pronounced or where conditions are rapidly deteriorating can be identified as areas of concern. This can be useful in budgeting, allocating manpower, and establishing project priorities.

Reliable data are needed to manage recreation just as reliable inventory data are needed to manage other natural resources, such as timber. Unfortunately, they are seldom available. In recreation, management has too frequently had to rely on guesswork or the personal experience and intuition of managers. Although a manger's professional opinion is important, it is no substitute for reliable and systematically collected inventory and monitoring data. This is particularly true where turnover in personnel occurs frequently, as it does in many governmental land-managing agencies.

In this chapter we will examine some of the techniques available for monitoring three important types of recreational facilities and resources: campsites, trails, and water bodies.

CAMPSITES

Camping is among the most popular of all recreational activities. Usually it involves highly concentrated use; consequently, impacts are often pronounced. Campsites vary greatly, from highly developed sites in large campgrounds that cater to travelers in recreational vehicles to remote, isolated, lightly impacted sites in the backcountry. As objectives vary among these different situations, appropriate monitoring techniques also vary. A monitoring program, to be efficient, must be developed with specific objectives in mind. Otherwise, important information may not be collected, and time and money may be wasted in collecting nice-to-know but marginally useful data.

Despite great variability in which monitoring techniques are appropriate in different situations, there are some characteristics that are generally desirable to all monitoring systems. A campsite monitoring system should provide accurate and meaningful information about how much impact has already occurred on campsites. This tells a manager how serious current problems are. It should also provide a reliable baseline for subsequent monitoring so that trends can be identified. A good system will have four characteristics:

1. Meaningful measures of impact are utilized.
2. Measurement techniques are reliable and sensitive.
3. Costs are not too high to prohibit an inventory of all campsites.
4. Measurement units can be relocated precisely.

The value of the information collected will depend on how carefully impact parameters—measures of impact—are selected. Some parameters measure current conditions, but not how much impact has occurred on the site. For example, some monitoring systems have measured vegetation cover on campsites. By itself, this is not a measure of impact because vegetation cover is dependent on many environmental factors as well as recreational use. Fifty percent vegetation cover may be perfectly natural, or it may represent a loss of as much as 50 percent of the natural vegetation. It is much more meaningful to compare the vegetation cover on a campsite with the cover of a similar undisturbed site. The difference provides a good estimate of how much vegetation has been lost.

Deciding on just one variable to measure can be difficult. It is usually cost-effective and easier to base a monitoring system on several different parameters. Sometimes it is convenient to aggregate these parameters into a single index of site condition. This can be done by rating each parameter, say on a scale of 1 to 3, and then taking the mean rating as an overall index. If this is done, it is important to retain the ability to disaggregate data. This will make it possible to evaluate change in individual parameters over time.

A second desirable characteristic of any monitoring system is reliability. Assessment techniques must be sufficiently precise to allow independent observers to reach similar conclusions about site condition. Monitoring is of little value if different people give widely divergent assessments of site condition. Precision depends on careful testing of techniques, detailed documentation of procedures, and consistent training of evaluators. Assessment techniques must also be sensitive enough to detect managerially relevant differences between sites and changes over time.

There is always a trade-off between reliability/sensitivity and cost. More precise methods take more time and cost more money. This may be prohibitive in large backcountry areas with numerous, remote, dispersed sites. For example, in Sequoia and Kings Canyon National Parks, more than 7700 backcountry campsites have been inventoried (Parsons and Stohlgren 1987). As the objectives of inventory are to characterize both the distribution and condition of sites and how they change over time, it is best to use as precise techniques as possible while retaining the ability to inventory *all* sites. Only by inventorying all sites is it possible to characterize the number and distribution of sites—a critical concern in dispersed use areas. Where relatively imprecise rapid survey techniques must be used in order to inventory all sites, it may also be desirable to take more precise measurements on a subsample of sites. This permits subtle changes to be detected, changes that can be related to differences in characteristics such as use levels, environmental characteristics, and other variables that might affect amount of impact.

Finally, to monitor change over time it is important to document the exact location of all areal units on which measurements were taken. This may apply to the entire campsite or to square plots, line transects, or any other sampling units that were used. Photographs are often helpful for relocating measurement units.

A number of useful campsite monitoring techniques have been developed (Cole 1989). They can conveniently be grouped into systems based on photography, condition class ratings, and either ratings or measurements of multiple impact parameters. The ideal program will use all three of these types to some extent.

Photographs

Photography has frequently been used for monitoring, sometimes systematically and sometimes not, sometimes to enhance field data and sometimes as the only monitoring tool. As with field data, photographs must be taken systematically, and their locations must be carefully documented or they are likely to be of little value. In our opinion, photographs are best used as a supplement to—rather than a replacement for—data collected in the field. It is unlikely that all of the information that should be collected can be captured on film. However, photographs can convey certain information not measured in the field. They can be used to validate field assessments and, of particular importance, they provide a visual means of conveying information on site condition quantified in field measurements.

Three photographic techniques that have been used as part of campsite monitoring programs are photopoints, quadrat photography, and campsite panoramas. More detail on each of these techniques can be found in Brewer and Berrier (1984).

Photopoints. The technique using photopoints involves taking photographs from a location that can be reestablished at a future date. Establishing and documenting the location of a photopoint is critical. Photopoint locations can be referenced to landmarks, such as unique rocks, or to permanent metal markers, star drill marks in rocks, or marks on trees. All locations should be referenced in terms of distance and direction from trees and other landmarks (Fig. 1). Reference points and photopoints should then be noted on sketch maps and photographs.

The location of a photopoint is important. Elevated points can provide good overviews. However, photos from a distance lose detail. In photographing forested sites, it is best to work on cloudy days when the contrast between shade and sunlight is reduced. Record the camera make and model, focal length of lens, height of the camera above the ground, filter type, and film type of each photograph. These should

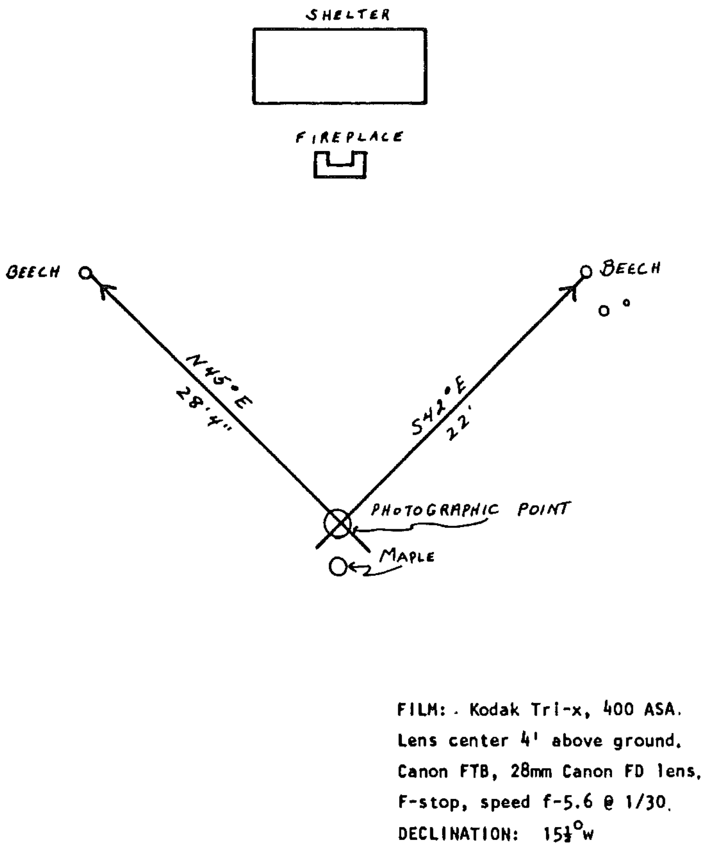


FIGURE 1. Sketch map referencing a photopoint. (*Source*: Brewer and Berrier 1984.)

be replicated as closely as possible, as should time of day and year. Carrying copies of the original photos with you will facilitate accurate replication.

