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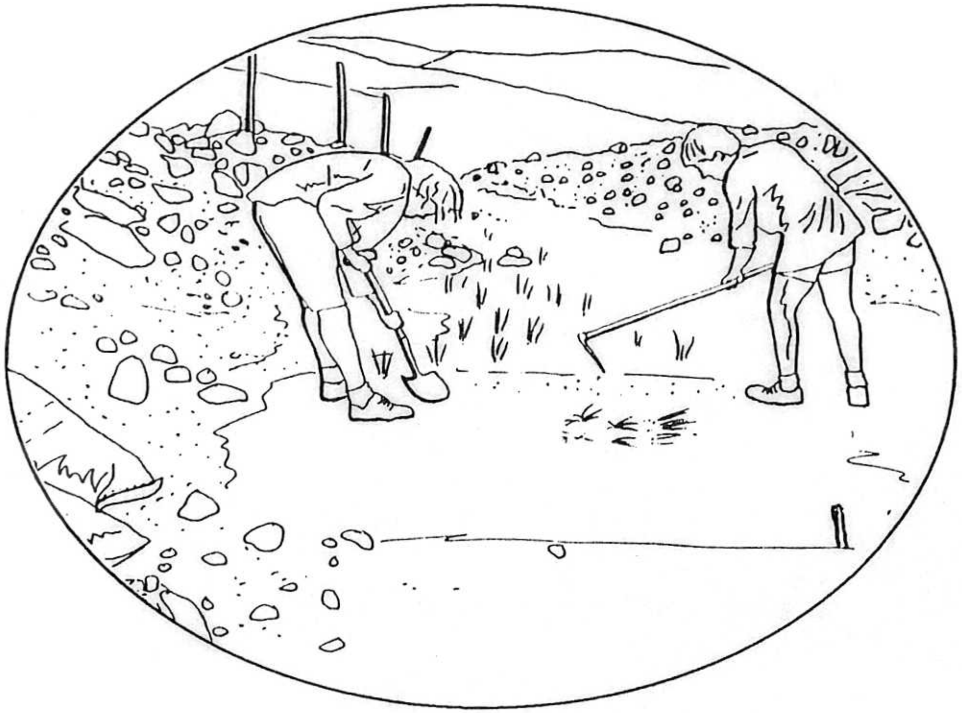

MANAGING THE IMPACTS OF RECREATION ON VEGETATION AND SOILS:

A Review of Techniques

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Graphics by G M McGowan

Natural Environment Research Council

Frontispiece: Preparing revegetation trials on Cairn Gorm at 1000m.

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MANAGING THE IMPACTS OF RECREATION ON VEGETATION AND SOILS: A REVIEW OF TECHNIQUES

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Part 1: BACKGROUND

1. INTRODUCTION

1.1 About this report

This study is a review of techniques available to manage the impacts of recreation on soils and vegetation. The information has been collected from written sources, and from discussions with practitioners, researchers and suppliers of materials.

Specific aims are to:

* outline the problems of deterioration at recreation access sites;

* describe the main types of techniques currently available and under development, and the situations where they may be appropriate;

* discuss the practical constraints on implementation;

* identify information gaps that might be filled by research and develop ment, or by improved monitoring or communication procedures.

The main emphasis is on countryside recreation sites in the United Kingdom. Examples of techniques or approaches from elsewhere are, however, included where these appear relevent to management in this country.

1.2 Selecting techniques

For straightforward problems the selection of an appropriate technique may be easy; one problem, one solution. For complex problems a more structured approach may be required (Figure1.1):

(1) The management problems need to be identified, and it is good practice to place them in the context of a site evaluation (of levels of use, and site resources.). This helps clarify the issues, although it also tends to reveal others! This preliminary exercise is needed to justify expenditure of time or resources as well as helping in:

(2) selection of techniques and;

(3) implementation.

(4) Finally, the effectiveness of the approach adopted should be assessed.

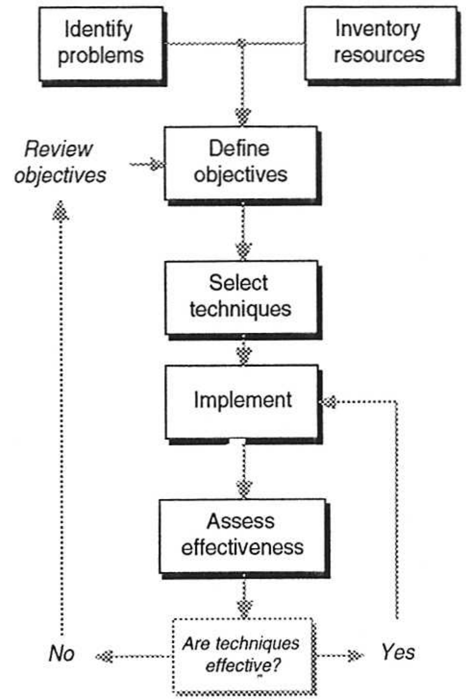


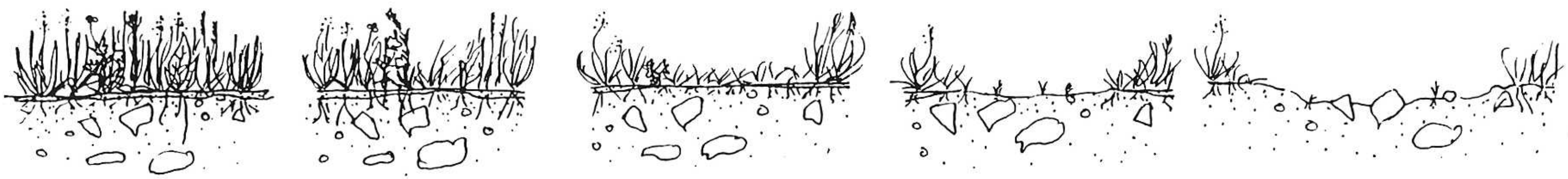
Figure 1.1 Choosing and implementing techniques

This last stage is important in order to make informed decisions about continuing with the current approach or changing to another. It can be used to justify further investment or to save the manager or others from wasting time and resources.

2. THE PROBLEMS

For nearly thirty years, recreation in the countryside has been encouraged by provision of long distance footpaths, car parks, picnic sites and by the development of new types of facility such as ski resorts. In hindsight the enthusiasm of countryside planners to make this provision has not generally been matched by funds for maintenance work, or by sufficiently rigorous control over siting, landscaping and management detail. At some types of site substantial damage to environmental resources has resulted. Symptoms include erosion of soil, damage to vegetation, proliferation of footpaths, disturbance of wildlife and visual intrusion. Taken together these features amount to a reduction in site integrity or intactness that may total more than the sum of individual impacts.

The severity of damage clearly varies a great deal in different situations; the impact of a worn mountain path is usually both physically and visually more serious than, for example, a path in a confined woodland setting. However, both the processes and sequence of deterioration are common to most recreational access areas. The following section outlines some of the principal changes



Use	Unused	Very light use	Light use	Moderate use	Heavy use
Vegetation impacts	None	Reduced height along route	Reduced species diversity Invasion by trample resistant species	Low plant cover on path, Few species. remaining	No vegetation on path Bare zone gets wider
Soil impacts		Slight soilcompaction	Comminution of plant litter. Moderate compaction	Loss of plant litter Severe compaction/ structural damage	Erosion of surface and exposure of subsoil

Figure 2.1 Damage to soils and vegetation with increasing use.

