13 Site Management

Site management techniques attempt to minimize impact by controlling where use occurs and by manipulating the site itself. If use occurs on relatively durable sites, impacts will be less pronounced than if use occurs on less durable sites. Alternatively, fragile places can be closed entirely to use. Design and treatment of sites can also do much to keep impacts within acceptable limits. Site management can affect the amount, type, and distribution of visitors, as well as the durability of the resource, and can be used to restore places that have been excessively damaged. Generally, site management is likely to increase in intensiveness and importance toward the more developed end of the recreation opportunity spectrum and in places that are heavily used. Everywhere, effective management will require a mix of both visitor and site management.

In developing site management plans, it is important to strive to maintain a natural appearance, particularly in wildland recreation areas. Even in wilderness, however, managers should not be paralyzed by a concern with avoidance of engineering if it is the only means of preventing equally "unnatural" resource damage. Curiously, many managers in wilderness have little problem with highly engineered trails, but they resist similar engineering levels for campsites and stock-use areas. The obtrusiveness of site manipulation must be carefully weighed against the obtrusiveness of site impacts and other means of solving problems.

Another concern in site management is cost, both to the visitor and to management. Closure of all sites at a lake to permit recovery and closure of a road to move a trailhead back 10 miles are costly actions for visitors. They may be justified, but evaluation of the severity of the problem at hand, the likely effectiveness of alternative actions, and costs to the visitor must all be considered. Many site management actions entail significant costs for management. These range from the high costs of installing irrigation systems to improve plant growth on campsites to lesser costs for building a corral or a hitch rail. Some actions are costly only in the construction phase; others entail significant ongoing maintenance costs. It is particularly wasteful to make an initial investment in a program that proves ineffective because of insufficient maintenance funds.

LOCATING USE ON RESISTANT SITES

One effective means of reducing impact is to see that most use occurs on durable sites. For example, Cole (1995) studied the resistance of 18 different vegetation types to trampling. The number of trampling passes required to eliminate 50 percent of the vegetation cover ranged from about 600 passes in an alpine sedge turf to just 20 passes in a subalpine forest with an understory dominated by ferns. This suggests that the sedge turf might be able to tolerate 30 times as much use as the forest, with no more impact. It is difficult to generalize about what makes a site durable, because a good location for a trail may not be a good location for a campsite. Even with campsites, a durable low-use site may not be a durable high-use site. Moreover, generalizations about durability are extremely site-specific; they vary from region to region. Given the importance of site durability, however, some generalizations for specific situations will be offered. Additional information is provided in Chapter 8.

On high-use campsites the most important durability considerations are probably overstory trees and the soil's erodibility, drainage, and depth. Other esthetic considerations should also be evaluated. Because tree regeneration is sharply curtailed on campsites, it is wise to locate campsites in stands of relatively young, long-lived trees that are not susceptible to disease. This will prolong the time that campsites will be forested. In the West, aspen groves should be avoided because they are highly susceptible to canker diseases when mechanically injured (e.g., through initial carving) by campers (Hinds 1976). Forested campsite life spans in aspen are on the order of 20 years. Ripley (1962) evaluated the susceptibility of 27 southern Appalachian trees and shrubs to disease infection, insect infection, and decline (Table 1). Knowledge about the durability of trees is important to decisions about campsite locations. The durability of ground cover vegetation is much less important because, with heavy use, even resistant ground cover is unlikely to survive.

It is important for erosion potential to be minimal, because developed campsites must be used for a long time. It is best to locate sites on relatively deep soils with a wide mix of particle sizes (e.g., loams) and at least a moderate amount of organic matter, as such soils have good drainage. Soils that drain well should not have serious problems with flooding and excessive runoff. Soils that are mostly organic should be avoided. However, thick organic horizons minimize the exposure of underlying

TABLE 1. Rankings of Trees from Most to Least Able to Withstand the Impacts of Recreation Use

Hardwoods		Conifers
1. Hickories	12. Red maple	1. Shortleaf pine
2. Persimmon	13. American holly	2. Hemlocks
3. Sycamore	14. Sourwood	3. White pine
4. White ash	15. Black birch	4. Pitch pine
5. Beech	16. White oaks	5. Virginia pine
6. Sassafras	17. Black walnut	
7. Buckeye	18. Red oaks	
8. Yellow poplar	19. Black locust	
9. Dogwood	20. Magnolia	
10. Black gum	21. Black cherry	
11. Yellow birch	22. Blue beech	

Source: Ripley 1962.

mineral soil that results from campsite use. Deep soils with moderately rapid drainage are also required for many human waste disposal systems that depend on on-site decomposition. Leonard, Spencer, and Plumley (1981) provide a useful table of limitations posed by certain physical site characteristics for overnight facilities (Table 2). Some of these guidelines apply only to the northern Appalachians, for which the table was developed; others are more general in applicability.

On lightly used campsites such as those in a portion of wilderness where use dispersal is being practiced, the most important durability consideration is the resistance of the ground cover vegetation. If properly managed, soil damage in such places should be minimal, and tree damage should not occur. The main concern is avoidance of vegetation loss, which, once it occurs, tends to attract further use to the site. It is always best to select sites without any vegetation at all. Examples include outcrops of bare rock, sand beaches, gravel bars, and some dense forests. Where vegetation is present, considerable information or experience may be needed to evaluate durability. Many of the resistant plant characteristics mentioned in Chapter 3 can be used to evaluate the resistance of different vegetation types. The most useful general guideline is that grasslands and meadows are more resistant than the undergrowth in forests (Fig. 1). Dry vegetation types are usually more resistant than moist types.

Selecting a durable route is often the most important tool in managing impacts on trails. It is certainly the least costly tool and should be the first line of defense, particularly in wilderness where the other major management option—engineering—is to be avoided as much as possible. The most important environmental factors affecting trail durability are usually topography, soil moisture, and soil erodibility. The slope of the trail and the extent to which the trail intercepts runoff from upslope are particularly important. Trails with steep slopes are likely to deteriorate rapidly unless steps are taken to control erosion. Trails that are aligned so that they run straight up slopes and are depressed well below the ground surface are also prone to problems. Such trails intercept overland flow and are quickly eroded by running water. On the other hand, trails with no slope at all often have trouble draining. Ideally, trails should have gentle grades with an alignment perpendicular to a moderately to steep sideslope. The importance of such a trail alignment increases as trail grade increases (Leung and Marion 1996). Where such a location cannot be sustained, engineering techniques will have to be used to mitigate the potential problems of a less than ideal location.

In many mountainous areas the most common cause of trail damage from the users's point of view is excessive soil moisture, which leads to development of muddy trails (Fig. 2). Muddy stretches are difficult to walk through. Moreover, in an attempt to avoid the mud, hikers and horses frequently skirt the stretch and, in doing so, widen the quagmire. In the Bob Marshall Wilderness "trail bogs" knee-deep in mud may be 100 yds long and almost as wide.

Areas of late snowmelt, high water tables, and places where water drains onto the trail are common situations in which problems with muddy trails occur. In the northern hemisphere, locating trails on south-facing slopes is a general means of avoiding problems with late snowmelt. Before locating a trail, it is worthwhile to observe where snow lasts longest, either in the field or with the aid of aerial photography.

TABLE 2. Physical Site Characteristics and Limitations for Overnight Facility Locations

	Limitations		
	None to Slight	Moderate	Severe
	Topography		
Slope	2 to 15 percent	15 to 30 percent	Greater than 30 percent
Landform	Valleys, footslopes, low-elevation ridges, terraces or benches on side slopes	Midslopes of mountains	Steep mountain side slopes, depressions, ravine floors, pond shorelines, bog lands
Aspect	East, south	West, north	Northwest, southeast (or aspects receiving most frequent storm winds)
	Soil		
Depth to impervious layer or seasonal high-water table	Greater than 5 ft	$2^1/_2$ to 5 ft	Less than $2^1/_2$ ft
Drainage	Rapid to moderately well drained	Moderately well to imperfectly drained or excessively rapid	Poorly or imperfectly drained
Flooding	None		One to 2 times per year during use season

Soil texture	Moderately coarse to medium texture (sandy loam to silt loams)	Moderately fine or slightly coarse texture (clay loams, silt-clay loams, or sandy soils of 65 percent sand)	Fine texture (clays), loose sand, or organic soils
Rockiness/stoniness	Cobbles/gravel—20 percent Surface rocks—25 ft apart	Cobbles—20 to 50 percent Surface rocks—5 to 25 ft apart	Cobbles—50 percent Surface rocks—5 ft apart
		Vegetation Types	
	Beech, maple, oak, hickory, pine stands	Spruce, fir, hemlocks, birch, alders, willows	Alpine, subalpine, bog, krummholz
		Water Supply	
For huts	Available potable water source provides quantity sufficient for daily consumption throughout season, e.g., 12 gal./person/day.	Water source has decreasing flow during season to 3/4 the quantity needed, and water must be stored.	Inconsistent flow from the water source and quantity is less than 12 gal./person/day.
For shelter or tent sites	Water flows from a spring, and the flow and quality are reliable all season. Spring outlet is within 250 yards of site.	Water flows from a spring, but flow is decreased to a trickle at the end of season. Spring outlet is 1/4 mile away.	Reliable spring water is more than 1/2 mile away.