Quadrat Photography. The quadrat photography technique is a replacement for cover measurements taken in the field. The advantage to photographs is that professional analysts do not have to go into the field; they can analyze the photographs in the lab. The disadvantage is the greater difficulty of making certain measurements, such as coverage of individual species, from photographs. As the height of the vegetation and the complexity of the ground cover increase, these interpretational problems become more serious. There are few situations in which quadrat photographs provide an accurate replacement for field measurements.

Brewer and Berrier (1984) describe the quadrapod, a device that holds a camera at a set distance above the ground. A series of replicable quadrat locations are laid out and, using the quadrapod, photographs are taken of each quadrat. Prints or slides are enlarged, and the areas of each ground cover type (e.g., vegetation, bare ground, or individual species) is traced onto paper for areal measurement. Individual quadrats can be followed over time, or mean percent coverage of each ground cover type can be calculated and compared over time.

Campsite Panoramas. The campsite panorama technique involves piecing together a series of photographs to provide a full 360-degree view of the campsite (Fig. 2). A camera is mounted on a tripod at a point that can be readily relocated, usually the center of the site. Camera height must be constant (and documented for repeat photos), and the camera must remain level. A series of photographs are taken by rotating the camera. Each photo should overlap the preceding one by at least 25 percent. In the lab, trim adjoining photos in the middle of the overlap area and mount the photos on mat board.

It is not feasible to take accurate measurements on these panoramic photos on account of distortion and problems with precise replication. They do provide a means of counting newly fallen trees or changes in facilities, and they provide a good overview of site change. They are also effective means of visually communicating quantitative data collected in the field.

Condition Class Estimates

In many areas, field assessments of impact are desirable but it is not feasible to spend more than a couple of minutes monitoring each campsite. This is usually the case in large, dispersed recreation areas, such as most backcountry areas and many roaded areas where people are allowed to camp wherever they want. Condition class ratings provide limited—but useful—information in these situations. Condition class systems consist of a series of condition descriptions. Overall impact is assessed, but individual impact parameters are not. Frissell (1978) suggests the following five classes:

1. Ground vegetation flattened but not permanently injured. Minimal physical change except for possibly a simple rock fireplace.
2. Ground vegetation worn away around fireplace or center of activity.
3. Ground vegetation lost on most of the site but humus and litter still present in all but a few areas.
4. Bare mineral soil widespread. Tree roots exposed on the surface.
5. Soil erosion obvious. Trees reduced in vigor or dead.

Each campsite is located on a map and assigned to whichever class best describes its condition.

Frissell's system was developed from experience in the Boundary Waters Canoe Area, Minnesota, and what is now the Lee Metcalf Wilderness, Montana. It applies well in coniferous forests in cool climates where growing seasons are short, litter accumulation is great, and ground vegetation is highly sensitive to disturbance. In other

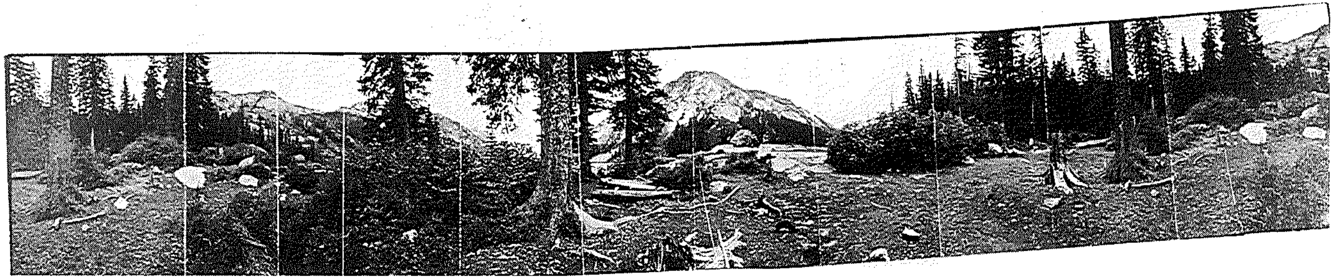


FIGURE 2. This 360-degree panoramic photograph of a campsite in the Selway-Bitterroot Wilderness, Idaho, has been used to monitor change on the site. (*Photo:* U.S. Forest Service.)

environments, such as mountain grasslands or deserts, the system does not work well. Different descriptions that reflect the impacts that occur in these other environments can be developed, however.

Condition class ratings are a relatively inexpensive way to answer some very important questions. How many campsites are there and where are they located?

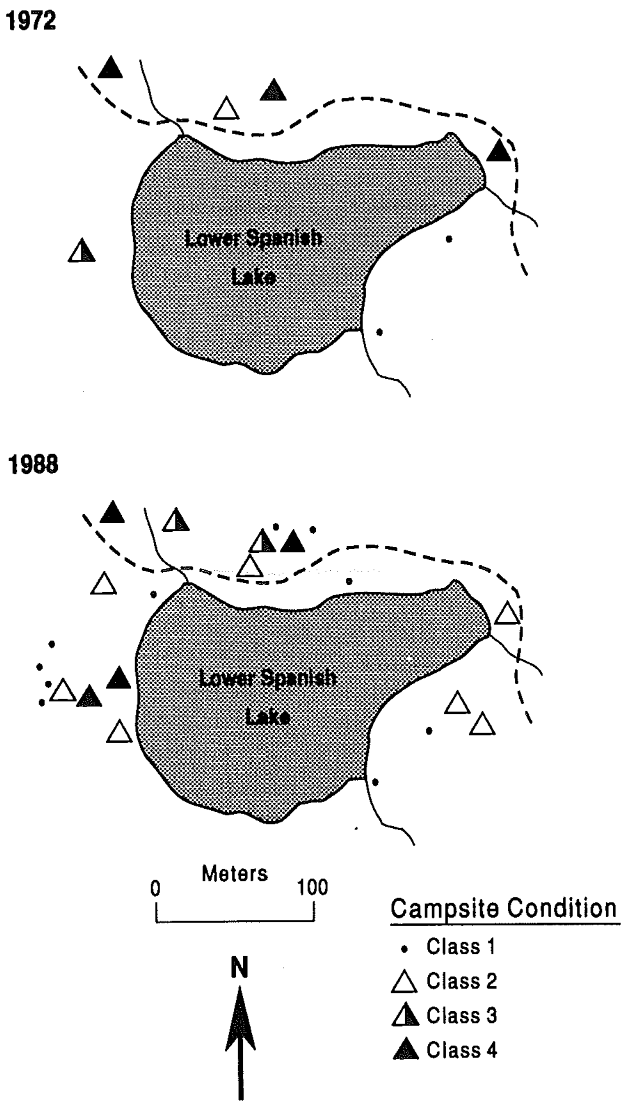


FIGURE 3. The number and condition of campsites around Lower Spanish Lake, Lee Metcalf Wilderness, Montana, in 1972 and 1988. (*Source*: D. N. Cole 1993.)

Condition class ratings also indicate which campsites are most seriously impacted. Repeat monitoring will indicate whether the number of campsites increased or decreased over time. Figure 3 shows the results, for one lake, of a campsite condition class survey conducted at two points in time. It shows which campsites are the old, traditional ones and which campsites are the most impacted. More important, it shows that total impact increased, between 1972 and 1988, primarily because the number of campsites tripled.

There are two primary drawbacks to condition class ratings. First, they cannot provide information on which types of impact on campsites are most serious. For example, is tree damage the primary problem, or is it vegetation loss? Second, these ratings are not a very sensitive way to monitor change in site condition over time. By the time conditions have changed enough to be reflected in a changed condition class rating, a profound amount of change has occurred.

Multiple Parameter Systems

The aforementioned concerns are addressed in multiple parameter rating systems, which evaluate a number of separate impact parameters. Such systems vary greatly in precision and, consequently, the time required to take measurements. Some utilize ratings whereas others require accurate measurements.

Multiple Parameter Ratings. In Sequoia and Kings Canyon National Parks, information is collected on vegetation density, vegetation composition, campsite area, area of the barren core, campsite development, presence of organic litter and duff, number of access (social) trails, and number of tree mutilations. Each of these is estimated or counted; time-consuming measurements are not required. Each parameter is assigned a rating, depending on amount of impact, and these ratings are totaled to obtain an overall impact rating (Parsons and MacLeod 1980). The advantages to such a system are:

1. It accounts for sites where one type of impact is high and another is low—in a condition class system such a situation results in a site partially matching several of the class descriptions.
2. It contains much more information, so that it is possible to track change in individual parameters, such as amount of tree damage, over time.
3. It retains the flexibility to change parameters or reevaluate the importance of parameters without having to reexamine every site. With the condition class system, managers cannot change their condition criteria without redoing the entire inventory.