2.1 Erosion of soil and vegetation

Most recreational traffic is on foot. Access by bicycle, vehicle or horse can be more damaging and is discussed further in Section 3. All types of traffic result in a similar sequence of deterioration of unprotected soil and vegetation (Figure 2.1).

Very light use may only cause a slight decrease in total vegetation cover, although there may be increases in branching (Dan Sun & Liddle, in press) and a decline in the incidence of flowering. Damage sufficient to cause small patches of bare ground will, in many types of habitat, result in invasion by trample resistance species such as *Loluim perenne* and *Plantago major* (Speight 1973).

Heavier use can reduce or even eliminate plant cover, with only the most trample tolerant species surviving in gaps between stones or in similar places where direct wear is low.

Damage to soils can begin while vegetation cover is intact, with soil compaction and the accumulation of plant litter (Burden & Randerson1972). As loss of vegetation takes place, there is disruption and progressive loss of soil horizons by direct physical abrasion or loosening and indirectly by water and wind erosion.

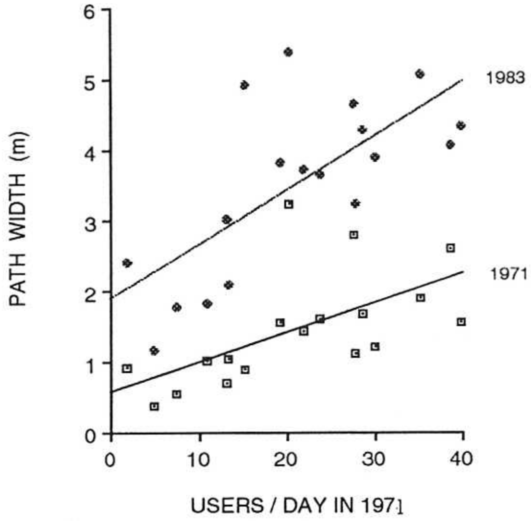


Figure 2.2 Path wear on the Pennine Way in 1971 and 1983 (Bayfield 1983)

In addition to physical changes in vegetation cover and in soil erosion resulting from recreational wear, there are effects such as reductions in the cover of orchids as a result of picking by tourists (Bratten 1985) and of dead wood for campsite fires (Bratten et al. 1979). Similarly there can be important changes in soil structure and chemistry resulting from compaction; in particular poor permeability to water can increase surface run-off, and reduced aeration can result in anaerobic conditions and poor root growth. Plant establishment is generally poor on compacted soils (Blom 1976).

Although examples of these types of changes can be seen at a wide range of heavily used recreational access areas ranging from bridleways to campsites they have been most studied on footpaths.

Much of the published information indicates that there have been progressive declines in the condition of footpaths, particularly in the uplands, and that in some places there has been a proliferation of routes. For example, observations on the Pennine Way in 1971 and 1983 (Bayfield 1985) showed that bare and trampled widths had about doubled over this period.

Similarly gloomy observations have been made elsewhere in Britain (see for example Watson 1991) and in many other parts of the world. An excellent review is provided by Cole (1985).

2.2 Visual impacts

Recreational access can be visually offensive in two quite different ways. Firstly,users can be intrusive to other users, particularly in so-called wilderness areas. This problem is more appreciated in North America, where very large tracts of unoccupied land held by the US Forest Service and National Parks Service are managed to keep the numbers of visitors to a prescribed level (Stankey & Schreyer 1985).

In Britain, there are few really remote areas, and complaints about numbers of people appear to be mainly confined to popular mountain routes and "honeypot" areas. Rationing of use to minimise inter-visitor types of impact is not considered to be within the remit of this review, although it is worth noting that habitats vary greatly in their capacity to "absorb" visitors, woodland having a high capacity and open mountains a low capacity.

It is also of note that there have been a number of moves in recent years to curtail the activities of some of the most contentious types of users such as mountain bikers, motor cyclists, cross country vehicles and even mass sponsored walkers.

The second way in which access can be regarded as intrusive is via associated artifacts such as paths, cairns, litter, campsites, snowholes, ski pylons and buildings. These features are more intrusive in some types of habitat than others, and are most visible on mountains, skylines and open ground. A good example of the intrusion of bulldozed hill roads in the Cairngorms is provided by the careful records of Watson (1984) which shows how dramatically the areas of remote ground have declined owing to the penetration of hill ground by vehicle tracks. Many such roads are classic examples of how not to site and build. A discussion on minimising the impacts of hill tracks is given in a report by the Countryside Commission for Scotland (1979) with emphasis on design, siting, and the use of sympathetic local construction .

Although artifacts are much less intrusive in ground with a high density of screening features such as sand dunes or trees, similar design principles apply as on exposed sites. There are still many examples of poor siting, bad design and use of inappropriate materials at recreation sites, in spite of the fairly ready availability of guidelines.

2.3 Implementation problems

There are many practical difficulties to the effective management of recreation sites. They include skill shortages, underfunding, management deficiencies, and logistical problems related to terrain and materials. A general complaint is the inadequate levels of funding for management of recreational access areas, even though in recent years quite large sums have been invested in, for example, the Three Peaks Project, National Trust footpaths in the Lake District and various Countryside Commission access projects.

Many such schemes still rely heavily on voluntary labour, and even the supervisory staff tend to be poorly paid and junior in grade. Overall there are frequent problems of skill shortages and of a lack of continuity due to poor career structures within this type of work. There is also a tendency for recreation access problems to have a low profile amongst professional planners, with such work having a fairly low budget and being managed by junior staff.

At some sites there are severe logistical problems in finding appropriate materials and delivering them to site cost effectively, and in some instances, the sheer magnitude of the task (as on some extensively damaged boggy moorland paths) is daunting.

Finally, there is a shortage of technical solutions to some problems such as revegetation of difficult sites, although there are also a number of solutions that are either not widely known, or have not yet been sufficiently tested.

2.4 Communication problems

2.4.1 Organisations

The problem of communication of ideas and experience in this field is not new. The Recreation Ecology Research Group (RERG) was formed in 1973 to discuss and disseminate information on this general theme, and operated successfully until about 1987, running useful workshops on a range of relevant topics, and publishing their proceedings. RERG fulfilled a particularly valuable role as a link between academic research and field managers.

The Countryside Recreation Research Advisory Group has held several workshops on different aspects of ground and footpath management. Following on from one of these, (on paths on soft ground at Settle in 1988), it was agreed to establish a newsletter for the inter-communication of experience in ground management, and particularly for the exchange of new technical information. Simon Rose of the Three Peaks Project issued two newsletters in this Footpath Information Network before it lapsed due to lack of support and pressure of other work. This reflects the general pressure on managers to deliver work on the ground rather than to generate advice for others to use.

In 1990 the National Trust opened its wardens' conference on footpath management to outside managers, and Climber magazine held an open conference on questions of upland path management. There have also been modest if useful local workshops run by the Countryside Commission for Scotland, particularly to tackle issues on long distance paths, and at least one visit by NT staff from the Lake District to discuss problems on Scottish mountains with their NTS counterparts.