Source: Leonard, Spencer, and Plumley 1981. Copyright © 1981 by Appalachian Mountain Club, used with permission of publisher.

FIGURE 1. Vegetation loss at this outfitter site in the Bob Marshall Wilderness, Montana, is low because it is located in a resistant dry grassland. (*Photo*: D. N. Cole.)

FIGURE 2. This trail traverses an area of high soil moisture. It is widening, developing parallel trails, and is difficult for hikers to negotiate. (*Photo*: D. N. Cole.)

High water tables can often be identified by using vegetational indicators. On a trail system in the Selway-Bitterroot Wilderness, for example, more than two-thirds of the muddiness problems were in one vegetation type, which, along with the vigorous growth of four individual species, indicates quite accurately where muddiness problems are likely to occur (Cole 1983). Soil color can also be used as an indicator of potential muddiness problems. Blue-gray and dark organic colors often indicate poor drainage, whereas yellows and reds often indicate good aeration and, therefore, good drainage. Soils that are primarily organic (e.g., peat or muck soils) and fine-textured soils are also likely to be muddy because drainage is poor. Again, engineering can compensate for a poor location, if necessary.

Certain soils are also less susceptible to erosion than others. Erosiveness is lowest in soils with good drainage and the ability to resist the detachment of soil particles. These properties are optimized in loams with a substantial organic matter content. Sandy soils have good drainage, but they are easily displaced; they are of intermediate desirability as trail locations. Clay soils resist detachment, but drainage is poor; they are even less desirable than sands. The most erosive soils are those with homogeneous textures of a moderate particle size (i.e., fine sands and silts) (Leung and Marion 1996). The prominent trail erosion problems in many mountain meadows result from the erosiveness of the homogeneous, fine-textured soils that have developed on the glacial outwash or lacustrine deposits characteristic of these meadows.

Garland (1990) developed a technique for assessing erosion risk for mountain footpaths in South Africa that can be used to identify favorable path locations before paths are planned and constructed. Indices of rainfall, lithology, and topographic slope were combined to produce erosion risk classes between one and four. The utility of this procedure was tested by comparing risk ratings and erosion status for sections of existing path. The correlation of prediction with reality was high, suggesting the technique has potential for aiding in the selection of routes that should have low maintenance requirements.

PERMANENT CLOSURES

Rather than focusing use on resistant sites, managers can also prohibit use of certain sites or ecosystem types. One of the most common prohibitions is against camping within a specified distance of water bodies, particularly lakes. In national parks, setbacks range from 5 ft to as much as one-half mile; the most common distance is 100 ft (Marion, Roggenbuck, and Manning 1993). Both social and ecological justifications have been provided for this action. Social reasons include (1) preserving the esthetic qualities of the lake that attracted people to the area in the first place, (2) reducing the visibility of campers—they are highly visible along the lakeshore, and (3) preserving the lakeshore as common space for all to use. Ecological reasons include (1) avoiding use of particularly fragile lakeshores, (2) reducing the potential for water pollution, and (3) avoiding the braided trails that often form when campsites are located close to the shore.

There is no doubt that the social justifications are significant. However, the ecological reasons are suspect. Lakeshores are not more fragile than places set back from water. In the Eagle Cap Wilderness there was little difference in impact on lakeshore sites and sites more than 200 ft from lakes (Cole 1982). Water quality is seldom a problem except where use is very heavy. Therefore, in most backcountry situations this is not a valid justification. There are certainly places where avoiding use of sites close to water bodies is important; there are also many places where this is unnecessary. Because such a prohibition keeps parties from camping where they most want to, the action should be taken only where it is necessary. Many of the same things could be accomplished through educating people about not damaging shorelines or polluting waters. Because social reasons for setbacks are the most telling, setbacks are more appropriate in heavy-use areas than in low-use areas.

Permanent closures have also been implemented in places where past impact has been so severe that such a drastic measure is the only option for recovery. Bullfrog Lake, one of the most scenic and fragile destinations in Kings Canyon National Park, California, was so heavily impacted that it was closed to all camping in 1961. Fireplaces and other evidence of camping occurred, but some places remained highly impacted (Parsons and DeBenedetti 1979). The National Park Service plans to maintain the ban on camping at Bullfrog Lake—partially because recovery is not yet complete but also to showcase an area that required such a drastic management response.

A common reason for closing an area to all use or certain types of use, such as camping, is the presence of vulnerable animals or rare and endangered plants. For example, waterholes of critical importance to animals, such as bighorn sheep, are often kept off-limits for overnight use. One of only three known populations of the endangered sentry milk vetch occurs at one of the most popular rim overlooks at Grand Canyon National Park. Serious declines in the viability of this population led park rangers to erect a fence around the population and reroute trails around it. Four years since protection, the population is still vulnerable but more stable than it was (Maschinski, Frye, and Rutman 1997). Interpretive displays can be used to educate the public about the need to preserve endangered species and to elicit their support for the drastic measures needed to protect the plants from trampling.

TEMPORARY SITE CLOSURES

In some areas, highly impacted sites have been temporarily closed to allow them to recover. Once they have recovered, these sites can be reopened for use. Other sites must be available for recreational use until the closed sites can be reopened. This action has been called "rest-rotation" because there is a rotation of open and closed sites. It bears some similarity to the type of dispersal in which use is spread among a larger number of sites. The major difference is that management formally controls which sites are open and which are closed. With rest-rotation, sites are also likely to be either open or closed for longer periods of time than sites in an area where managers are attempting to disperse use. Consequently, they become more highly impacted after periods of use. A rest-rotation strategy could be applied in a number of recreational situations but is most important in campsite management. Temporary campsite closures have been used in both developed and backcountry campsite situations.

The critical factor in assessing the appropriateness of rest-rotation is the relationship between the length of recovery periods and the period of time it takes for impact to occur. If recovery takes much longer than deterioration, a rest-rotation system will require either that there be many closed sites for each open site or that the capacity of the area to serve normal visitor loads be reduced.

As described earlier, deterioration of a campsite often occurs within the first few years after the site is opened to use. This has been demonstrated on wilderness campsites in the Boundary Waters Canoe Area (Merriam, Smith, Miller, Huang, Tappeiner, Goeckermann, Blomendal, and Costello 1973), on canoe-accessed sites in Delaware Water Gap National Recreation Area (Marion and Cole 1996), and on car camping sites in Pennsylvania (LaPage 1967). In these cases impact increased dramatically for a year or two and then tended to level off.

Although a two-year deterioration period may be relatively standard on sites that receive at least a moderate level of use, recovery periods are much more variable. Recovery rates vary greatly in response to such factors as length of the growing season and moisture regime. Around a backcountry lake in Kings Canyon National Park, Parsons and DeBenedetti (1979) found that soil compaction had returned to pre-use levels within 15 years after closure; however, quantities of organic matter were still low, and ground cover vegetation was still disturbed. In an oak stand in Minnesota, soil recovered from compaction in just under a decade (Thorud and Frissell 1976). At Delaware Water Gap, most evidence of campsite impact disappeared in six years (Marion and Cole 1996). However, even in this unusually resilient environment, recovery still takes much longer than deterioration.

Difficulties with rest-rotation are most serious in wilderness areas where active revegetation is difficult and, many believe, not appropriate on a major scale. Moreover, recovery periods are often particularly long because of harsh growing conditions. The effectiveness of temporary closures was evaluated at Big Creek Lake in the Selway-Bitterroot Wilderness, Montana, where 7 of 15 campsites were temporarily closed to allow recovery. Eight years after closure, vegetation cover on closed sites was still only one-third of normal, and bare soil was exposed on 25 percent of the site compared with just 0.1 percent on controls (Cole and Ranz 1983). The most dramatic change over the eight-year period was the development and deterioration of 7 new campsites near the closed sites. Within eight years after their creation, vegetation loss and bare soil were as pronounced on these sites as on long-established sites in the area. The major effect of the temporary closure, then, was to increase the number of impacted sites. Recognizing this, area managers eventually reopened the closed sites and abandoned the idea of rotating sites.