Cole (1983a) refined the system developed by Parsons and MacLeod (1980). In his system each parameter was recorded separately, and the objectivity of some of the rating descriptions was increased. To illustrate how the system works, Fig. 4 shows a campsite that managers might want to monitor. Figure 5 shows a completed form for that campsite. The following detailed instructions explain how the form is used.

FIGURE 4. The condition of this campsite in the Eagle Gap Wilderness, Oregon, has been recorded on the form in Figure 5. (*Photo*: D. N. Cole.)

Item 19, Vegetation Cover. Using the coverage classes on the form, estimate the percentage of the campsite covered with live ground cover vegetation—not dead vegetation or trees or shrubs taller than a person. (Note the need to define what is meant by *ground cover vegetation*). Circle the appropriate coverage class. Do this for the campsite and do it for a nearby, unused site similar (except for the recreational impact) to the campsite.

Item 20, Mineral Soil Exposure. Using the same coverage classes, estimate the percentage of the campsite and the same undisturbed comparative site without either live ground cover vegetation or duff—that is, the percentage with exposed mineral soil.

Item 21, Vegetation Loss. Utilizing the information in Item 19, record the difference, in number of coverage classes, between vegetation on the campsite and the comparative area. If there is no difference (e.g., both the campsite and comparative area are class 4, 51 to 75 percent), circle rating 1. If coverage on the campsite is one class lower than on the comparative area (e.g., the campsite is class 3, 26 to 50 percent and the comparative area is class 4, 51 to 75 percent), circle 2. If the difference is more than one class, circle 3.

Item 22, Mineral Soil Increase. Utilizing the information in Item 20, record the difference in mineral soil exposure class between campsite and comparative area. In this case ratings of 2 and 3 are given when mineral soil cover is one, or more than one, class higher on the campsite, respectively.

Impact Evaluation	On Campsite			On Unused Comparative Area		
(19) Vegetation Cover: (Be sure to compare similar areas, same species, slope, rockiness, and canopy cover)	1 – 0-5% 2 – 6-25%	3 – 26-50% 4 – 51-75%	5 – 76-100%	1 – 0-5% 2 – 6-25%	3 – 26-50% 4 – 51-75%	5-76-100%
(20) Mineral Soil Exposure: (percent of area that is bare mineral soil)	1 – 0-5% 2 – 6-25%	3 – 26-50% 4 – 51-75%	5 – 76-100%	1 – 0-5% 2 – 6-25%	3 – 26-50% 4 – 51-75%	5 – 76-100%

	Rating (Circle one category) 1	2	3	Calculation of impact index (do in office)
(21) Vegetation Loss:	(No difference in coverage)	(Difference one coverage class	(Difference two or more coverage classes	2 × 3 = 6
(22) Mineral Soil Increase:	(No difference in coverage)	(Difference one coverage class)	(Difference two or more coverage classes)	3 × 2 = 6
(23) Tree Damage: Number of trees scarred of felled 10 Percent of trees scarred or felled 50 (est.)	(No more than broken lower branches)	(1-8 scarred trees, or 1-3 badly scarred or felled	(>8 scarred trees, or >3 badly scarred or felled)	2 × 3 = 6
(24) Root Exposure: Number of trees with roots exposed 5 Percent of trees with roots exposed 25 (est.)	(None)	(1-6 trees with roots exposed)	(>6 trees with roots exposed)	3 × 2 = 6
(25) Development:	(None)	(1 fire ring with or without primitive log seat)	(>1 fire ring or other major development)	2 × 3 = 6
(26) Cleanliness: Number of fire scars 2	(No more than scattered charcoal from 1 fire ring)	(Remnants of >1 fire ring, some litter or manure	(Human waste, much litter or manure)	1 × 1 = 1
(27) Social Trails: Number of trails 4	(No more than 1 discernible trail)	(2-3 discernible, max. 1 well-worn	(>3 discernible or more than 1 well-worn)	2 × 1 = 2
(28) Camp Area Estimated area 1600 (ft^2)	(<500 ft^2)	(500-2000 ft^2)	(>2000 ft^2)	3 × 2 = 6
(29) Barren Core Camp Area: Estimated area 600 (ft^2)	(<50 ft^2)	(50-500 ft^2)	(>500 ft^2)	2 × 4 = 8

(30) Photo Record ______

(31) Comments: (Details about location of site, impacts, management suggestions, etc.)

(32) Impact Index 47

FIGURE 5. This form records information on the condition of the campsite shown in Fig. 4. (*Source:* D. N. Cole 1983a.)

Item 23, Tree Damage. Count the number of trees with nails in them, ax marks, initials, and other human-caused scars. Also include stumps and/or cut-down trees. Do not count the same tree more than once and do not count trees on which the only damage is branches broken off for firewood. After recording this number, estimate very roughly what percentage of all the trees on the site have been damaged. If no trees are damaged, give the site a rating of 1. If one to eight trees are damaged or if one to three trees have been felled or have bad scars (scars larger than 1 ft^2), give the site a rating of 2. If more trees are damaged, give the site a 3.

Item 24, Root Exposure. Count the number of trees with exposed roots and assign a rating based on this number.

Item 25, Development. Assign the site a rating of 1 if there are no facilities—not even a fire ring. A fire site is considered a ring only if the ring of stones is there; if they have been scattered, it is a fire scar. If there is only one fire ring, primitive log seats, or both, assign the site a 2. If there is more than one fire ring or more elaborate facilities, assign the site a 3.

Item 26, Cleanliness. Count the number of fire scars on the site, including any fire rings as fire scars. Assign the site a 1 if there is only one scar and essentially no evidence of litter, stock manure, or human waste. Assign the site a 2 if there is more than one fire scar or if litter or stock manure is evident. If litter or stock manure is "all over the place" *or* if there is any evidence of human waste, assign the site a 3.

Item 27, Social Trails. Social trails are the informal trails that lead from the site to water, the main trail, other campsites, or satellite sites. Discernible trails are trails that can be seen but that are still mostly vegetated. Well-worn trails are mostly devegetated. Count the total number of trails. Assign the site a rating based on the number of discernible and/or well-worn trails.

Item 28, Camp Area. Estimate the total area disturbed by camping and assign the site a rating based on this area.

Item 29, Barren Core Camp Area. Estimate the area within the camp without any vegetation. Bare area may or may not be covered with duff. Areas with scattered vegetation are not counted as barren area. Give the site a rating based on this area.

After the form has been filled out in the field, it is possible to calculate an overall impact index (Item 32). The ratings for each parameter are multiplied by a weight. The weights for each parameter are decided by managers based on their opinion of the relative importance of each parameter. The products of each rating and weight are then summed to give the impact index. In the Bob Marshall this index varied from 20 (minimal impact) to 60 (maximum impact). This range was then divided into four classes: light (ratings 20 to 29), moderate (30 to 40), heavy (41 to 50), and severe impact (51 to 60). These ratings were used to map the distribution of sites in each of these impact classes to give a graphic display of where campsite impacts are most numerous and pronounced (Fig. 6).