2.4.2 Training

A wide variety of organisations - the British Trust for Conservation Volunteers and Scottish Conservation Projects, the National Trust and the National Trust for Scotland, and some Naturalists' Trusts, provide in-house training in ground management and other countryside skills for their own volunteers and volunteer leaders. These courses, however, tend to concentrate on established and fairly straightforward techniques, simply because those are usually best suited to the time-scale and skills levels of volunteer work.

Professional training is also provided at a variety of tertiary institutions offering courses in countryside management, but in general the emphasis tends to be on country-park type provision and wood crafts rather than on more difficult and arcane ground management techniques.

Undoubtedly this partly reflects the main market for the skills of the graduates of these courses, but it is also a consequence of the lack of readily available advice and wider experience in the more specialised areas.

2.4.3 Advice

The main published advice remains the practical handbooks produced by the British Trust for Conservation Volunteers, particularly those on coastlands and on footpaths. The footpath volume (Agate, 1983), is seriously out of date on geotextile applications and on vegetation management, while lacking detail on key techniques like pitching. In striving to be comprehensive, it perhaps suffers from its format as a fairly thick A4 document. Practical handbooks in other parts of the world tend to be pocket-size, as in the Appalachian Trail manual, or to be loose-leaf, which allows easy copying for field use and ready up-dating as technques evolve.

The Countryside Commission for Scotland information leaflets are a good example of the loose-leaf format, covering advice for dunes, lochshores, footpaths and other ground management. Many of these leaflets are the results of past CCS trial and demonstration projects. The coverage is somewhat patchy, and not as up-to-date as it might be.

At least two of the land managers most closely involved in path management - the National Trust and the Forestry Commission - produce in-house advice and technical notes for staff, but these are not widely available. The Commission has recently completed a wide-ranging review of its path management practice, of which one product has been some new technical advice in the Commission's own Recofax series (Forestry Commission 1991).

Some techniques have been written up in the reports of recent trial and demonstration projects such as those on the Pennine Way and Three Peaks. These have resulted in a range of contract reports on aspects of vegetation management. There is also a valuable, if diffuse, body of experience published in Countryside Commission reports of site management at a range of sites from the UMEX experiments and Tarn Hows through Kynance Cove to Cannock Chase. Other useful reports have been published by the Peak District Moorland Restoration Project.

In general, however, despite a good deal of recent experimentation, many trials have been completed without any generally accessible account having been produced, and there seems to have been a failure to ensure that both successful and unsuccessful techniques have been adequately described. In consequence the same sorts of mistakes continue to be made, and resources wasted. Much of the experience of the few centres of excellence (for example in stone pitching) continues to be passed on largely by small-scale demonstrations and word of mouth.

3 SITE EVALUATION

A careful site evaluation or inventory can provide baseline information helpful for defining problems and objectives, and for selecting possible courses of management action.

Clearly the inventory should be selective, but it will usually be found useful to include an assessment of types and levels of use, an outline of key site resources such as vegetation, wildlife and soil types and constraints such as planning designations and accessibility. Each of these factors can influence the choice and suitability of management techniques.

3.1 Types and levels of use

There are major differences in the impact of different types of recreational use (Table 3.1). Some activities like walking cause management problems only at moderate or high levels of use.
A few activities such as horse riding and use of vehicles cause sufficient disturbance at low frequency to justify special management, although there are also some specialised activities such as bird watching and rock climbing that can cause disturbance disproportionate to their numbers.

Often it is not the numbers of users *per se* that cause problems, but the

Table 3.1 Comparison of types and extent of impacts resulting from various types of recreational use. Definitions: ***Extent;*** *local, confined to less than 10% of most sites; extensive >10%.* ***Severity;*** *low, formal management at sensitive sites; moderate, management needed for heavy use; severe, management needed even for light use.*

	Main physical impacts				Extent		Severity		
Type of use	Surface abrasion	Surface impaction	Rutting	Other Impacts	Local	Extensive	Low	Moderate	Severe
Walking	*	*	*		*	*	*	*	
Horse riding	*	*	*		*	*		*	*
Cycling	*	*			*			*	
Vehicles	*	*	*		*				*
Ski-ing	*			*Vegetation & soil sliced off*	*	*		*	
Rock climbing	*	*		*Damage to cliff vegetation*	*			*	
Orienteering	*					*	*		
Camping	*			*Fire rings, shading of vegetation*	*		*	*	
Bird watching	*			*Disturbance of wildlife*	*		*	*	
Picnicing	*			*Litter*	*		*	*	

way in which they are concentrated along individual routes or in sensitive locations. Thus it is usually desirable to assess the distribution of use as well as numbers of users. Changing distribution by closing routes or opening new ones may sometimes be a better solution to an erosion problem than limiting numbers. This option is discussed further in section 8.

3.2 Soils

Soils vary greatly in their trafficability (resistance to wear) (Table 3.2). Surfaces with a high proportion of coarse particles (rocks or stones) are generally least affected by recreational use, and clay and peat soils most affected in that they show the greatest erosion of soil material and changes in soil structure.

Most soils have lower trafficability (resistance to wear) under wet ground conditions (Table 3.2) because water acts as a lubricant and allows soil particles to rub against each other and soil compaction to occur. Peat and clay soils are particularly vulnerable to wear under wet conditions, and often require special protection such as improved drainage, more durable surfacing or reduced levels of use.

Table 3.2 Trafficability of broad soil categories in relation to soil wetness

	Soil categories (predominant soil texture)						
Soil wetness	Rock	Gravel	Sand	Loam	Silt	Clay	Peat
Dry	High	High	Moderate	Moderate	Moderate	High	Low-moderate
Wet	High	Moderate	Low-moderate	Low	Low	Low-very low	Very low

3.3 Vegetation

The wear-resistant properties of vegetation vary from species to species. However, the types of wear exhibited by different communities reflect not only the durability of the vegetation, but also the extent to which the vegetation structure limits or modifies recreational movement (Table 3.3). For example stands of rushes are not easily walked through, so use and wear tend to be confined to meandering routes between clumps. In contrast short grassland has high trafficability but low resistance to movement, resulting in extensive scuffing with only a few areas of localised severe wear. Bog and fen have poor wear resistance but high impedance to movement, with the result that there tend to be few but heavily worn paths.

Table 3.3 Trafficability, resistance to recreational movement and typical patterns of wear on some broad categories of vegetation. Wear can vary a great deal with circumstances.

	Trafficability	Resistance to recreational movement	Common patterns of wear
Grassland			
- short	High	Low	Extensive scuffing but few bare paths
-tall	Moderate	Low-moderate	Extensive braiding
Woodland	Moderate-low	High	Few, heavily worn routes, some local braiding
Bog and fen	Low	High	Few, heavily worn routes
Cliff	Low	High	Patchy heavy wear of vegetationat top and bottom of cliffs and on ledges
Sand dune	Moderate	Moderate-high	Few, heavily worn routes and some extensive narrow braiding
Heathland	Low-moderate	Moderate-high	Few, densely worn routes
Mountain	Low-high	Low-high	Few, heavily worn trails and some extensive braiding and scuffing

4 THEORETICAL CONSIDERATIONS

This section discusses studies of factors that influence site wear and sensitivity to disturbance, and which have a bearing on technique selection or effectiveness. Specifically it outlines studies factors influencing soil erosion, the deterioration of footpaths, vegetation sensitivity to disturbance, and effects of different types of use. The examples given are not intended to be exhaustive, but rather to give a flavour of the approaches that have been adopted, and to highlight gaps in knowledge.