In resilient environments, where active rehabilitation is feasible, rest-rotation may work. Legg, Farnham, and Miller (1980) demonstrated how over-winter closure of developed campsites in Texas, when aided by rototilling organic matter into the soil, allowed soil compaction levels to quickly return to normal. Even on resilient developed sites, it would be prudent to be cautious in attempting rotation. By experimentally closing and revegetating one site, recovery periods can be estimated. If recovery is sufficiently rapid, funding and manpower are available to do the revegetation, and the number of sites is sufficient to accommodate both open and closed sites, then rest-rotation might be worth implementing on a large scale.

Another reason for a temporary site closure is to avoid disturbance of animals during times when they are vulnerable. Examples include the closure of beaches when sea turtles are nesting and the temporary closure of trails where grizzly bears have been sighted so as to avoid encounters with humans.

INFLUENCING SPATIAL DISTRIBUTION OF USE

Site manipulation can be used both to influence the spatial distribution of visitor use and to increase the durability of the sites on which use occurs. Trails provide an excellent example of how site manipulation influences use patterns. People seldom venture off trails, so managers can control where most people go simply through careful consideration of where they build trails. Three primary means of affecting visitor use are manipulation of ease of access, development of facilities in some places and not in others, and design of concentrated-use sites, such that traffic flow is contained.

Ease of access is primarily related to the number, distribution, and condition of roads and trails. Roads can be closed to make roaded areas accessible only to nonmotorized users or to increase the difficulty of reaching some internal destination. Such an action is likely to reduce total use of the area and to shift the balance of types of use. This can be beneficial to wildlife and water quality, which will be less disturbed because of the shift away from motorized use. Internal destinations are likely to be less crowded and impacted because of reductions in use. The principal costs are borne by motorized users and those with less time to get to internal destinations. Neighboring areas may also be adversely affected if increased use causes increased impact. These costs can be minimized by providing alternative, attractive areas for displaced users—areas where increased use can be planned for and accommodated.

A somewhat less effective and drastic means of accomplishing the same thing is to not maintain or to reduce the quality of access roads. This may exclude legitimate users who lack vehicles capable of driving the roads, while permitting access to inappropriate users who visit the area primarily for the challenge of driving the rough roads. Such a program may also lead to resource damage problems, particularly erosion of the road surface and a reduction in water quality. Another alternative is to build new roads or to improve the quality of existing roads in areas into which management wants to divert use.

Trail systems can be manipulated toward the same ends. Building new trails and improving the quality of existing trails are likely to increase use, whereas closing or not maintaining trails is likely to decrease use. Type of use can be altered as well. Low levels of maintenance are likely to exclude use by stock and motorized vehicles. Pristine areas are more likely to remain that way if they are left trailless. Usually the effectiveness of such attempts to manipulate use distribution will be increased if combined with information about the distribution and condition of roads and trails.

Nonmaintenance of trails, which serves as a "psychological barrier" to use for certain visitors, is a common practice in some backcountry areas. Removal or nonreplacement of trail signs and log bridges across streams are also means of reducing use. When these practices are used by management, visitors should be made aware of them so they can plan their trips accordingly.

Trailhead facilities also affect ease of access and, therefore, visitor use. Developed boat ramps will attract motorboats, and removal of a ramp will decrease motorized use. Similarly, a ramp for unloading horses from stock trucks and trailers will increase horse use (Fig. 3). Providing a campground and overnight horse-holding facilities at a trailhead will increase use of that trail. Even the size of the parking lot provided will influence amount of use.

Development of facilities within a recreation area will also change use patterns. For example, building a horse camp at a lake is likely to attract more horse use to that area, particularly by novice users who are highly dependent on such facilities. Hikers who dislike contact with horse parties and who know of the facility are likely to avoid the area. In many cases—because some users are likely to be attracted, while others are repelled—development of facilities may have more effect on the type of use than on the total amount of use. The most common internal facilities for attracting use in backcountry areas are trails, huts and shelters, horse-holding facilities, and improved potable water supplies. In roaded areas interpretive facilities, developed

FIGURE 3. Provision of trailhead facilities for loading and unloading horses is likely to increase use by parties with horses. (*Photo*: R. C. Lucas.)

swimming beaches, and improved picnic areas and campsites are common attractions. Stocking a lake with fish and improving fish or wildlife habitat are also effective means of increasing particular types of use. Dismantling facilities or not stocking lakes can have the opposite effect. To effect a change it is important that the public be informed of the change. Word of mouth can be effective, but it may be desirable to advertise attractions, facilities, or management improvements.

Facilities can reduce resource damage in several other ways. They usually concentrate use, which, as we discussed in the last chapter, is desirable in many situations. Use concentration is most desirable where use levels are high, the usual case in situations where facilities are provided. The best examples are in camp and picnic areas. Tables and fireplaces concentrate the impact associated with preparing and eating food. Toilets concentrate human waste, and garbage cans, if provided, concentrate litter. Horse-holding facilities concentrate the impact of horses (Fig. 4). Facilities can also shield the resource from impact; we will discuss this in more detail later.

It is also important to design traffic flow on and between sites in such a way that as little area as possible is frequently trampled. This is particularly relevant to the design of developed multisite campgrounds. Impact occurs wherever people walk between sleeping areas, eating areas, water sources, toilets, garbage cans, and attractions. Total impact is closely related to the proportion of the area that is frequently walked on. This proportion can be minimized through the use of barriers and signs and by manipulating the attractiveness and location of trails and other facilities provided. People tend to take the shortest path between facilities, although this is influenced by visibility,

FIGURE 4. Hitching rails confine pack stock trampling to a small area and avoid damage resulting from tying stock to trees. (*Photo*: D. N. Cole.)

signing, ease of travel, and attractiveness. Routes between facilities will tend to be used if they meet these criteria; impact will be minimized if the location of facilities and attractions channels use along as few routes as possible. For this reason, Leonard, Spencer, and Plumley (1981) advocate a linear arrangement of facilities in densely forested backcountry areas in the Northeast (Fig. 5).

If shortcuts develop between facilities, it is often best to try to incorporate these into the existing trail system (McEwen and Tocher 1976). Sometimes this is unacceptable, and the manager must turn to barriers or signs, more obtrusive means of management.

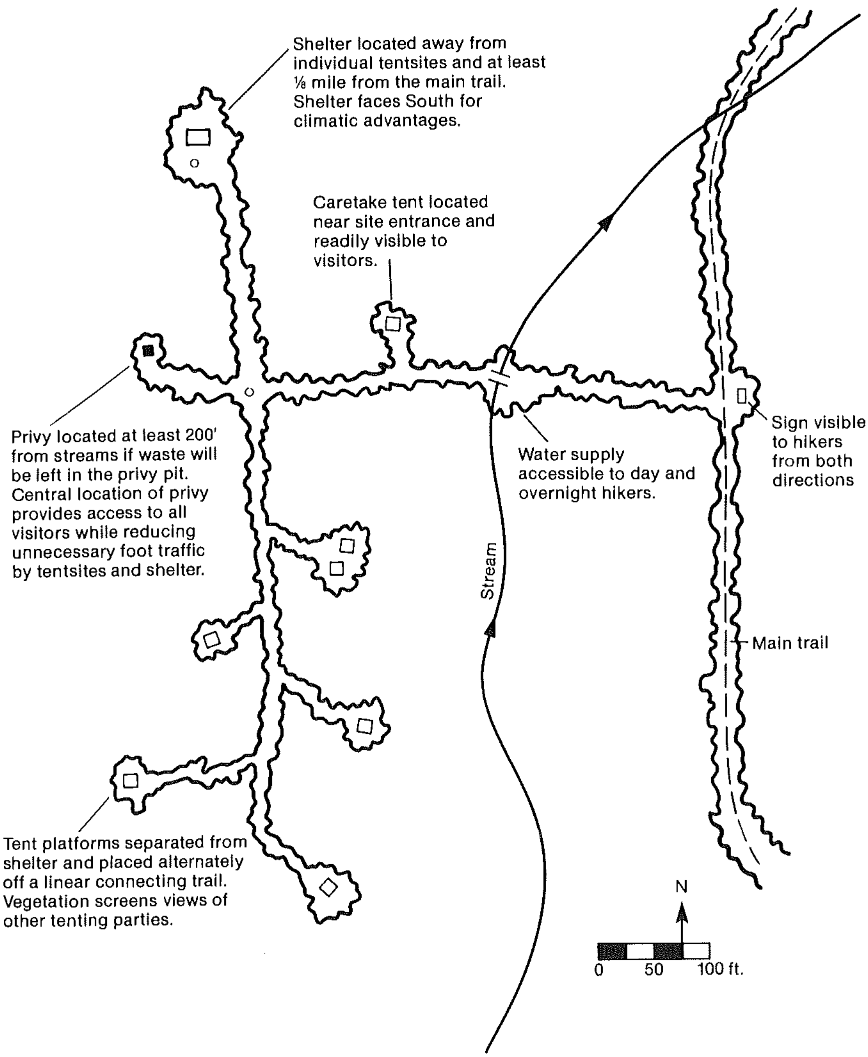

FIGURE 5. A linear layout of overnight facilities that concentrates traffic flow and impact but separates and disperses visitor groups. (*Source*: Leonard, Spencer, and Plumley 1981.)