The keys to such a system are selecting meaningful parameters, developing very specific definitions so that interpretations are consistent, developing ratings that adequately differentiate between campsites (if 90 percent of the campsites are rated 1, this does not provide much information), and then investing in training. Each area will do well to modify existing systems to its particular needs. In the Eagle Cap Wilderness, Oregon, where sites are smaller than in the Bob Marshall and where sites have less tree damage on account of less stock use, the same impact parameters were used, but some of the rating definitions were more stringent. For example, in the

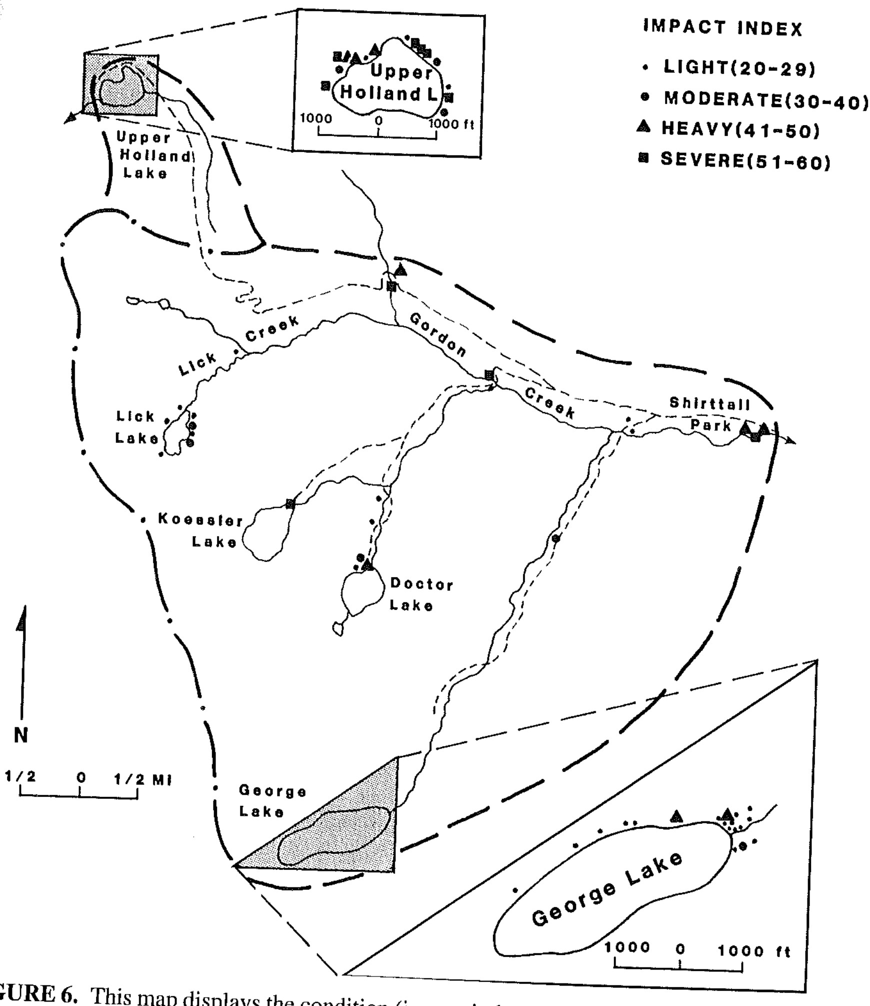


FIGURE 6. This map displays the condition (impact index) of all campsites in a portion of the Bob Marshall Wilderness, Montana. (*Source*: D. N. Cole 1983a.)

Eagle Cap, the boundary between ratings of 2 and 3 were 1000 ft^2 for camp area and one badly scarred or felled tree (Cole 1983a). This compares with 2000 ft^2 and three trees in the Bob Marshall.

In the Boundary Waters Canoe Area the same parameters were used, but an additional parameter has been added—length of shoreline disturbed by boat landings. In Grand Canyon National Park there are few trees, only patchy vegetation and organic matter, and campfires are prohibited. Several different parameters were selected to monitor sites there. Rangers in Grand Canyon are estimating barren core area, soil compaction, social trails, vegetation disturbance around the perimeter of the site, tree damage, litter, and campfire evidence.

Such a system provides a lot of information at relatively low cost. Using these techniques, Cole (1993) was able to document pronounced increases in campsite impact in wildernesses in the western United States, resulting primarily from an increase in the number of sites. Individual campsites can be monitored by trained individuals in 5 to 10 minutes. The problem is that the information is not very precise. It is not uncommon, for example, for different evaluators to give the same campsite very different ratings for individual parameters. We have found, however, that overall index ratings do not vary greatly between different evaluators. This suggests that the low precision of data collected using this system is most problematic in trying to draw conclusions about changes over time—for separate types of impact, such as amount of tree damage—on individual campsites.

Multiple Parameter Measures. The best way to get accurate, replicable data for individual campsites is to take careful measurements in the field. Where they can be afforded, measurements are best. Keep in mind, however, that it is important to inventory all sites. Therefore, a system based on measurements may be feasible only where there are a small number of campsites. This may be the case in a developed campground or in backcountry areas with designated sites. For example, measurements were used in the backcountry at Great Smoky Mountains National Park where there were only 113 legal sites and 289 illegal sites (Bratton, Hickler, and Graves 1978). Compare this with the situation in Sequoia and Kings Canyon National Parks where there are more than 7700 backcountry campsites.

Let's look at a methodology developed to examine impacts and trends on individual sites in the Eagle Cap Wilderness, Oregon (Cole 1982; Cole and Hall 1992).

In the Eagle Cap each sample site consisted of both a campsite and a similar undisturbed site in the vicinity. This undisturbed site serves as a control, a measure of what the campsite was like before it was camped on. On each campsite, linear transects were established, radiating from an arbitrarily established center point in 16 directions. Distances were measured from the center point to both the first significant amount of vegetation and the edge of the disturbed part of the campsite (Fig. 7). This defined the area of the barren central core of the site (bare area) and the entire disturbed area (camp area). Both are important indicators of impact. Tree seedlings and mature trees were counted within the entire disturbed area. Any human damage (e.g., ax marks, initials, etc.) was noted. Tree seedlings were also counted on a 50 m^2 control plot close by. Differences between campsite and control, in the

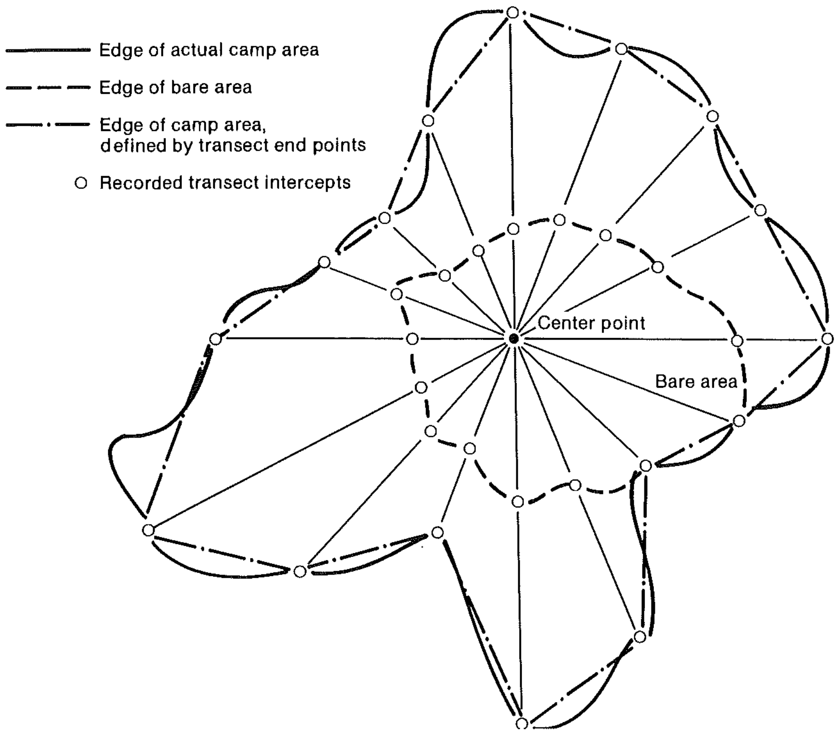


FIGURE 7. The campsite measurement system used in the Eagle Cap Wilderness recorded bare area, camp area, number of damaged trees, and number of tree seedlings. (*Source*: D. N. Cole 1982.)

density of seedlings (the number per m^2), are attributed to recreational impact. Measures of impact for tree damage are the number of damaged trees and the percentage of all trees on the campsite that are damaged.