4.1 Erosion studies

Outline

Estimates of soil erosion by water can be made by applying the Universal Soil Loss Equation (Meyer & Wischmeir 1969) where:

$$A = R\,K\,L\,S\,C\,P$$

A is the computed soil loss per unit area; R is the rainfall factor, K is the soil erodibility factor for a standard plot 22 m long with 9 per cent slope. The slope length factor (L) steepness factor (S) vegetation management factor (C) and erosion control factor (P) are ratios of soil loss from specified site conditions to that from a standard plot.

This simple equation was devised for use on agricultural land, where it has proved broadly successful under a wide range of site conditions, but it does not take account of the effects of recreation on vegetation and soil properties that affect erodibility. Morgan (1985) has suggested a new generation of soil loss models to take some of these factors into account, such as the damage to vegetation cover, and changes in bulk density.

Applied to data on impacts of hiking, motor cycles, and horse riding by Weaver & Dale (1978), the new model successfully predicted the observed rates of erosion for hikers and horses but gave a value for motor cycles almost an order of magnitude too high. The model indicated that complete loss of topsoil was likely after 17 years use by hikers, and 13 years use by horses or motorcycles. Morgan noted that although the new approach appeared potentially useful for estimating likely erosion rates, it required validation by further refinement and testing with suitable recreational site data, which was, and remains in short supply.

Technical gaps

Further detailed observations of erosion rates could be justified to permit the development of more sophisticated erosion models, although the practical relevance to management techniques would be limited.

4.2 Path wear and deterioration

The factors that influence path deterioration are many, and include soil and vegetation characteristics and the type and intensity of use. There are, however, some relatively straightforward relationships between site characteristics and path wear that are of fairly general applicability, and which have important implications for path design and management. The following notes are based on work on paths in the Cairngorms, but subsequently confirmed by studies in other types of terrain (review by Liddle 1988, 1989). In the Cairngorms investigations, the effects of site factors were determined by examining path sample data where site characteristics other than the major variable were similar. For example, samples that varied in surface wetness were otherwise similar in terrain type, level of use, soil and vegetation types. The data showed that irrespective of the level of use, path width increased with the surface wetness and roughness and also with the angle of slope along the path. More surprising was that the roughness of adjacent ground decreased path width; paths were narrowest where they passed through the roughest terrain (provided the path surface remained of the same quality). (Figure 4.1).

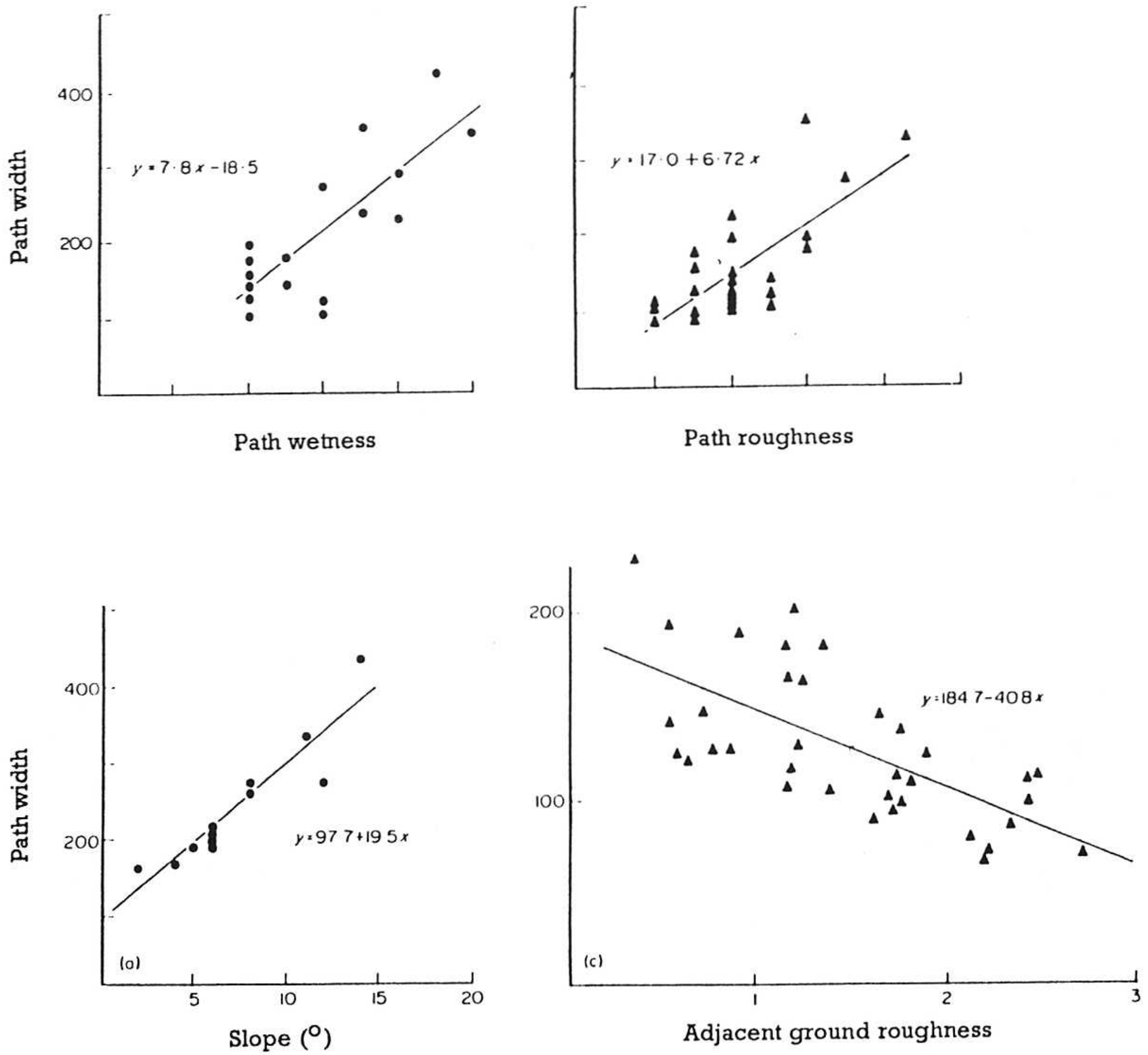


Figure 4.1 Relationships between path width (cm) and a) ground wetness, b) surface roughness, c) slope along the path and d) the roughness of adjacent ground, for various paths in the Cairngorm mountains, Scotland (Bayfield 1973).

Although fairly obvious, these relationships are of considerable importance for path design and management. Clearly for minimum path deterioration the path surface needs to be dry and smooth (minimum values for wetness and roughness) and avoid steep slopes where possible.

The effect of adjacent ground roughness implies that paths should be sited through broken terrain rather than smooth ground, if a choice exists. Furthermore, deterioration might be limited on existing routes by increasing the roughness of ground adjacent to paths by placing rocks or logs or planting tussocky or otherwise coarse vegetation as obstacles to help reduce path spread.

A further important observation concerned the relative impacts of uphill and downhill walking. Downhill walkers were found to take more steps and to have a greater impact with each step than uphill walkers. They also tended to deviate more from the centre of the path than walkers going uphill, possibly because when walking uphill the field of view (and choice) is relatively restricted. The differences increased with slope steepness. These observations imply that it may be possible to reduce the impacts of use if the direction of travel can be manipulated so that users go mainly uphill on steep slopes and downhill on gentle slopes. On circular walks for example, there is usually an optional direction for use.