Barriers range from the undesirable extreme of barbed wire fencing to earthen barriers to unobtrusive plantings of shrubs and trees. Signs such as "Please stay on the path" are another less than desirable option. This is another area in which effectiveness and obtrusiveness must be balanced.

Bayfield and Bathe (1982) evaluated the effectiveness of six techniques for closing undesired paths in a woodland in Scotland: rope, barbed wire, and plank barriers; arrows, logs, and brushwood. The plan barrier also included a notice, "Path closed for restoration." The plank with notice was most effective, deterring about 90 percent of visitors. The logs and brushwood kept only about 50 percent of visitors off the paths. At Mount Rainier National Park, in Washington, Swearingen and Johnson (1995) found that signs were effective in reducing the frequency of off-trail traffic on sensitive subalpine meadows and that the most effective sign was one that carried the threat of a fine. Moreover, they found that visitors were particularly likely to stay on trails when a uniformed employee was present, even when those employees were not enforcing regulations.

Trail impact can also be reduced by confining use distribution. The most common problems are shortcutting switchbacks and trail widening, leading to development of either a continuous wide bare area or a system of multiple trails. The key to avoiding such problems is to make staying on the trail the easiest alternative for the hiker. Switchback cutting can be minimized by keeping them few in number and out of sight of each other, utilizing wide turns where possible, and building barriers between the upper and lower legs of the switchback. These considerations must be balanced with a concern for proper trail drainage, as discussed in the following section.

Wide trails occur where the trail tread is rough relative to the adjacent land. These conditions cause the hiker to walk off the trail, widening it. Widening is also a problem with horse use on side hills. Horses tend to walk on the downhill side of the trail, which breaks down this outer edge and widens the trail. Trail roughness can be reduced by removing rocks or surfacing the trail. Alternatively, the roughness of adjacent land can be increased by piling rocks along the trail. Piling rocks on the outside of wide trails caused by heavy horse use is a common use of this technique. Douchette and Kimball (1990) report on the effectiveness of low rock walls built to confine traffic along a ridgetop trail through fragile alpine habitat in New Hampshire. Twelve years after wall construction, mean path width had decreased from 3.6 m to 2.1 m. Although there was an initial outcry about the visual intrusion of the walls on the beauty of the alpine area, 81 percent of visitors, 12 years later, found them to be unobtrusive.

SITE HARDENING AND SHIELDING

Engineering—after proper location—is the major defense managers have against deterioration of trails. Although excessive engineering is to be avoided, particularly in more primitive recreation areas, engineering solutions are often necessary and appropriate. After all, trails are a largely artificial, visually obvious addition to the landscape—a flat, barren, compacted strip through the environment. Most visitors do not mind the artificiality; they accept it as the price for increased accessibility.

The problems that most commonly require engineering solutions are trail erosion and damage to areas that are wet or poorly drained. The two simplest, least costly, and lowest-maintenance techniques for erosion control are outsloping of the trail tread and incorporation of drainage dips. Outsloping involves building the trail so that the outer edge is lower than the inner edge. This causes water to drain off the trail. Drainage dips are short sections of trail built with a grade opposite to the prevailing grade of the trail. If a trail is climbing uphill, for example, short sections of down-grade provide periodic interruptions of what would be a continuous down-trail channel. Coarse material at the low point of dips helps prevent erosion there.

Two other tools for controlling erosion are water bars and steps (Birkby 1996). Both should be part of the original trail construction design; they will be much less effective once substantial amounts of erosion have occurred. Water bars, made of wood or stone, are oriented at an angle to the slope and trail and divert water off the tread (Fig. 6). Steps are oriented perpendicular to the slope; they slow water down and hold soil. Both are placed closer together and become more important with increases in slope, the amount of water on the tread, and soil instability.

Water bars are particularly important close to the top of slopes where water can be diverted before picking up momentum. It is important that they be oriented at the proper angle to the trail—usually 20 to 40 degrees. A steeper angle encourages erosion; a shallower angle leads to excessive sedimentation behind the bar. The appropriate angle increases as trail grade increases (Birkby 1996).

It is important to be concerned with what happens to the water after it is diverted off the tread. Sometimes a ditch is needed to handle the diverted water. Where drop-offs adjacent to the trail are steep, rocks may help dissipate the energy of the falling, diverted water. This will help avoid gully erosion and undercutting of the trail. Frequent maintenance is required to keep water bars from filling in with sediment and becoming highly erosive little waterfalls. Disturbed bars (horses, particularly, have a habit of dislodging them) and rotted wooden bars need to be replaced periodically.

Not allowing water to flow onto the trail is as important as diverting water off the trail. Water is particularly likely to flow onto the trail where it crosses small drainageways. In such places water should be kept off the trail with culverts under the trail or, if the drainage is very small, with rock-lined ditches across the trail. Even with culverts it is critical to use a system large enough to handle floods. Where water seeps onto the trail in many places and the trail cannot be outsloped, it may be necessary to construct parallel ditches along the trail. If there is much gradient to the ditches, erosion may occur unless ditches are rock lined and have check dams or periodic side ditches to drain them.

Where erosion is particularly severe, primarily at off-road vehicle concentrated-use areas, it is important to control where eroded material is deposited. Otherwise, it will be carried into streams, where it reduces water quality and adversely affects fish populations. At off-road vehicle areas in California, debris basins have been built to trap sediment. Initially underengineered, many early sedimentation basins were washed out in floods. Proper engineering is critical if these basins are to remain functional.

Bridges, in addition to serving a visitor safety purpose, protect against erosion at stream crossings. They should be considered wherever a steep bank of erosive

FIGURE 6. Rock water bars divert water off this trail in Yosemite National Park. The rock steps in the foreground also reduce the potential for erosion. (*Photo*: D. N. Cole.)

material must be negotiated. Various types of bridging are the only means of avoiding serious resource damage where trails intercept springs or cross wet areas or areas with a high water table. Any trampling of water-saturated soil causes both churning and compaction of the soil. The end result is a quagmire that widens and lengthens over time.

If the wet area is neither too deep nor too long, it can be bridged with stepping stones. Three more elaborate options are to build turnpike, puncheon, or corduroy. Turnpiking involves building up the trail bed, using material from parallel ditches. The trail material is held in place with logs or rock (Fig. 7). The base of the trail should be above the water level in the ditches, and the trail material should provide

FIGURE 7. Turnpiking can be used to elevate sections of trail above surrounding wet areas. The trail surface is sand held in place by log stringers. Culverts allow water to pass beneath the trail. (*Photo*: D. N. Cole.)

reasonably good drainage. It may be necessary to import gravel or some other well-drained material to build up the trail. Where drainage problems are more severe, puncheon can be used to elevate the trail above the wet area without disrupting drainage. Puncheon consists of a decking of logs or timbers set on log or timber stringers along the side. It is important to maintain good drainage under the trail and to extend the stretch of puncheon into areas of good drainage at either end. Corduroy, the most common form of bridging in wildland areas, is merely a primitive form of puncheon construction. Native logs are laid perpendicular to log stringers. Drainage control is less elaborate. Corduroy deteriorates rapidly, must be replaced periodically, and can be dangerous.

Raised walkways have also been effective in reducing damage in a number of other sensitive environments. They are commonly used in coastal environments to allow visitors to move from parking areas to the beach without damaging intervening sand dunes (Carlson and Godfrey 1989). By elevating the walkway and leaving spaces between boards, room is left for sand accumulation and light can reach plants growing beneath the walkway. Walkways are also used to minimize damage from heavy traffic in fragile tundra environments, such as at Logan Pass in Glacier National Park, Montana.

Surfacing of trails may be necessary where use is very heavy, particularly where they are used by horses or motorized vehicles. It is also necessary where trails cross wet areas or rockslides. Gravel should be used on segments that cross wet areas or rockslides. On heavy-use trails other options include wood chips, soil cement, and, as a last resort, paving (Fig. 8). Trail durability can also be increased by using geosynthetic materials buried beneath soil or gravel. Particularly useful over wet and unstable soils, geosynthetics serve as a barrier between underlying mucky soils and the dry, coarse tread material laid on top of the geosynthetic material. They also add the tensile strength needed to support heavy loads (Hesselbarth and Vachowski 1996).