On each campsite, approximately 15 quadrats, 1 m by 1 m, were located along four transects that ran from the center point to the edge of the site and that were oriented perpendicular to each other. The distance between successive quadrats decreased with distance from the center point so that the central part of the campsite was not oversampled. In each quadrat the coverage of total vegetation, of exposed mineral soil, and of each plant species was estimated (Fig. 8). Coverages were estimated to the nearest percentage if under 10 percent or in 10 percent coverage classes between 10 and 100 percent. The midpoints of each coverage class were used to calculate mean percentage cover for each of these types of ground cover. These cover estimates were compared with similar estimates on controls. Again, differences are considered to be measures of the amount of recreational impact that has occurred on campsites. For example, mean vegetation cover was 55 percent on controls and 8 percent on campsites. Therefore, we infer that camping removed vegetation from 47 percent of the average site. Note that this is a more precise way to estimate cover loss than was used in the multiple parameter rating system described earlier.

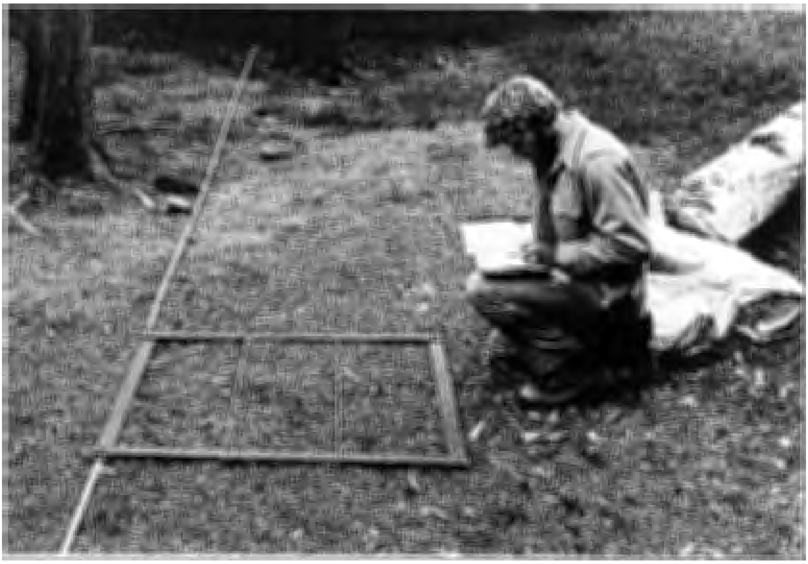


FIGURE 8. Estimates of the percent coverage of vegetation and other ground cover parameters are often made with the aid of a quadrat. (*Photo*: D. N. Cole.)

On both campsites and controls, four soil samples were collected to measure bulk density, organic content, and chemical composition. Water infiltration rates were measured, as were pH and the depth of surface organic horizons. Soil samples were systematically distributed to avoid bias and oversampling of any part of the site.

Using data collected in this fashion, Cole and Hall (1992) were able to identify subtle shifts in different impact parameters over an 11-year monitoring period, despite the fact that conditions were relatively stable on most campsites. For example, mean vegetation cover on campsites was actually higher in 1990 than in 1979; mineral soil exposure increased greatly over this period, however (Table 1). The data were also helpful in differentiating between change that resulted from camping use and natural change, as reflected in changing conditions on controls. This system, then, provides a large amount of precise information about campsite condition, even for individual campsites. The problem with the system is that it can take an hour or two to monitor each campsite.

A Compromise. Marion (1991) has provided a detailed procedural manual for a multiple parameter monitoring system that utilizes measures and counts that are gathered in a rapid fashion. It is less precise and sensitive than the Eagle Cap measurement process but more precise than multiple parameter rating systems. It takes two trained evaluators about 30 minutes to monitor a campsite—again, a compromise between the measurement and rating approaches. He has used the system successfully in a number of national parks, particularly in the eastern United States.

TABLE 1. Mean Change in Ground Cover Conditions on 20 Campsites in the Eagle Cap Wilderness

	Vegetation Cover		Mineral Soil Cover		Organic Horizon Thickness	
	Camp	Control	Camp	Control	Camp	Control
Conditions						
1979	15	60	33	1	0.2	0.9
1990	19	60	44	3	0.2	0.9
Number of Sites						
Increase	12	4	16	7	5	8
Decrease	7	4	3	3	7	9
Unchanged	1	11	1	9	8	2

His technique involves identifying site boundaries and measuring distances from a permanent center point to site boundaries. He replaced the procedure of transects radiating out at set angles (as described for the Eagle Cap process) with a procedure in which the transects radiate out at variable angles, depending on what provides the most accurate measure of camp area. This results in a more accurate measure of camp area (Marion 1995). Following this procedure, tree damage is assessed in much the same way it was in the Eagle Cap. Vegetation cover and mineral soil exposure are roughly estimated for the entire campsite and a control (in the manner described for the multiple parameter rating system). The number of social trails and fire sites are quickly counted and the amount of trash and human waste is quickly assessed.

TRAILS

Monitoring of trail conditions can be useful for the same reasons that campsite monitoring is useful. Information on trail condition and trend can be used to evaluate the acceptability of current conditions and whether or not trail management programs, including maintenance and reconstruction, are working. With trails, it is particularly important to establish specific objectives for trail conditions. Most trail impact (soil compaction, vegetation loss, etc.) is planned and desirable. Therefore, it is critical to define what conditions will be considered problems and to monitor these conditions.

Trail monitoring can also provide useful information about the relationship between trail condition and environmental conditions and design features. Often most of the trail segments that are deteriorating are located in just a few environmental situations (e.g., in highly erosive soils or in locations with seasonally high water tables) or in places where trail design is inadequate (e.g., where trails exceed a certain slope or lack a sufficient number of water bars to divert water off the tread). Monitoring can be used to correlate trail problems with these conditions, and the knowledge generated can be used to guide the future design and location of new or reconstructed trails.

Available techniques can be conveniently grouped into three types: replicable measurements of a small sample of trail segments, rapid surveys of a large sample of trail segments, and complete censuses of trail conditions, problems, and solutions.

Replicable Measurements

Detailed quantitative methods, using replicable measurements, permit subtle changes to be detected. However, the need to accurately document and relocate permanent measurement locations makes this a time-consuming process that may not always be worth the increased ability to detect subtle changes. Consequently, replicable measurements will often be less useful to managers than more rapid survey techniques.

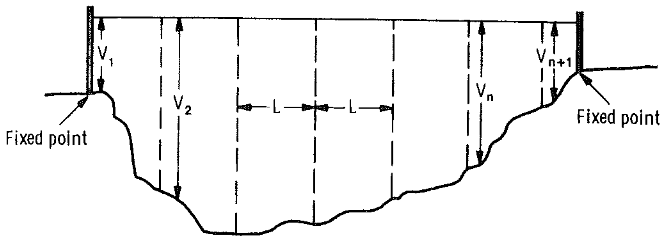
Two schemes for locating replicable sample locations can be used. First, sample points can be distributed in a random or systematic fashion along the trail. This sampling design permits an unbiased assessment of the condition of the trail system as a whole. Repeat measurements, at a later date, allow managers to evaluate how much change has occurred on the entire trail, as well as on the individual sample locations. Alternatively, sample points can be located purposively on trail segments of particular interest to managers. For example, managers may be particularly interested in monitoring change on segments where pronounced erosion has already occurred or where some new type of trail design is being used. Such situations can be more efficiently studied by locating samples purposively, rather than randomly or systematically. With purposive sampling, it is not possible to assess the condition of the entire trail, however.

The trail conditions that management considers to be a problem will determine what should be measured. Perhaps the most serious problem at specific locations is erosion. Soil erosion can be assessed by successively measuring the cross-sectional area between the trail tread and a taut line stretched between two fixed points on each side of the trail. The change in cross-sectional area between successive measurements documents erosion (if area increases) or deposition (if area decreases) of material.

Leonard and Whitney (1977) provide a detailed description of this technique, using nails in trees as fixed points. This means of locating fixed points limits sample locations to forested areas. By using other fixed points, such as rods set in the ground or rods temporarily placed in receptacles permanently buried in the ground, sample points can be located in a greater variety of situations.

After locating the two fixed points, stretch a taut line and/or tape measure between the two points. Fixed points should always be far enough apart to allow for future increases in trail width. Take a series of vertical measurements of the distance between line and trail tread at fixed intervals along the tape. The interval should be small enough to permit at least 20 vertical measurements per transect. Measurements will be most precise when (1) the line is elevated above any vegetation or microtopography along the edge of the trail, (2) the line is kept taut, and (3) a plumb bob or level is used to take vertical measurements. The cross-sectional area below the taut line can be computed from the vertical measurements using the formula in Fig. 9.