Technical gaps

No substantial technical gaps.

4.3 Vegetation susceptibility to trampling

In recent years, Grime (1979, 1983) has outlined a model of plant growth strategies in terms of three main factors, competition, stress and disturbance. The model is summarised by an equilateral triangle, in which the three sides represent the relative importance of competition, stress and disturbance (all on a percentage basis) (Figure 4.2). Thus ruderals, stress-tolerators and competition-tolerators occupy respective corners of the triangle, and the strategy of individual species can be described by their relative position in the model. Positions can be determined from large data sets of species occurrence in different types of site. For example the contours of occurrence of *Poa annua* in the triangle suggest ruderal characteristics, (ability to survive in heavily disturbed conditions) whereas *Pteridium*

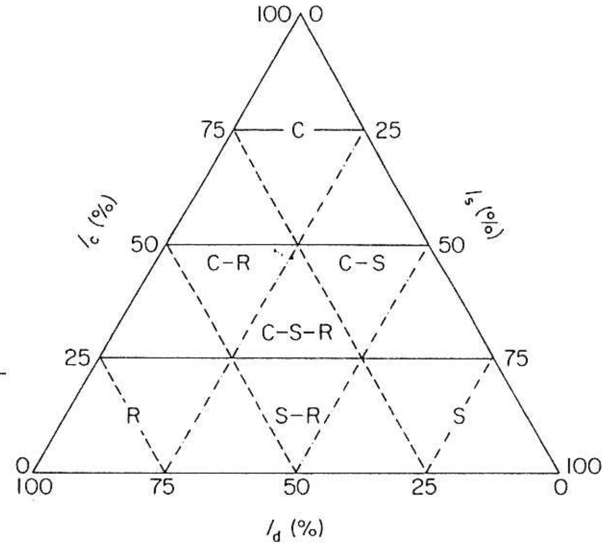


Figure 4.2 Model describing the various equilibria between competition, stress and disturbance in vegetation and the location of primary and secondary strategies: C, competitor; S, stress tolerant; R ruderal; C-R competitive ruderal; S-R, stress tolerant ruderal; C-S, stress tolerant competitor; C-S-R , 'C-S-R strategist'. I_c, relative importance of competition; I_s, relative importance of stress ; I_d relative importance of disturbance.

aquilinum (bracken) occurs mainly near the competition-tolerance corner, but is intolerant of disturbance.

Data on strategy of a wide range of species in the Sheffield area are provided in an ecological atlas (Grime, Hodgson & Hunt 1988). This provides a generalised basis for predicting the responses of vegetation to disturbance by recreation and other activities.

There have been several other approaches to estimating the relative sensitivity of vegetation to disturbance Lists of trample-tolerant species include those given by Speight (1973) and Liddle (1975). Other workers have have subjected individual communities to experimental trampling. Examples include chalk grassland (Chappel et al 1971), lowland grassland and heathland (Harrison 1981) sand dunes (Liddle 1973) and mountain heaths (Pryor 1985).

Yet another approach has been to survey paths and rank species susceptibility by association with the degree of path wear (mountain vegetation (Moss 1991)) and coastal dunes (Buitrago 1984). Unfortunately, because of the wide range of methodologies used, few of the approaches listed above have given results that can be easily compared. This situation has led Cole and Bayfield (1992) to propose a standardised protocol for field trampling studies.

Technical gaps

Comparable data for a wide range of plant communities and site conditions would be valuable for route selection, and to predict likely patterns of deterioration of new routes, as well as for environmental impact assessment work.

4.4 Effects of different types of use

The general impacts of different types of use are quite well known, but there have been only a fairly small number of detailed studies. The impacts of walking have been most thoroughly investigated (Liddle 1988 provides a review) and the effects of camping have been the subject of a series of papers in the USA (Cole 1985 provides a review). The impacts of skiing have been studied in several countries (Grabherr 1985, Bayfield 1973) and effects of off-the-road vehicles and snowmobiles have been investigated in a variety of habitats, mainly in the USA.

Less popular activities such as orienteering have been little studied (Jeppersen 1987), and there has so far been only a few examinations of the recently popular activity of mountain biking (MacIntyre 1991, Rees 1990). Horse riding has also been little investigated, although there is an early study on the effects of race horses on turf (Perring 1967) and some research is currently underway at Writtle Agricultural College (pers comm).

A few investigators have tried to compare different activities under the same site conditions. Leney (1974) for example compared sitting, picnicking, walking and running, and Weaver et al (1979) compared the impacts of the same number of passes by a hiker, motor cyclist and horse rider on grassland and forest vegetation. This is one of the most complete studies of its kind, and showed that horses were substantially more damaging, and motor cycles slightly more damaging than hikers.

Recent studies comparing mountain bikes and walkers have indicated that bikes cause slightly more damage than foot traffic (MacIntyre 1990, Rees 1990) although impacts appeared to vary with the type of habitat.

Table 4.1 Effects of 1000 passes by different types of user on grassland and forest vegetation in the Pacific Northwest (Weaver et al 1978)

		Hiker	Motor-cycle	Horse
Bare ground (%)	grassland	47	50	72
	forest	98	98	100
Path width (cm)	grassland	28	34	84
	forest	34	62	68
Erosion depth (mm)	grassland	42	49	68
	forest	23	36	64
Bulk density (g/cc)	grassland	1.2	1.3	1.3
	forest	1.1	1.0	1.2

Rees also examined the effects of different ground moisture conditions (dry, moist or wet) on impacts (in birch woodland grassland) and found substantially heavier damage resulted when the ground was wet. Studies by Bayfield et al (1981) on lichens showed the opposite trend, of much higher damage during dry ground conditions, when lichens are brittle. These types of study could have considerable importance for management of visitors, although the problem of controlling numbers or distribution when ground conditions are unsuitable appear formidable!

Technical gaps

There is still an inadequate data base on impacts of different types of activity, and particularly comparative studies and studies of impacts under different ground and site conditions. As with studies of vegetation sensitivity to disturbance the lack of a uniform methodology makes comparison of existing studies difficult.

Part 2: TECHNIQUES

5.1 Route selection

A carefully selected route should be visually attractive but of low visual intrusion, be easily maintained and have minimum liability to erosion. The design criteria and approaches required are similar to those used to minimise impacts of roads, fencelines and other linear features in the landscape.

5.1.1 Minimising visual impacts

Dominant landscape elements can be grouped into four categories, colour (both vegetation and rock/soil) line (linear elements such as vegetation boundaries, horizons) texture (surface vegetation and soil) and land form or terrain [Bureau of Land Management (1980)]. Route selection should aim to minimise visual disruption of these elements. The visual absorptive capacity (VAC) of landscapes varies a great deal. Examples of factors that contribute to high and low capacity are given in Table 5.1 (partly based on USDA 1977).

Table 5.1 Factors that influence the Visual Absorptive Capacity of landscapes

	Absorptive Capacity	
	High	Low
Landform	High variety of landforms Gently rolling terrain Numerous linear features Feature landforms present	Low variety Flat or uniform slopes No linear features No feature landforms
Soils	Fertile Dark soils	Infertile Light soils (due to contrast with green vegetation)
Vegetation	High degree of pattern Trees/shrubs present Revegetation easy	Low patterning None Revegetation difficult
Intervisibility	Route with low visibility from other locations	Route highly visible

Woodland, sand dunes, and morainic landscapes are examples that tend to have a high absorptive capacity and downs, mountain plateau and lowland heaths low capacity.