The major means of increasing the resource durability of camp and picnic areas are to surface areas that receive concentrated use and to construct facilities that shield the resource, such as tent pads, shelters, fire grates, and toilets. In heavy-use areas, it is possible to minimize compaction, improve drainage, and avoid the creation of muddy, wet areas by surfacing tent sites, eating areas, and trails between facilities with gravel or wood chips. This will also serve to concentrate use and avoid damage to intersite zones. Although such surfacing is generally inappropriate in wilderness

FIGURE 8. This motorcycle trail has been hardened in an inconspicuous manner with soil cement. (*Photo*: R. F. Washburne.)

areas, it is debatable whether surfaced areas are any less "natural" than barren, dusty, or muddy devegetated areas.

A more elaborate means of shielding the ground, used particularly in the eastern United States, is the construction of tent platforms and shelters. Tent platforms are flat wooden structures that elevate and separate tents from the ground surface. They can be portable or not and can be built to accommodate one or several tents (Leonard, Spencer, and Plumley 1981). A shelter can be created by placing a roof and sides on the platform. Shelters attract visitation; this results in more concentrated use and impact (Fig. 9). In Great Smoky Mountains National Park, shelters receive 37 percent of backcountry use; however, they account for only about 10 percent of the total area of campsite disturbance (Marion and Leung 1996). Overnight sites with developed facilities tend to be large and highly impacted, but properly designed facilities keep impacts to acceptable levels and the amount of impact per person is low because use and impact are concentrated on shielded sites.

At water-based recreation areas, it is important to surface boat ramps. This reduces erosion and also increases accessibility and public safety. The boat ramp in Fig. 10 allows rafters on Idaho's Middle Fork of the Salmon River to get their rafts down to the river without damaging the riverbank excessively.

Provision of fire grates is another means of concentrating impact and/or shielding the site. A fire pit on the ground concentrates impact at one point. This keeps campfire impact from spreading and disturbing a large area. Grates that are elevated also shield the ground from the impact of the fire. At Delaware Water Gap National

FIGURE 9. Backcountry shelters concentrate use and impacts, but if properly designed, lead to low amounts of impact per visitor night of use. (*Photo*: W. E. Hammitt.)

FIGURE 10. A boat ramp on Idaho's Middle Fork of the Salmon River reduces damage to the riverbank. (*Photo*: D. N. Cole.)

Recreation Area, managers reduced the total area of disturbance on canoe-accessed campsites by 50 percent in just five years (Marion 1995). The primary reason for this improvement was installation of a fire grate at each campsite. This provided a focal point for camping activities, allowing peripheral areas to recover.

A final facility that concentrates impact and shields the resource is the toilet. Toilets are standard in developed areas and have become increasingly common in heavily used parts of wilderness. Almost one-half of national parks use toilets in at least some places in the backcountry (Marion, Roggenbuck, and Manning 1993). Some toilet systems merely concentrate waste in pits. When the pit is full, it is covered over and a new pit is built elsewhere. In other systems waste is either removed from the site or treated and then redeposited in the vicinity. Waste can be either chemically treated or composted. Table 3 displays alternative waste disposal methods, their appropriateness at various sites, associated costs, and visitor acceptance.

TABLE 3. Methods for Disposing of Human Waste in Remote Recreation Areas

Method	Maintenance Requirements	Appropriate Uses	Costs and Visitor Acceptance	Comments
Cat hole. Each user digs a shallow hole and buries fecal matter. Waste decomposes before being leached through soil.	None.	Dispersed recreation areas that receive light use and have soil cover.	Visitor education and cleanup of improperly disposed waste. Visitor acceptance is good.	Few problems with this approach if use levels are low and visitors are educated. Problems increase with use.
Carry out. Waste is deposited in plastic bags, specially designed plastic tubes, or specially designed portable toilets. These containers are emptied outside the area.	Owners maintain containers, but disposal facilities require maintenance. Waste in plastic bags must be incinerated. Reusable containers can be disposed of in SCAT machines or trailer dumps.	Effective wherever visitors can be persuaded to comply. Has been highly successful on rivers and is being used on popular mountaineering routes.	Plastic bags can be incinerated for about $1/lb. SCAT machines and dump stations cost $20,000 to $100,000 to install and then $3000 to $5000/year to maintain. Acceptance is high on rivers, low elsewhere.	When this system works, it is ideal. Visitors "leave no trace." However, compliance can be difficult to obtain and specialized disposal facilities are required.
Pit toilet. Waste is deposited in a hole dug at least 5 ft deep, usually covered with toilet seat and a structure for privacy. When full, the pit is covered with dirt. Waste decomposes before leaching through soil.	Pit and structure have to be periodically moved. Toilet paper may be provided, and lime may be added to the pit to reduce odors.	Appropriate where use levels are moderate to low. Available sites may be limited by soil type and depth, surface water location, terrain, and groundwater depth.	Costs typically about $500 to $5000 for installation. Subsequent costs limited to periodically moving the pit and structure and toilet paper and lime, if provided. Visitor acceptance is fairly good.	Odors and flies are a problem. Sometimes there are not enough sites to relocate the toilet. Water contamination can occur if pits are improperly located. Otherwise, this system is effective and low cost.

(*continued*)

TABLE 3. (*Continued*)

Method	Maintenance Requirements	Appropriate Uses	Costs and Visitor Acceptance	Comments
Transportable privy. A toilet seat and structure are constructed over a removable drum or small fiberglass vault. The drum or vault is replaced when full and removed and emptied, generally by pack animal, helicopter, or vehicle.	Drums and vaults must be replaced when full. Containers may have to be stored and maintained. Waste must be dumped in sewage treatment facility.	As use levels increase, the frequency of replacement increases. This technique is most appropriate where sites for digging a pit are limited, water contamination potential is high, or use levels are high but frequent removal is possible.	Initial cost of a structure and drum or small vault is $500 to $5000, excluding labor. Removal costs can be high and are dependent on use levels and remoteness. Acceptance is high, although use of helicopters is controversial in wilderness.	On-site impacts are generally low. There are few limitations to where toilet can be located. However, maintenance costs are high and transport by helicopter or vehicles can be considered inappropriate.
Compost toilet. Waste decomposes in a digester tank into compost or humus. Waste is reduced, in volume and weight, by as much as 80%. It can be removed from the area or, in some cases, can be spread on the ground or used in reclamation projects.	Needs frequent maintenance. A carbon source, usually wood chips, must be mixed with feces, sometimes as frequently as twice a week. Finished compost must be removed periodically.	Appropriate where use levels exceed the capacities to use other waste management systems. But will be ineffective unless a commitment is made to provide adequate maintenance.	Commercial composting toilets cost $10,000 to $30,000 to install. A DC power source is needed, or power can be provided by photovoltaic panel, wind turbine generator, or thermoelectric generator. Less expensive passive composters are also available where use is low. Acceptance is high.	This technique is highly effective in high-use places, where frequent removal of material is difficult. The disadvantages are the high installation and maintenance costs.

Dehydrating toilet. Waste is deposited in a basket or tank where the liquid in fecal matter is evaporated. Weight and volume can be reduced 75%. When full, waste must be dug out and removed by pack animal, helicopter, or vehicle.	Commercial dehydrators have not met maintenance expectations. When modified appropriately, they may require weekly maintenance, primarily removal of waste. Dried sludge may be incinerated, buried, or disposed of in a sewage treatment facility.	Appropriate in a low-humidity climate. Certain commercial products require site modifications, and frequent maintenance is required. This technique can handle a high volume of use.	Typically costs $10,000 to $20,000 to install, as well as periodic maintenance and removal costs. Acceptance is high.	This technique is effective if the need to modify units on-site can be dealt with, if they can be maintained appropriately, and if the climate is appropriate.
Low-volume flush toilet. Waste is flushed down toilet into septic system, which must be pumped regularly. Effluent is disposed of in a leach field, sand mound, or constructed wetland. Water supply can be gravity fed or pumped.	System may require winterization. Pumps will require maintenance, and septic system needs pumping, with wastes removed to sewage treatment facility.	Appropriate in high-use areas, where plumbed systems are deemed acceptable.	Costs are likely to be $15,000 to $30,000. Maintenance costs are high, particularly where systems require winterization. Visitor acceptance is good, except in remote locations where plumbing is considered inappropriate.	Good system where considered appropriate and maintenance requirements can be met.