When trail segments are to be reexamined, the fixed points should be relocated, and the taut line should be repositioned at precisely the same height above the fixed point



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

Where A = cross- sectional area

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

L = Interval on horizontal taut line

FIGURE 9. Layout of trail transect and formula for calculating cross-sectional area. (*Source*: D. N. Cole 1983b.)

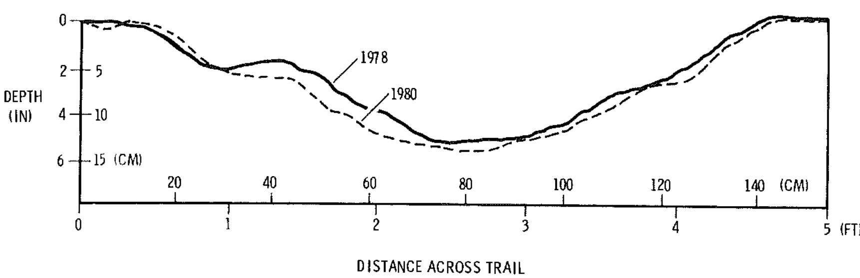


FIGURE 10. Cross-sectional profiles for the same trail transect in 1978 and 1980. Over this 2-year period 17 in^2 of material were eroded away. (*Source*: D. N. Cole 1983b.)

as in the original sample. Vertical measurements should be taken at the same interval and starting from the same side as in the original measurements. The idea is to remeasure precisely each vertical measurement. Precise relocation becomes increasingly important as the number of vertical measurements per transect decreases. Results show changes over time in the cross-sectional area of the trail (Fig. 10). Using this technique, Cole (1991) found virtually no change in cross-sectional area over an 11-year period for an entire trail system in Montana. However, at one purposively located segment, cross-sectional area increased more than 2 ft^2. This illustrates the different conclusions that might be drawn from a random sample as opposed to a purposive sample.

Rinehart, Hardy, and Rosenau (1978) developed a technique for measuring cross-sectional area with stereo photographs. As with the quadrapod photographic method of monitoring conditions on campsites, this technique does not really save time, and interpretation of results can be difficult.

The location of the fixed points must be well documented. One means of doing this is to measure the distance from the trailhead to the trail transect with a measuring wheel (cyclometer). If markers identifying the fixed points are readily visible, this may be all that is necessary. A less obtrusive option is to bury metal stakes that can be relocated with pin locators (a type of metal detector). The cyclometer and photos of the transect identify the approximate location of the transect. Exact locations are referenced to landmarks, and the pin locator leads to the metal stakes.

Detailed measurements of this type are most useful to researchers investigating the relationship between trail condition and factors that influence trail condition. Managers may find it useful for evaluating the effectiveness of alternative trail construction and design techniques. For example, if a new method of trail hardening is being tried, change could be followed both on the hardened segment and a similar unhardened segment. By comparing differences in the amount of change on hardened and unhardened segments, the benefits of hardening can be assessed in relation to its cost before investing in its widespread use.

Rapid Survey Samples

As with campsites, a useful alternative to time-consuming sampling of a few places is to make rapid assessments of many trail segments. This approach is particularly useful on trail systems because there are usually many trail miles to assess. Moreover, simply measuring trail width and depth is often as meaningful as taking cross-sectional measurements, and width and depth measurements can be taken in little time. In rapid surveys substantial time is saved by not relocating sample points. The resulting loss of precision is compensated for by the ability to take a much larger sample in the same amount of time. Monitoring involves comparing two independent samples, each consisting of a large number of observations, instead of reexamining a single small sample of sites.

To conduct a rapid survey, simply hike a specified distance along the trail, collect data on trail condition, and then hike on to the next sample point. Distances between sample points have varied from 50 to 500 m. Appropriate distances between sample points will depend on the trail mileage to be surveyed and the complexity of situations involved. There should probably be at least 100 observations for each situation of concern. For example, only 100 observations would be needed to assess the condition of a trail. However, if a low-use portion were to be compared with a high-use portion, 200 observations would be needed. The most common measures taken at each sample point are width of the trail (either the tread or the entire zone of disturbed soil and vegetation), width of bare ground, and maximum depth of the trail. Bayfield and Lloyd (1973) also noted the number of parallel trails and the presence or absence of the following "detracting features": rutting, stepping, surface deterioration, gullying, lateral erosion, bad drainage, esthetic intrusions, vandalism, and litter.

From this data it is possible to calculate mean width and depth of the trail and the proportion of the trail on which there are particular detracting features. Such data provide a useful characterization of trail conditions and problems and permit an assessment of change over time and a comparison of different trails. For example, Cole (1991) reported changes on a trail system in Montana between 1980 and 1989. Over that period, mean total trail width (the zone disturbed by trampling) increased from 100 cm to 125 cm; however, bare width (the zone without vegetation) and depth did not increase significantly. Similar increases in trail width have been documented elsewhere, using rapid survey samples (e.g., Lance, Baugh, and Love 1989). It is also possible from such data to estimate the percentage of the trail that exceeds certain depth and width standards. If objectives state, for example, that no more than 1 percent of all trails will be more than 1 ft deep, this can be monitored easily using survey techniques.

Census Techniques

Working on horse trails in Rocky Mountain National Park, Summer (1980) divided each trail into segments and then placed each trail segment in one of four erosion classes (Table 2). She used these data to relate the extent and severity of trail erosion to the geomorphic surface on which the trail was located. Summer found, for example, that most trail segments on alluvial terraces fell into either the negligible or low erosion classes; segments on alluvial-colluvial fans where boglike conditions prevail were usually in the high erosion class. She used this information to make suggestions about where trails should or should not be located. Although this was not done, it would be possible and useful to develop objectives limiting the percentage of the trail system in high erosion classes, and then monitor the percentage of the trail system in each erosion class. Where conditions are deteriorating, particularly

TABLE 2. Erosion Classes for Horse Trails in the Rocky Mountains

Erosion Class	Evaluation of Present Stability
Negligible	No marked disturbance within trail; some gravel and soil may be moving imperceptibly downslope; on monitored sites, maximum mean incision is less than 2 cm and widening is less than 25 cm.
Low	Some deepening and/or widening of trail; cobbles and soil may begin to accumulate along trail edge; on monitored sites, maximum mean incision is 2 to 6 cm and/or widening is 25 to 50 cm.
Moderate	Noticeable deepening and widening; hoofprints less than 5 cm deep; boulders and cobbles may or may not show evidence of movement; soil and vegetation disrupted; on monitored sites, maximum mean incision is 6 to 8 cm and/or widening is 50 to 100 cm.
High	Very noticeable deepening and widening; hoofprints greater than 5 cm deep; boulders and cobbles obviously moved downslope or beyond trail edge; soil and vegetation disrupted and moved downslope; on monitored sites, maximum mean incision is greater than 8 cm and/or widening is greater than 100 cm.

Source: Summer 1980. Appeared in *Journal of Soil and Water Conservation*, copyright © 1980 by Soil Conservation Society of America.

where the percentage of the trail in high erosion classes exceed objectives, management actions would be called for.

Another useful approach is to census all trail "problems." The first step here is to define in precise terms exactly what will be considered a problem. The number and length of problems can be recorded while walking the trail; then the location of each trail problem can be mapped. This information can be useful in budgeting for trail maintenance and in allocating manpower to various trail segments. By noting the segment, site, design, and use characteristics of each problem, it should be possible to identify consistent patterns of problem occurrence. Knowledge of occurrence patterns can be used to develop guidelines for trail location, design, and maintenance.

On a trail system in the Selway-Bitteroot Wilderness, for example, Cole (1983b) censused all trail segments that were either incised more than 10 in. or muddy for at least part of the use season and that were at least 3 ft long. At each problem segment, maximum depth and width of the segment, habitat type (vegetation, soils, and topography), and slope of the trail were noted. More than two-thirds of the muddy segments were in one vegetation type. If future trails avoid this type, most of the muddiness problems should be eliminated. Incision problems were strongly correlated with trail slope; almost 90 percent of the problems were on segments with slopes greater than 4.7 degrees. The solution here is to make better use of water bars on stretches where steep pitches cannot be avoided. Development of such guidelines could greatly increase the cost-effectiveness of trail building and maintenance programs. It basically amounts to learning from past mistakes.