Some general siting guidelines to help minimise visual intrusion include:

Avoid:

1. Straight alignments and abrupt changes of direction
2. Direct ascents

3. Skylining
4. Crossing linear features

Prefer:
1. Flowing curves
2. Oblique ascents
3. Make maximum use of topographic shelter
4. Follow visual boundaries of topography, vegetation or soil

Box 1 VISUAL ABSORPTION CAPACITY (VAC)

The USDA Forest Service (1984) have described a ranking system for visual absorption capacity of potential ski areas. This is probably not applicable to other types of area, but illustrates the types of factors influencing VAC in a mountain environment.

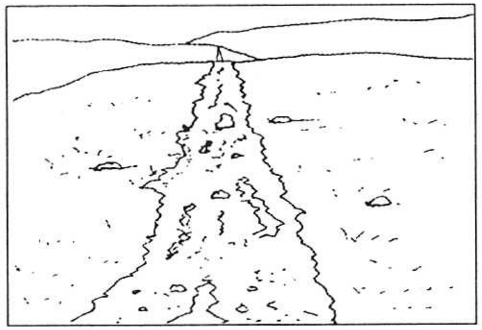
		Score		
		1	**2**	**3**
Existing vegetation and landforms	Aspect relative to viewer	80-100°	60- 80° 100-120°	< 60° >120°
	Slope	>60°	25-60°	0-27°
	Vegetation height	0-6ft	6-30ft	>30ft
	Vegetation density	0.20%	20-80%	80-100%
Landscape diversity		Low	Medium	High
Vegetation regeneration potential	Soil productivity	Low	Medium	High
	Aspect	180-270° 270-360°	90-180°	0-90°
Soil	Colourcontrast	White to yellow	Medium	Brown-black
	Erosion hazard ratings	High	Medium	Low
	Soil stability	Low	Medium	High

VAC score 10-16 : Low ; 17-23 : Medium ; 24-30 : High

5.1.2 Minimising erosion

In order to minimise potential erosion the path surface should be smooth and well drained. Location is also important. In particular:

- direct ascents of steep slopes should be avoided,as satisfactory drainage is difficult to achieve and trampling damage to the surface can be high;



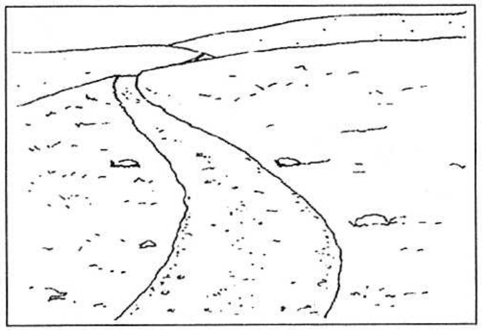


Figure 5.1 Avoid direct ascents. Choose ablique routes to minimise visual impact and reduce erosion

- streams and drains should be crossed at right angles to avoid the stream eroding the path route

- where feasible design routes so that users ascend steep slopes and descend gentle slopes, as downhill use is more damaging than uphill;

- avoid crossing areas of excessive seepage or gulleying; choose well drained slopes;

- avoid areas of poor vegetation cover, as these are likely to be easily damaged by trampling;

- site where feasible through rough terrain and tall or tussocky vegetation, as these will help minimise the spread of users on to adjacent ground.

5.1.3 Techniques for route selection

Pace and peg

The route is selected on the ground, and pegged at intervals. Ideally more than one line should be pegged, and independent observers asked to walk the lines and comment, to help select a preferred route. This method is ideal for short routes (<2 km).

Aerial photo-interpretation

For longer routes, 1:10,000 (or more detailed) aerial photographs can be used in conjunction with similar scale ordnance survey maps to select alternative lines. In mountain areas stereo-oblique photographs are a better but more expensive alternative. Colour or false colour photographs are helpful in indicating vegetation types and lines of seepage, but are not always available from existing aerial photo libraries. Possible routes should be fine tuned and pegged on the ground before final selection.

Computer aided routing

Sophisticated software programmes are available to help visualize and place features such as lines of roads, fences and paths. They involve preparing a digital map of ground contours and then superimposing potential routes. The output is typically a 3D perspective of the route. Some versions permit the operator to "walk through" the computer model of the area, and add vegetation and soil shadings.

An example of a sophisticated software system is that produced by MOSS, and requires a Sun, Apollo or Vax Engineering Workstation. MacContour is a less powerful system that will run on a Macintosh computer, and Modelshop and similar 3D graphics programmes are sometimes also used for visualization. As in the case of aerial photo-interpretation, some field fine tuning is usually required.

Computer visualization can also be used to analyse the visual impact of non-linear site features such as buildings, car parks and ski pistes. A good discussion of this approach is given in the USDA handbook for ski areas (1984).

Advantages and drawbacks of the three methods of route selection are given in Table 5.2

5.1.4 Landscaping

Much of the detail of landscaping individual features such as culverts, path surfaces, and planted areas will be discussed in following sections.

Some general principles can however be spelt out. Sympathetic materials should be used wherever possible. In the countryside this usually means stone or wood rather than concrete or steel.

Materials should not contrast in colour with the surrounding ground. Dark matt colours are generally to be preferred, and dark substrates are less intrusive than light.

Planting schemes, placement of rocks and shapes of cut and fill slopes should attempt to blend with

Table 5.2 Pros and cons of route selection techniques

	Pros	Cons
Pace and peg	Cheap Very sensitive to ground conditrions	Lacks birds eye perspective
Aerial photo-interpretation	Provides birds eye perspective Easy to lay out several routes	Moderately costly in time and equipment Aerial photographs not always available. Black and white photos do not provide good vegetation details Needs field fine tuning
Computer aided routing	Very detailed analysis of visual impacts of route, and views for users. Easy comparison of alternative lines	Most expensive option Needs field fine tuning

surrounding contours and surface patterns as far as possible. Although smooth curves are desirable for route lines, cut and fill slopes will usually blend in better if they have irregular margins.

5.1.5 Further work

There are no obvious technical gaps in route selection and landscaping, although well documented case studies would be helpful for practising managers and planners.

6 SOIL EROSION PROTECTION

6.1 Introduction

This section is mainly concerned with control of surface erosion phenomena. Control of deep seated erosion (slumps and landslides) is largely achieved by careful slope design and drainage (Section 9), although some sub-surface protection down to a metre or more can also be achieved by tree planting (Section 11).

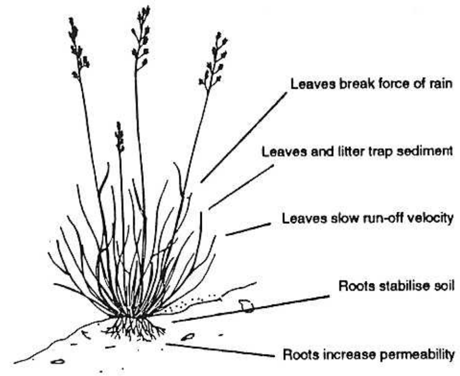


Figure 6.1 Erosion protection provided by vegetation

The aims of erosion control are to:

- break the impact of raindrops;
- trap water-borne sediment;
- stabilise the upper layers of soil against slippage and surface detachment.