Source: Land 1995.

Outside of wilderness and other areas where preservation of natural conditions is paramount, durability of vegetation can be increased either by altering the vegetation composition in favor of more resistant species or by applying cultural treatments that make existing plants more resistant. Both are common practices in developed recreation areas and have a place in many wildland settings where use is at least moderately high.

An example of species replacement is planting turf grasses in a picnic ground to take the place of natives that have been eliminated by trampling. Generally, the only resistant plants available are (1) grasses, usually commercially available mixes of exotic species, or (2) shrubs and trees large enough to avoid being trampled. Thorny shrubs can be particularly useful. In the Grand Canyon, for example, expansion of backcountry campsites is being controlled by planting prickly pear cactus. The cactus establishes well from transplants and effectively discourages use of areas that are being rehabilitated. In deciding on which species to use, it is important to match species to local environmental conditions, particularly to amount of shade, soil fertility, and moisture. Trees should be long-lived, resistant to insects, diseases, and windthrow, and relatively small in size. It is also important to decide whether or not to encourage growth of exotic species. Exotics are often attractive, durable, and easy to establish; however, they frequently require more maintenance and are "unnatural."

The durability of vegetation can also be increased through use of various cultural treatments. Perhaps the simplest treatment is to thin the overstory. Numerous studies have documented a negative relationship between overstory canopy cover and ground cover vegetation impact. Generally, as shade decreases, vegetation cover increases and the amount of vegetation loss caused by recreational use decreases (Marion and Merriam 1985). Shade discourages the growth of grasses, which are almost always more resistant to impact than other plant types. Even within the same species, plants growing in a shady environment tend to be particularly flimsy as they spread out to capture sunlight. On campgrounds in the southern Appalachians, reducing canopy cover from 90 to 60 percent doubled grass cover; a further reduction to 30 percent cover tripled grass cover (Cordell, James, and Tyre 1974). Thinning trees, then, can increase both the quantity and hardiness of the ground cover. Thinning can also increase the vigor of the remaining overstory trees, improve wildlife habitat, and enhance esthetics and recreational opportunities. It is important, however, to maintain adequate screening between sites and not to increase susceptibility to windthrow.

Other treatments include irrigation and fertilization. These two treatments are likely to be particularly important in trying to maintain a sod of exotic grasses in a dry climate. In an area with a wet climate watering may not be necessary.

The importance of fertilization varies with soil conditions. Where trace elements are limited, their inclusion in soil amendments can lead to spectacular increases in growth. It is always worth investing in soil testing to identify any nutritional deficiencies. Even in soils without known deficiencies, exotic grasses usually respond well to additions of complete nitrogen-phosphorus-potassium fertilizers.

The pH of soil is also important. Native plants in coniferous forests grow best in moderately acidic soils (pH about 5.0), whereas exotic grasses prefer a neutral pH. Coniferous soils are likely to need liming to reduce acidity if conversion to grasses is desired. Where naturally acidic coniferous soils are neutralized by recreation use—remember that campfires tend to increase pH—an amendment like peat moss will promote growth of acid-living native species.

Either flood or aerial irrigation can be used to water plants (Jubenville and Twight 1993). With flood irrigation, water is diverted by ditch systems to the recreation area, where it is spread out across the ground. The developed campgrounds in the bottom of the Grand Canyon utilize flood irrigation to maintain cottonwood trees and some brushy screening between sites. Aerial irrigation can be used more flexibly. Either portable above-ground sprinklers or a buried underground system can be used. Either system is costly. A buried irrigation system used at a developed campground in Idaho cost almost $100 per unit per year in the late 1960s (Beardsley, Herrington, and Wagar 1974); this would be more than $400 per unit per year in the 1990s—a cost of $1.00 per visitor-day of use. Another problem with irrigation is related to the susceptibility of soil to compaction when it is wet. Watering should occur after, not before, periods of heavy use. If feasible, it may be best to close the campground or portions of the campground (loops) one day per week for watering.

Despite these problems, the value of irrigation and fertilization was illustrated in an experimental renovation and maintenance program conducted on the previously mentioned campground in Idaho (Beardsley, Herrington, and Wagar 1974). Large devegetated campsites were all seeded yearly with a mixture of exotic grasses. On some sites this seeding was the only treatment applied. Other sites were also either fertilized once a year, watered once a week—at a rate three times the normal summer rainfall—or both. Vegetation cover was monitored over a four-year period. As you can see from Fig. 11, seeding, by itself, resulted in little improvement in vegetation cover. This is not surprising, because exotic grasses are poorly adapted to a coniferous forest environment. Both watering and fertilization, by themselves, caused pronounced increases in cover, but the combination of the two was twice as effective as either one by itself.

Similar results were found in a campground in an aspen grove in Utah (Beardsley and Wagar 1971). Watering and fertilization, together, caused the greatest increase in ground cover. Fertilization, by itself, was less effective than watering, and fertilization without seeding or watering was no more effective than doing nothing at all. An interesting result of this study was that while these treatments did increase ground cover under aspen, similar treatments under a dense coniferous overstory had little effect. Without thinning and, perhaps, some removal of organic horizons, it is unlikely that any treatments can establish much vegetation under a dense coniferous overstory.

In England, fertilization was effective in reducing bare ground within trampled vegetation, still in use, by as much as 80 percent (Bayfield and Aitken 1992). However, some neighboring vegetation types experienced only modest improvements following fertilization and some types experienced no benefit at all.

A final conclusion derived from these evaluations of cultural treatments is that they will be effective only when combined with careful site design and surfacing of concentrated-use areas. As discussed earlier in this chapter, good design channels traffic along paths and roads and minimizes the area that is frequently trampled. Areas used so heavily that vegetation and organic horizons are entirely eliminated

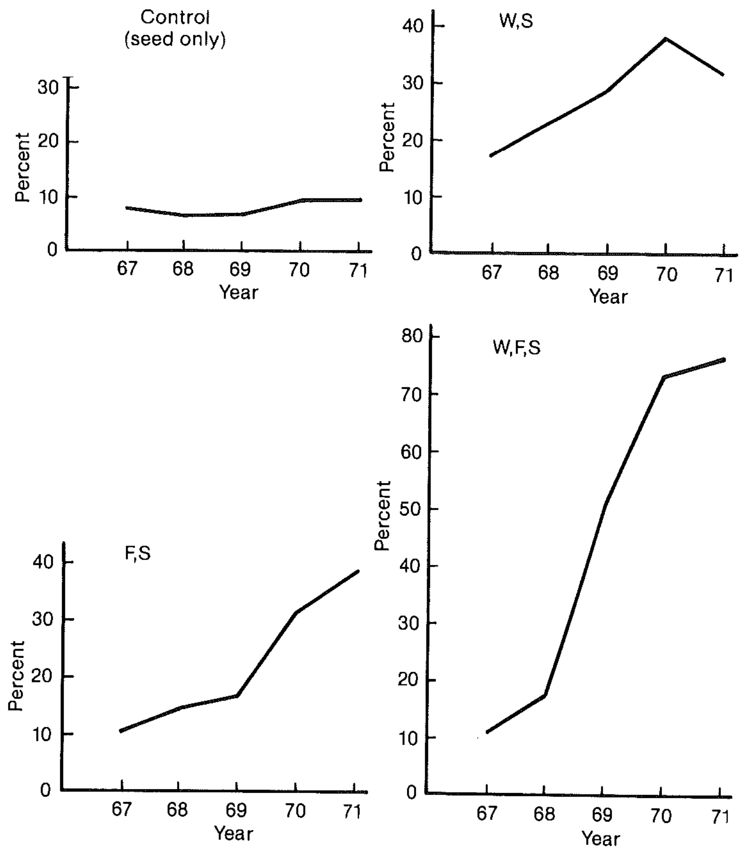

FIGURE 11. Percentage of available growing space on campsites covered by ground vegetation after various combinations of watering (W), fertilizing (F), and seeding (S). Treatments were initiated in 1967 and continued for 4 years. Data are from Point Campground in Idaho. (*Source*: Beardsley, Herrington, and Wagar 1974.)

should be surfaced to promote drainage, reduce compaction, and minimize problems with dust and mud.