Censuses can also be used to relate trail conditions to objectives. How this is done depends on how objectives are written. One option is for objectives to state that no segments will be more than, say, 1 ft deep. In this case, trails will have to be censused to see whether any segments are deeper than 1 ft. An option that is usually more realistic and efficient is to write probabilistic objectives (e.g., no more than 1 percent of the trail will be more than 1 ft deep). In this case, either trails can be censused or rapid survey techniques can be used.

Recently, Marion (1994) has used census techniques to assess trail conditions in several parks in the eastern United States. He emulated Cole's approach of hiking along trails with a measuring wheel, documenting the starting and ending points of well-defined "problems." In addition, he recorded the starting and ending point of certain trail design, construction, and maintenance features: maintained gravel, excessive grade (>20 percent), and trail corduroy. He recorded the location of drainage dips, water bars, lateral drains, retaining walls, culverts, and steps. For several of these features, he also assessed effectiveness. From these data, he was able to describe the number and length of these design features and draw tentative conclusions about their effectiveness. For example, he concluded that tread drainage was the most critical maintenance need along trails in Great Smoky Mountains National Park, and that water bars were more effective than drainage dips in dealing with this problem.

Elsewhere, Williams and Marion (1992) illustrate the value of prescriptive work logs. When problems are encountered along the trail, assessors attempt to prescribe the trail work needed to mitigate each problem. Assessors note the distance along the trail—from the measuring wheel—and describe the problem and the solution, using a pocket dictation device. This information can be used to prioritize and budget trail work. Clearly, someone highly knowledgable about trail design and maintenance is needed to describe the trail problems and appropriate solutions.

WATER BODIES

Monitoring of water is a critical concern in a variety of situations. Health aspects of water quality are important where drinking water is provided and in bodies of water where swimming occurs. Physical and chemical aspects of water quality are important in areas with objectives that stress maintenance of substantially natural conditions and in areas that maintain populations of sensitive fish species. Some of the situations in which monitoring of water quality may be necessary include natural and artificial lakes where heavy boating use may be affecting water quality, roaded areas where recreational use of roads may cause deterioration of water quality, and wilderness areas where the strong emphasis on natural conditions is reflected in stringent water quality standards.

Many techniques for monitoring water quality require sophisticated equipment, laboratory analyses, and highly trained technicians. However, recent advances in development of "user-friendly" techniques and equipment are changing this situation. For example, probes have been developed that allow evaluators to read off chemical concentrations when the probe is inserted in the water (Fig. 11). Books have also

FIGURE 11. Because of health hazards, water quality is monitored in heavily used wildland recreation areas. (*Photo*: National Park Service.)

been written to make water quality monitoring available to a broader range of people (Mitchell and Stapp 1994).

It is important to consider where sampling will occur, the frequency and duration of sampling, and the types of measurements that should be made. All of these considerations depend on the objectives for the area. In monitoring lakes, sampling is often done at the outlet. This provides a good indication of the condition of the lake as a whole. However, where localized pollution is expected, adjacent to a boat ramp or a campsite for example, sampling should be conducted in this area. Where stream pollution is suspected, sample just above the suspected source, immediately downstream, and far downstream from the source. Along streams it may be necessary to establish several sampling locations if the objective is to characterize an entire stream system.

It is usually desirable to monitor water quality in undisturbed places as well, to establish a control for comparison with disturbed conditions. For a lake this commonly involves sampling the inlet stream or part of the lake away from heavily used parts. With streams it is sometimes necessary, but undesirable, to establish control sampling locations on an entirely different stream.

The frequency and duration of sampling can be decided on only after some idea of data variability has been obtained. Bacteriological contamination can vary greatly in relation to the timing of recreational use (Flack, Medine and Hansen-Bristow 1988) and precipitation events. Sampling frequency and duration must be adequate to reveal such patterns.

The final consideration is what parameters to measure. Monitoring procedures and standards of quality for drinking water and water to swim in are well-developed and generally agreed upon. The primary measurement technique involves counting coliform bacteria in a sample of water. Coliform bacteria, while not pathogenic themselves, are found in human feces and often occur in the company of organisms that represent health hazards to humans. They are counted because they are convenient to work with, and they have been shown to be good indicators of bacteriological contamination. The standard membrane filter technique involves filtering and incubating water samples and then counting the number of indicator organisms in each sample. Refer to the American Public Health Association (1985) for more detail. The number of organisms found can then be compared with various health standards that have been advanced. For drinking water, acceptable coliform counts are usually on the order of one or two bacterial colonies per 100 ml of water (depending on whether federal or state standards are used). Acceptable levels for full-body contact, such as swimming, are more variable between states but are usually on the order of hundreds of coliform bacteria colonies per 100 ml of water. Some experts believe it is better to base health standards on the number of fecal coliforms rather than on total coliform counts. Managers should determine what federal, state, or local requirements apply—in this case objectives already exist—and take whatever measures are appropriate.

Although monitoring water is not as simple as campsite and trail monitoring, it is now possible to buy the equipment to conduct membrane filter monitoring for less than $1500. Training takes only about a day.

Recently, increasing numbers of water bodies, even in remote areas, have been contaminated with the protozoan *Giardia lamblia* (Suk, Sorensen, and Deleanis 1987).

This organism is currently a more significant health threat in wildland recreation areas than bacteria. Moreover, it is difficult to monitor. Improved procedures for monitoring *Giardia* contamination are being developed (Hibler and Hancock 1990). However, *Giardia* samples must be large (on the order of hundreds of gallons), and the presence of *Giardia* cysts must be identified by experts using microscopes.

A wide variety of physical and chemical water quality parameters can be examined. It can also be useful to sample plankton, algae, and other aquatic biota. In a study designed to determine baseline conditions and possible effects of visitor use on some subalpine lakes in Kings Canyon National Park, Silverman and Erman (1979) measured orthophosphate and nitrate concentration, pH, conductivity, temperature, dissolved oxygen, plankton, and periphyton. In most cases techniques used are either standard methods recommended by the American Public Health Association (1985) or techniques described in special field analysis test kits.

Although it is helpful to collect information on as many parameters as possible, this may be wasteful, particularly if the increased costs associated with this lead to an undesirable reduction in sampling frequency or the number of sample points. If this is the case, one must reexamine objectives and evaluate which parameters are most likely to indicate adverse effects on water quality. Where use of roads in erodible material is common, increased sedimentation can adversely affect fish populations; in such places monitoring of suspended solids is particularly worthwhile. Recreational trampling, even in remote backcountry areas, can lead to increases in the concentration of certain elements. Sometimes growth of aquatic plants can be stimulated by increases in the concentration of elements that formerly limited plant growth. In Kings Canyon National Park, for example, recreation-related increases in iron stimulated aquatic insects, worms, and small clams, and a depletion of nitrate (Taylor and Erman 1980). In Gatineau Park, Quebec, trampling increased phosphorus levels in a small lake. This stimulated growth of phytoplankton and reduced the transparency of the water (Dickman and Dorais 1977). Thus, in one case, it is most important to monitor iron and biota on the bottom of the lake; in the other case, it is most important to monitor phosphorus and suspended plankton.

These case studies illustrate the complexity of monitoring water quality. A relatively high level of expertise is needed to do more than simply monitor bacteria levels. It is probably best to start out monitoring many parameters at various times and places. This should give some idea of temporal and spatial variability to help decide on sampling frequencies and locations that are both effective and efficient. It will also become clear which parameters are the best indicators of adverse impact. Although something of a "shotgun approach" is required at first, the program should become increasingly efficient over time.

REMOTE SENSING

There are a number of situations in which remote sensing, particularly aerial photography, can be a useful and cost-effective means of monitoring impact. Wherever tree cover is lacking, taking air photos is a good way to monitor change in the number and area of devegetated places. Price (1983) has shown how air photos can be used to monitor visitor impact on meadows around Sunshine Ski Area in Banff National Park, Alberta. Repeat photos show where new trails are developing and where existing trails are widening or becoming braided.