Vegetation is almost the perfect control agent since it performs all these functions. It also reduces the velocity

Box 2. COMPARISON OF EROSION PROTECTION PROVIDED BY VEGETATION AND JUTE EROSION NETTING (Bayfield unpublished)

Trays of sandy loam 34 cm x 18 cm were sown with vegetation or left unsown. The vegetation mixtures were:

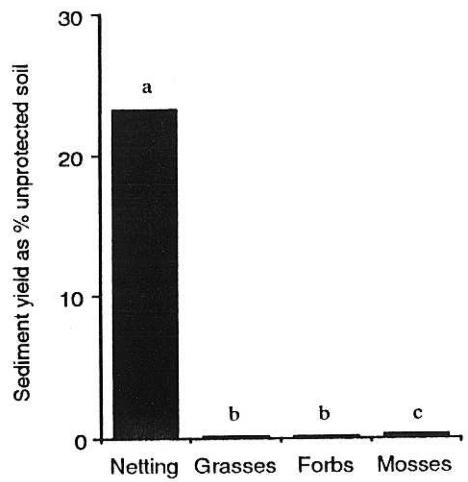
1. Grasses (rate 3g/m²)
Agrostis capillaris, Phleum pratensis, Festuca rubra

2. Forbs (rate 3 g/m²)
Trifolium repens, Plantago lanceolata , Plantago major, Rumex obtusifolius

3. Mosses (0.5 l/m² of chopped fragments)
Sphagnum rubellum, Polytrichum commune Aulacomnium palustre, Dicranum scoparium

A further set of trays were surfaced with jute erosion netting (1.5 cm mesh). There were five replicates of each treatment. All trays were inclined to 30° from the horizontal, and subjected to artificial rain at a rate of 1 litre/min for 5 minutes (this is equivalent to torrential rain). The volume of sediment washed from each tray was measured.

All the vegetated trays had very low rates of erosion (less than 2% of control, unprotected trays). Even moss cover gave substantial protection. Hessian erosion netting reduced sediment yield by about four fifths but was still much less effective than vegetation



Loss of sediment from trays protected with vegetation or jute erosion netting (as % of unprotected controls) Columns with different letters are significantly different at p=0.05 of surface run-off, and increases surface permeability.

Almost any type of vegetation cover is effective. Laboratory studies with different vegetation grown on the same soil have shown that even moss cover can reduce soil erosion by more than 98% (Box 2). The only drawback of vegetation for erosion control is the time taken for establishment; there is normally a window of risk between planting and control of several weeks.

Other methods of control are less effective than vegetation (Table 6.1), but can provide more or less immediate protection. They include use of geotextiles for surface protection, to trap sediment and for shallow subsurface stabilisation, glues to protect the soil surface, and methods of moulding the surface to trap sediment and reduce the velocity of run-off. Often the function of these techniques is short-term, to provide protection until vegetation is established, but in some cases they provide longer-term stabilisation.

6.2 Geotextiles

An introduction to geotextiles is given in Box 3. There are three main types of geotextiles used for erosion control;

1) nettings laid on the surface mainly to trap sediment and slow surface run-off;

(2) partly buried three dimensional nettings intended to provide some shallow subsurface stability, and sediment trapping; and

(3) subsurface cellular webs, which provide deeper surface stability.

6.2.1 Surface nettings

Geojute is an example of this category. It is a jute based open weave netting with a mesh size of 1-2 cm. The netting

*Table 6.1 Effectiveness of various types of erosion control treatments: ** very effective; * moderately effective*

	Property:					
	Increase permeability	*Reduce impact of rain*	*Reduce velocity of run-off*	*Surface stabilisation*	*Trap sediment*	*Subsurface stabilisation*
Vegetation	**	**	**	**	**	**
Geotextiles:						
Jute netting			**	*	**	
Enka mat			*	*	*	*
Geoweb			*		*	**
Mesh elements			*		*	**
Mulch mats		**	**	*	**	
Surface glues				**		
Surface moulding	**		*		*	

Box 3 GEOTEXTILES

What are geotextiles?

The term geotextile is used to cover a wide range of flexible porous sheet engineering materials that can be draped over or incorporated into soil surfaces to improve their structural properties. The main functions of geotextiles are:

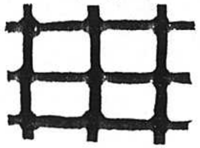
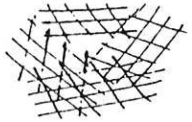
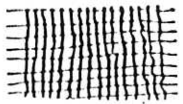
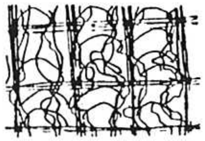
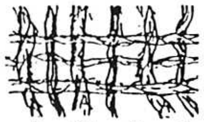
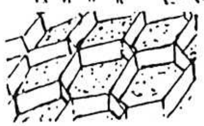
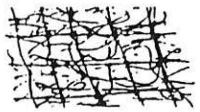
- **reinforcement**; to improve bearing strength

- **separation (filtration)** to prevent mixing of fine or coarse materials (filter fabrics are often used under gravel paths to prevent the freely drained surface becoming clogged with fines from the subsoil)

- **erosion control** to prevent soil surface particles from washing or blowing away, and to trap sediment. These geotextiles are frequently used as a substitute for vegetation on bare ground to provide surface stability until vegetation cover is established.

Types

Many different materials are used, including plastics, steel and natural fibres such as straw and jute. There are also many composite geotextiles. Sheets can be formed by extrusion, weaving, welding, stitching or by combinations. Some geotextiles used for erosion control include a mulch layer and a reinforcement layer and are pre-sown with seeds. The variety of engineering geotextiles is enormous, and increasing, but only a limited range is of interest for use at recreation sites.

	Examples	Material	Mesh Size	Rigidity	Strength (kN/m²)
Reinforcement Geogrid		Extruded plastic	1-3 cm	High	20-30
Wiretex		Woven Polypropylene and wire	1-3 cm	Low-	10-15
Mesh elements		Polyamide	1 cm	Moderate	Not stated
2 Filtration Terram		Non-woven plastic felt	350 microns	low	3.5
Lotrac		Woven polypropylene	230 microns	low-	9
3 Erosion contrc Enkamat		Welded polyamide	3 mm?	Moderate	Not stated
Geojute		Woven jute	0.5-3 cm	Very low	Not stated
Geocell		Non-woven plastic felt	300 microns	Moderate	Not stated
Greenfix		Straw/coir	Not stated	Low-moderate	Not stated

is rolled out and pegged in place with long wire staples. It has the advantages of stretching and closely fitting irregular ground contours (particularly after being wetted), and also of being biodegradable). The jute retains some of the moisture from rain and surface flow, and rots to provide surface organic material, both features which may be of minor benefit to establishing vegetation. As the netting is merely pegged to the surface, no special soil preparation is required.

6.2.2 Three dimensional nettings

Enkamat types of geotextile are made from two or more layers of fine and coarse grade net, tacked together to provide both reinforcing and soil holding abilities. In use they are laid on the ground and soil is worked into the upper layer. The geotextile is thus placed at or just below the surface. These materials are stronger than jute netting, and not biodegradable. Unless laid very carefully, they do not fit as closely to the surface as jute, and sometimes surface run-off can wash out soil from under the netting, leaving the netting suspended, visually intrusive and ineffective.