In some situations site durability can also be increased by improving soil conditions, particularly by relieving soil compaction and increasing the organic content of soils. At a campground in Texas, Legg, Farnham, and Miller (1980) experimented with various means of relieving soil compaction without closing the entire campground. They experimented with various lengths and seasons of closure, with rototilling, and with incorporating wood chips and grass seed into the soil. Rototilling proved to be detrimental if it was done without closure or incorporation of wood chips into the soil. Rototilling destroyed soil structure, and this apparently prevented the over-winter recovery that usually occurs in these soils. Merely closing campsites during winter to promote over-winter recovery allowed compaction levels to return to near normal. Incorporation of wood chips into the soil greatly reduced bulk density, and the seeding of grasses resulted in less erosion during winter. The authors conclude that, at least in this area, rest-rotation of campsites is feasible, particularly if organic matter is incorporated into the soil. Where organic matter is added to soil, the populations of soil microorganisms that decompose this material can increase. These organisms may tie up much of the available nitrogen in the soil and deprive plants of nitrogen. It may be necessary to compensate for this by adding high-nitrogen fertilizer, along with organic amendments.

Surface application of wood chips—mulching—was effective in encouraging plant growth on closed day-use picnic areas in four Maryland state parks (Little and Mohr 1979). Surface application promotes moisture retention and inhibits surface runoff. The authors believed that scarification, breaking up the soil with rototillers or hand tools, can cause problems in forested areas because it can disturb tree roots. Moreover, in their study, scarification did not increase vegetation growth. Their primary suggestions for rehabilitation were to confine use to hardened parts of the site and to mulch little-used parts of the area.

REHABILITATION OF CLOSED SITES

In some situations there is no option but to permanently close and rehabilitate recreation sites. Common reasons for such an action include excessive site damage that cannot be controlled with continued use, a decision to relocate the facility on a more durable or desirable site, and rehabilitation of previous damage that is unlikely to occur in the future because of a change in either type of use or management. Many of the cultural treatments we have been discussing—watering, fertilizing, seeding, mulching, and so on—can also be used to rehabilitate closed sites. Some are not appropriate; replacing native vegetation with exotic, trampling-resistant species or thinning the overstory to encourage grasses makes little sense if use of the site is to be curtailed. Other techniques, particularly eliminating all use on the site, become even more important.

Rehabilitation of camp or picnic sites and trails is most common. Other recreation sites that may require rehabilitation work are overgrazed meadows and off-road vehicle areas. Although a considerable amount of rehabilitation work has been done, little of it has been documented. Most experience in site rehabilitation comes from revegetation of mines and rangelands.

Regardless of the facility being rehabilitated, five basic steps are required:

1. *Eliminate use*. Some effective means must be devised for keeping visitors off closed sites. Particularly in fragile areas, even infrequent use can destroy the fruits of years of work. Providing attractive alternative use areas is of critical importance. Channeling use away from the area, using either attractions or barriers, may also be helpful. A sign to a viewpoint, away from the closed area, may be effective. Use of branches and brush to block a trail may keep people from using it. "Planting" rocks or logs on a site will discourage overnight use but may not curtail day use. Signs or other information

about the closure, reasons for the closure, and the location of replacement facilities may be necessary (Fig. 12). Where closed areas are intermixed with open areas, it may be necessary to delineate closed areas with some sort of fencing to prevent use. The fencing material can vary from string to stouter materials, such as lumber.

Keeping users off closed sites can be a particularly serious problem in wilderness areas, where management strives to be as inobtrusive as possible. Because even people walking across a site to go fishing can destroy rehabilitation work, there may be no alternative to obtrusive fencing until substantial recovery occurs. Information about the location of and reasons for rehabilitation programs will increase compliance because visitors know what to expect and why and how to comply. Research indicates that wilderness visitors support even obtrusive site management techniques—signs, barriers, and plantings—where needed to reduce impacts (Cole, Watson, Hall, and Spildie 1997).

2. *Control drainage and erosion on the site.* On camp and picnic areas it is important to keep drainageways from flooding the site; some sort of mulch may also be needed to control sheet erosion on the site. Control of gully erosion on trails is more difficult. The techniques for minimizing erosion of used trails, described in the preceding section, are all appropriate. On closed trails check dams, built across the trail, can be used to reduce erosion and encourage sedimentation behind the dams. Mulching can also be useful.

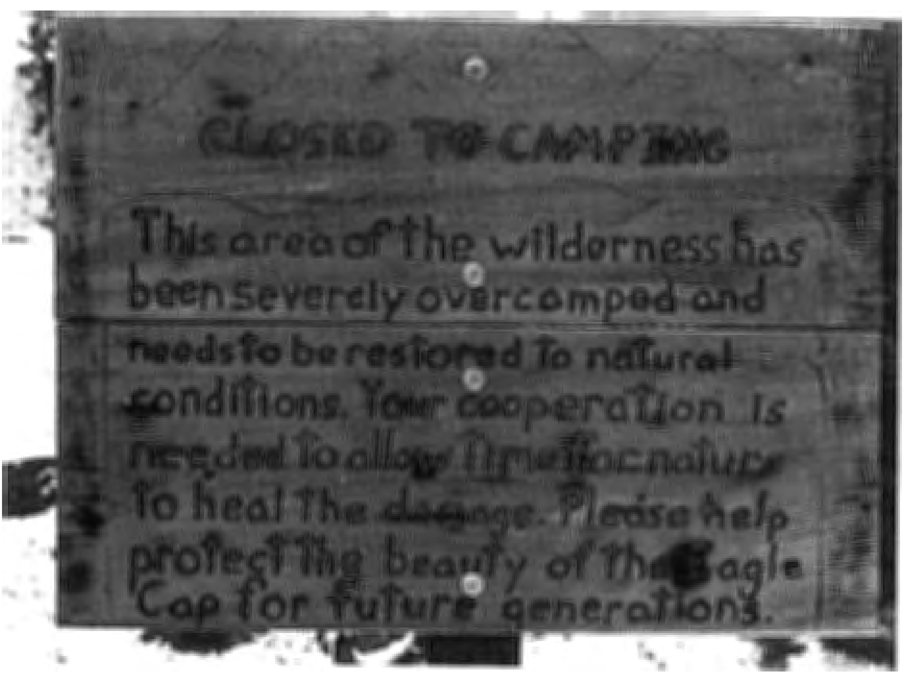

FIGURE 12. Sign used to keep visitors off a campsite in the Eagle Cap Wilderness, Oregon, while the site was being rehabilitated. (*Photo*: D. N. Cole.)

3. *Prepare the soil.* The nature of soil preparation is highly variable; it ranges from doing almost nothing on lightly disturbed backcountry sites to extensive grading and importing soil in severely eroded off-road vehicle areas. The principal objectives of this step are to reduce soil compaction and to improve the organic matter content, fertility, moisture content, and biotic integrity of the soil. Exactly what treatments are needed will depend on characteristics of both the undisturbed and the damaged soil, as well as the nature of the vegetation to be reestablished. Soil scarification, breaking up compacted soil, is usually critical for both seed germination and root and plant growth. The soil is broken into large clods with shovel, pick, or rototiller, and then these clods are broken down into individual soil crumbs by hand or rake (Rochefort 1990). All compacted soils should be scarified, although one should be careful to minimize destruction of roots and plant parts that are capable of vegetatively reproducing. Also, as Legg, Farnham, and Miller (1980) found, scarification may be of little value unless organic matter is either incorporated into or spread on top of the soil. Addition of organic matter is probably effective in minimizing the tendency of soils to be compacted by rainfall and other natural forces.

The value of adding organic matter to the soil and the best type to add depends on soil pH and the optimum pH for the vegetation to be reestablished. Peat moss and coniferous duff promote acidity, whereas steer manure is good for basic soils (Schreiner and Moorhead 1981). Liming can also reduce the acidity of soils. Rotting logs can be planted to provide ongoing sources of organic matter and shelter for plantings. It is important to replenish large woody debris on sites where it has been entirely removed, because such debris plays a critical role in the functioning of many ecosystems (see Chapter 2). Where substantial quantities of organic matter are added, it may also be necessary to add nitrogen to the soil. Soil nitrogen is likely to be depleted by the increased number of microorganisms that are involved in breaking down the supplemental organic matter.

Soil biota, including mycorrhizal fungi, are critical to the health of soil because they often form symbiotic relationships with plants. When plants have been eliminated from a site for years, many of these organisms disappear. Reintroducing plants will not automatically bring these organisms back, but many plants will not grow well as long as they are absent. Often microbes can simply be reintroduced by mixing some "native" soil, from adjacent undisturbed areas, onto the scarified soils.

Fertilization is important where exotic plants are being established. As this is less common on permanently closed sites, fertilization may be less important than in places where recreational use continues. Fertilization appears to be more critical to the establishment of vegetation from seeds than from transplants. Fertilization is often of little value if not accompanied by watering (Beardsley and Wagar 1971). Generally, fertilizers should be used cautiously, particularly in wilderness, where their use tends to favor exotic species and can contribute to eutrophication of nearby waters. Information on desirable soil preparations can often be obtained from university extension services provided by land grant colleges, the federal Soil Conservation Service, state soil testing labs or departments of conservation, and local planning offices.