In Grand Canyon National Park, backcountry campsites are often clustered closely together in accessible places where water is available. These locations develop mazes of informal trails and tent pads. It is difficult to monitor changes in these trail and campsite complexes using only the field measurements and rapid estimation techniques discussed previously. With air photos, however, the number and areas of both trails and tent pads can be traced onto maps. Overlays drawn from repeat photos, taken at later dates, can be used to identify changes over time. New Geographical Information System (GIS) technology presents novel and more sophisticated analytical options. However, the value of GIS applications to recreation impact management is probably less profound than for many other natural resource applications.

A final situation in which air photos are useful is in monitoring impacts resulting from use of off-road vehicles in areas without a dense canopy cover. Such use leads to the development of tracks and large devegetated areas in places of concentrated use. This situation is analogous to the Grand Canyon trail and campsite complexes just described. Overlay maps and GIS technology can again be used to monitor change in the number and size of tracks and devegetated areas.

DEVELOPING A MONITORING SYSTEM

Both Cole (1989) and Marion (1991), in their campsite monitoring sourcebooks, stress the importance of following a sequence of steps in developing a monitoring system. It is important to resist the urge to simply rush out and apply a monitoring system you heard about from a friend or in a class. Systems must be carefully tailored to existing situations; they must also be maintained and nurtured. Otherwise, time will be spent on unproductive activities, critical data will not be collected, quality control will be lost, and eventually programs will be abandoned. Typically, program abandonment will be blamed on the monitoring technique, when in fact most of the blame should be placed on inadequate attention to the *process* of developing a monitoring system.

The steps that Cole and Marion suggest differ somewhat. Generally, the steps involve (1) evaluating system needs and constraints, (2) reviewing and selecting monitoring approaches and impact evaluation protocols, (3) testing and refining those protocols, (4) documenting protocols and training evaluators, (5) developing field collection procedures, and (6) designing data analysis and reporting procedures. These authors note that it is critically important to decide on how you want to use the monitoring data—what questions you want to be able to answer—before deciding on a system. It is also important to allocate sufficient time to training. Marion (1991) is exemplary in the detailed training manual he provides. This will more than pay for itself in improving data quality. Finally, it is important to attempt to assess the precision of the data you collect. Any difference in estimated condition, at two different points of time, will include both the amount of change that has actually occurred and some degree of measurement error. Only when you know the likely magnitude of measurement error will you be able to estimate the magnitude of real change.

REFERENCES

American Public Health Association. 1985. *Standard Methods for the Examination of Water and Wastewater.* 16th ed. Washington, DC: American Public Health Association. 1268 pp.

Bayfield, N. G., and R. J. Lloyd. 1973. An Approach to Assessing the Impact of Use on a Long Distance Footpath—The Pennine Way. *Recreation News Supplement* 8:11–17.

Bratton, S. P., M. G. Hickler, and J. H. Graves. 1978. Visitor Impact on Backcountry Campsites in the Great Smoky Mountains. *Environmental Management* 2:431–442.

Brewer, L., and D. Berrier. 1984. Photographic Techniques for Monitoring Resource Change at Backcountry Sites. USDA Forest Service General Technical Report NE-86. 13 pp.

Cole, D. N. 1982. Wilderness Campsite Impacts: Effect of Amount of Use. USDA Forest Service Research Paper INT-284. 34 pp.

Cole, D. N. 1983a. Monitoring the Condition of Wilderness Campsites. USDA Forest Service Research INT-302. 10 pp.

Cole, D. N. 1983b. Assessing and Monitoring Backcountry Trail Conditions. USDA Forest Service Research Paper INT-303. 10 pp.

Cole, D. N. 1989. Wilderness Campsite Monitoring Methods: A Sourcebook. USDA Forest Service General Technical Report INT-259. 57 pp.

Cole, D. N. 1991. Changes on Trails in the Selway-Bitterroot Wilderness, Montana, 1978–89. USDA Forest Service Research Paper INT-450. 5 pp.

Cole, D. N. 1993. Campsites in Three Western Wildernesses: Proliferation and Changes in Condition Over 12 to 16 Years. USDA Forest Service Research Paper INT-463. 15 pp.

Cole, D. N., and T. E. Hall. 1992. Trends in Campsite Condition: Eagle Cap Wilderness, Bob Marshall Wilderness and Grand Canyon National Park. USDA Forest Service Research Paper INT-453. 40 pp.

Dickman, M., and M. Dorais. 1977. The Impact of Human Trampling on Phosphorus Loading to a Small Lake in Gatineau Park, Quebec, Canada. *Journal of Environmental Management* 5:335–344.

Flack, J. E., A. J. Medine, and K. J. Hansen-Bristow. 1988. Stream Water Quality in a Mountain Recreation Area. *Mountain Research and Development* 8:11–22.

Frissell, S. S. 1978. Judging Recreation Impacts on Wilderness Campsites. *Journal of Forestry* 76:481–483.

Hibler, C. P., and C. M. Hancock. 1990. Waterborne Giardiasis. In G. A. McFeters, ed. *Drinking Water Microbiology: Progress and Recent Developments.* New York: Springer-Verlag, pp. 271–293.

Lance, A. N., I. D. Baugh, and J. A. Love. 1989. Continued Footpath Widening in the Cairngorm Mountains, Scotland. *Biological Conservation* 49:201–214.

Leonard, R. E., and A. M. Whitney. 1977. Trail Transect: A Method for Documenting Trail Changes. USDA Forest Service Research Paper NE-389. 8 pp.

Marion, J. L. 1991. Developing a Natural Resource Inventory and Monitoring Program for Visitor Impacts on Recreation Sites: A Procedural Manual. USDI National Park Service Natural Resources Report NPS/NRVT/NRR-91/06. 59 pp.

Marion, J. L. 1994. An Assessment of Trail Conditions in Great Smoky Mountains National Park. USDI National Park Service, Southeast Region. 155 pp.

Marion, J. L. 1995. Capabilities and Management Utility of Recreation Impact Monitoring Programs. *Environmental Management* 19:763–771.

Mitchell, M. K., and W. B. Stapp. 1994. *Field Manual for Water Quality Monitoring*. Dexter, MI: Thomson-Shore Printers. 272 pp.

Parsons, D. J., and S. A. MacLeod. 1980. Measuring Impacts of Wilderness Use. *Parks* 5(3):8–12.

Parsons, D. J., and T. J. Stohlgren. 1987. Impacts of Visitor Use on Backcountry Campsites in Sequoia and Kings Canyon National Parks, California. Cooperative National Park Resources Studies Unit Technical Report No. 25. 79 pp.

Price, M. F. 1983. Management Planning in the Sunshine Area of Canada's Banff National Park. *Parks* 7(4):6–10.

Rinehart, R. P., C. C. Hardy, and H. G. Rosenau. 1978. Measuring Trail Conditions with Stereo Photography. *Journal and Forestry* 76:501–503.

Silverman, G., and D. C. Erman. 1979. Alpine Lakes in Kings Canyon National Park, California: Baseline Conditions and Possible Effects of Visitor Use. *Journal of Environmental Management* 8:73–87.

Suk, T. J., S. K. Sorenson, and P. D. Dileanis. 1987. The Relation Between Human Presence and Occurrence of *Giardia* Cysts in Streams in the Sierra Nevada, California. *Journal of Freshwater Ecology* 4:71–75.

Summer, R. M. 1980. Impact of Horse Traffic on Trails in Rocky Mountain National Park. *Journal of Soil and Water Conservation* 35:85–87.

Taylor, T. P., and D. C. Erman. 1980. The Littoral Bottom Fauna of High Elevation Lakes in Kings Canyon National Park. *California Fish and Game* 66(2):112–119.

Williams, P. B., and J. L. Marion. 1992. Trail Inventory and Assessment Approaches Applied to Trail System Planning at Delaware Water Gap National Recreation Area. In Proceedings of the 1992 Northeastern Recreation Research Symposium. USDA Forest Service General Technical Report NE-176, pp. 80–83.