4. *Plant the site.* Under certain favorable circumstances, natural revegetation may occur rapidly without much assistance. This is most likely at low elevations, where growing seasons are long, on productive soils, and in places that receive abundant but not excessive light and moisture. Elsewhere, rehabilitation will have to be assisted either by transplanting nursery-grown plants or plants from neighboring areas or by seeding. This step involves deciding which species to use, preparing propagules for planting, and then doing the actual planting.

In deciding which species to use, the most important consideration is whether or not the species is adapted to the site. As noted before, it is difficult to grow grass in heavy shade or on acidic soils. Similarly, it is difficult to grow forest-floor species in a meadow. With native species it is best to use plants from local and similar environments. Sometimes even the same species from a distant location or elevational zone is poorly adapted, genetically, to the site. Species that successfully colonize neighboring naturally disturbed areas are particularly good choices for revegetating disturbed areas. Resistant species, including exotics, may be desirable in places where it may be difficult to avoid consistent ongoing use.

Seeding is a cost-effective means of assisting the natural revegetation processes on many sites. Generally, it involves spreading seed over the loosened soil surface—by hand, with a hand-held seed spreader, or with a hydromulch machine. Then the seeds are lightly raked into the soil and tamped down to ensure good contact between the seed and the soil. The best time to plant seed varies from place to place and can be critical to success. In the mountainous national parks of the Pacific Northwest, for example, it is best to sow seed in the late fall. This is optimum for breaking seed dormancy and for ensuring germination early in the short growing season.

Finally, it is usually helpful to cover the ground surface with a mulch to protect the seed from predators and erosion and to improve seed germination. Either commercial or native mulches can be used. Commercial mulch mats come in rolls that can be laid over seeded ground and anchored with rocks and woody debris. These consist of a mulch fiber (usually paper, excelsior, straw, or coconut) held together by a photodegradable netting (Rochefort 1990). Ideally, both the mulch material and netting decompose and disappear after two to five years. Native mulch consists of any plant material (litter, duff, or plant parts) that can provide protection to underlying seeds. Native mulches are less costly and visually obtrusive than commercial mulch mats; they also contribute organic matter and sometimes viable seed. However, they are not as effective a deterrent to recreation use, may be more difficult to anchor in place, may be less effective in protecting against erosion, and may not be available in the quantities needed.

Seed can sometimes be obtained commercially but usually must be collected locally. Seed mixes of exotic species are readily available; however, they are inappropriate for many wildland applications. The availability of commercial native seed mixes is increasing, but these mixes are costly and not available for the entire range of ecosystem types that need restoring. When collecting locally, seed should be taken from places that are quite similar and close to the place being restored. Seed must be ripe. If it is loose, it can be collected with a butterfly net, a battery-operated vacuum, or simply shaken onto a cloth around the base of the plant (Birkby 1996). Seed should be collected from many different plants to maintain genetic diversity. Once collected, seed can either be sown immediately or transported and stored. If stored, it should be cleaned. This involves separating the seed from the chaff by shaking, blowing, or sieving the seeds through a strainer. Seed should be carefully labeled and stored in a cool, airtight container until ready to be sown (Birkby 1996).

In many favorable environments, seeding works well. High germination rates, for many different species, occur virtually every year. Frequent rain during the season when germination and establishment are occurring appears to be a key to seeding success. In other environments, successful reproduction from seed is a rare event. This is the case, for example, in many high elevation environments, where most recolonization of natural disturbances is by vegetative spread rather than seed germination and establishment. Particularly in these places, transplanting may be the only practical means of rapidly revegetating a site.

Transplanting involves taking an established plant and placing it in a hole dug out several inches wider and deeper than the root ball of the plant. The top of the root ball is placed slightly below the ground surface so that water can collect in a slight depression around the plant (Rochefort 1990). Soil is added to the hole and packed down tightly. If this soil comes from a local native source, it can serve to inoculate the soil with desirable microbes. The plant is watered with a mixture of water and vitamin B-1 to reduce transplant shock. Finally, the planting is often covered with mulch.

The difficulty in transplanting is obtaining a source of transplants. Options include digging up plants in the neighboring area or growing transplants in nurseries—from collected seed, cuttings, or by division of plants capable of reproducing from underground stems or rhizomes—and then transporting these plants to the site. Transplanting with native vegetation is easiest but creates the problem of disturbing the donor sites from which the plants are taken. Plants should be taken from a large area and only from places with a fairly dense vegetation cover. Clearly, this technique will seldom be an effective way to revegetate large areas. It is critical to minimize damage to roots when digging the plants. Often it is better to move a section of turf than a number of individual plants. In general, transplanting success is greatest with grasses, sedges, mat-forming plants, and plants with runners (Birkby 1996). Ideally, plants should be moved when they are dormant and when the weather is cool and cloudy. After being dug up, they should be transplanted as rapidly as possible, and any damage to the donor site should be repaired. Clusters of plants should be placed in a random rather than regular pattern to mimic natural growth.

Whether grown from seed, cuttings, or root divisions, greenhouse plants have to be hardened off (subjected to the rigors of living outdoors) before being transported to the restoration site. Transportation can be costly, involving the use of helicopters, pack animals, or backpackers if they cannot be moved by vehicle. Plants must be kept moist during transport. Packing plants in wet burlap bags or plastic bags with damp moss can help (Birkby 1996). Once at the restoration site, greenhouse plants are less fragile and easier to plant than native plugs (Rochefort 1990). They can be dumped out of their containers and placed directly in the ground.

5. *Maintain the plantings.* Ongoing maintenance activities will vary from place to place. In some situations yearly fertilization and weekly watering are necessary; in

other situations little maintenance is required. "Please water me" signs can be a good means of getting help from visitors. All areas will profit from careful documentation of the rehabilitation techniques that were used, as well as monitoring of how successful the effort was. Photographs and counts of plants can help in evaluating success. Before launching into a full-scale program, experimentation with different species, types of soil preparations, and planting techniques will save much time and money in the long run.

Even with all this effort, revegetation can be an exceedingly slow process. In many cases transplant survival has been high, but growth and spread have been slow. Transplants on road cuts in the alpine zone of Rocky Mountain National Park were surviving after 40 years, but they had not spread significantly (Stevens 1979). Similar slow growth and spread are common wherever the climate is severe and growing seasons are short (Fig. 13). Three years after being planted on closed campsites at subalpine lakes in Yosemite National Park, only 19 percent of the transplants were alive and total vegetation cover had increased by less than 1 percent (Moritsch and Muir 1993). This emphasizes the need to avoid damage rather than plan to fix it after it occurs.

Somewhat different techniques may be needed to rehabilitate trails, primarily because erosion is more of a problem on trails. Once erosion problems are solved, however, trail restoration is often more successful than camp or picnic area restoration.

FIGURE 13. These transplants on a campsite in the Eagle Cap Wilderness, Oregon, have survived for five years, but they have not spread. (*Photo*: D. N. Cole.)

This success may reflect the narrowness of the disturbed area. As a result, vegetation can rapidly recolonize old trails—either from seed or by vegetative spread. The keys to success are controlling erosion and filling the trail tread with soil to the level of the surrounding topography.

Palmer (1979) experimented with various means of rehabilitating multiple trails in Tuolumne Meadows, Yosemite National Park, California. The most successful technique involved cutting off the sod ridges between multiple trails at the level of the trail tread and stacking the sod in the shade. The soil beneath both the trails and the ridges was spaded up to eliminate compaction, and sand was added to bring the whole area up to the level of the surrounding meadow. Finally, the vegetation from the sod ridges was divided into transplant plugs and planted in the soil. Utilizing this technique, trail scarring was less obvious and transplants were spreading within several years. This technique has proven successful in eliminating almost all evidence of many old trails.

A final example of restoration is the rehabilitation of meadows in Sequoia and Kings Canyon National Parks, California. These meadows had been severely disturbed by a history of overgrazing by both recreational and domestic livestock. This use led to loss of vegetation cover and shifts in species composition that favored unpalatable and weedy species. The most serious problem was accelerated erosion. Destruction of sod and trampling of streambanks increased erosion. Increased downcutting by streams lowered water tables, drying out meadows. This allowed lodgepole pine seedlings to germinate and become established in meadows. Many meadows were shrinking dramatically as this invasion of trees progressed. Meadow rehabilitation involved both visitor and site management. The amount, distribution, and timing of stock use was controlled. In addition, erosion was controlled by building check dams, grading stream banks, and planting banks with willow cuttings (DeBenedetti and Parsons 1979).

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