6.2.3 Geocells

These are three dimensional webs providing a network of cells resembling honeycomb (eg Armater). The webs are placed on the slope to be protected, pegged down at intervals with stakes, and the cells filled with soil. This is a substantial reinforcement technique that can provide subsurface stabilisation to about 10 cm or more, and some surface protection by reducing the velocity of run-off and sediment trapping. Because of its high cost and heavy earthmoving requirement, it is not often justified for erosion control at recreation sites, but is included here for completeness.

6.2.4 Mulch mats

Mats such as Greenfix are sheets of lightweight netting enclosing a mulch layer of straw, coir or other organic material. The mats are sometimes pre-sown with appropriate grass seed, or may be laid on top of sown slopes. They are pegged down with wire staples, and provide protection from raindrops, reduce run-off velocities and trap sediment. The mulch can have the disadvantage in some situations of stifling the growth of vegetation, although in the longer term decomposition adds valuable organic matter to the soil. Mulch mats are bulky and relatively costly, and like geowebs not often justified at small-scale recreation sites.

6.2.5 Mesh elements

This technique involves reinforcing soils by mixing them with small pieces of plastic mesh. The mesh acts as a root substitute to strengthen the soil, and to some extent trap sediment and reduce run-off velocities. The main drawback to this technique is the problem of satisfactorily mixing the mesh elements into the soil to be protected. In commercial practice soils and mesh are often pre-mixed off site, but this substantially increases costs.

6.2.6 Technical gaps

There are a large number of geotextiles available for erosion control. Most have been developed for large-scale civil engineering purposes. All are effective for some types of situation but costs vary widely, and it is difficult to make a selection on the basis of manufacturers claims. Some small scale field trials to compare contrasting types would be helpful in indicating which types are best suited to recreation sites. Some laboratory testing of a small range of geotextiles has been undertaken by Silsoe College.

6.3 Surface glues

6.3.1 Introduction

Surface glues, also known as tackifiers or soil stabilisers are usually applied to soils as a component of hydroseed mixtures (see section 11), or sprayed on after manual seeding or planting. They form a porous skin on the surface to prevent soil particles washing away, and are mainly intended for short-term protection.

As in the case of geotextiles, there are a large number of products on the market. All appear to be more or less efficient as glues, although there is very little comparative information on the effectiveness of different formulations. In selecting a product important considerations will be cost, and the method of application. Powder glues are much easier to apply to small areas than emulsions, which tend to clog small sprayer equipment. (Table 6.2.) All types can be used in hydroseeding. Although each manufacturer claims low toxicity, some products are more toxic to plants than others. Bayfield and McGowan (1990) compared the toxicity of a small range of glues on both grasses and bryophytes, and found several products significantly suppressed growth; in particular Huls 801 and Cellocol LZX. Two (Terrabind and M166) had a stimulating effect on the growth of some test species. It was not clear if this effect was due to release of nutrients, or some hormonal effect of the glues.

Table 6.2 Examples of surface glues

Type	Proprietory example	Liquid(L) or powder (P)	Ease of application	Notes
Bitumen emulsion	Bitumuls 55	L	Difficult	Darkens light coloured soils
Latex emulsion		L	Moderate	
Resin	Huls 801	L	Easy	Moderately toxic
Wood resins	Terrabind	L	Difficult	Stimulates growth
Hydrophilic polymer	Landfix	P`	Easy	
Potato starch	Cellocol LZX	P	Easy	Weak gluing effect

6.3.2 Technical gaps

There is a case for more laboratory testing of glues for particular types of soil, and to check for possible toxicity . This is particularly pertinent for difficult sites such as those at high altitude, with a high proportion of bryophytes. This is fine tuning, however, and for general purposes almost any of the glues will probably perform adequately.

6.4 Surface moulding

6.4.1 Outline

This technique consists of cutting horizontal ledges or grooves in slopes instead of dressing them to a flat profile. This approach is fairly common in the United States (USDA 1977) and is also used in the tropics (Barker et al 1989), but appears to have been rarely tried in the UK. In the USA, serrated "steps" are recommended, between 15 cm and 1.3 m high. In Malaysia, grooves 5 cm deep and 25 cm between centres are cut in the dressed surface (Bayfield & Barker 1992). Both methods help trap water-borne sediment, reduce run-off velocities, and increase slope permeability.

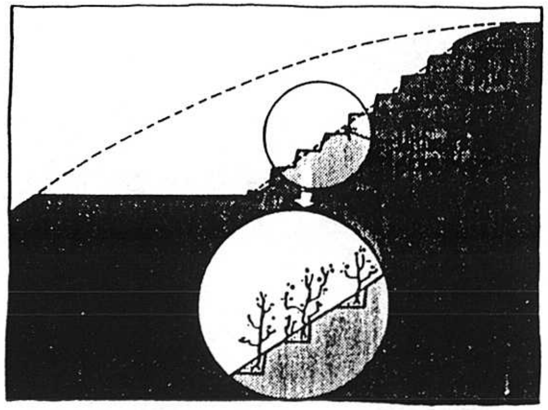


Figure 6.2 Serrated steps used to reduce erosion and improve vegetation establishment (USDA 1977)

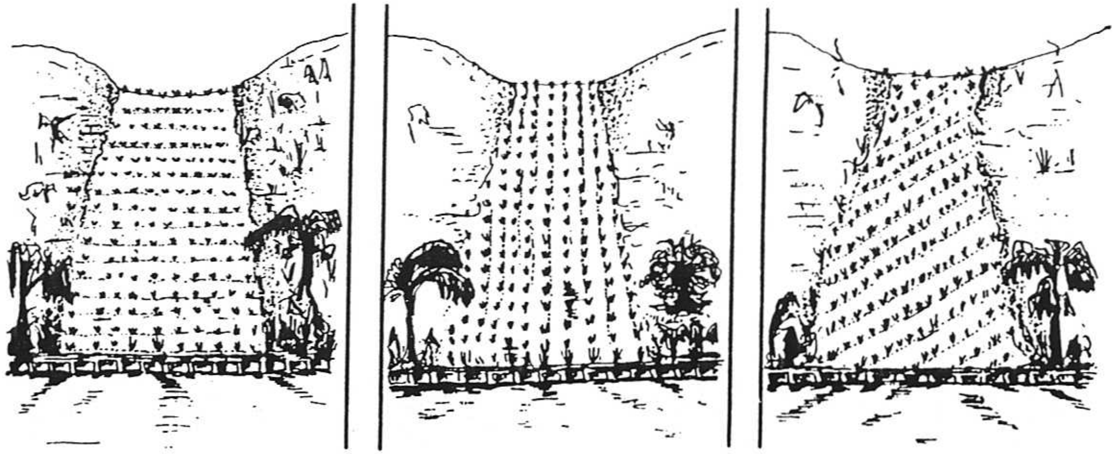


Figure 6.3 Methods of grooving and planting eroding road slopes in Nepal (Howell et. al. 1991)

Trials by the Malaysian Thai Development Company (Prajay Ruenrig, unpublished) indicate about 25-75% better germination of grasses and legumes on grooved slopes, probably because of better permeability and moisture retention than on ungrooved slopes.

Recent work in Nepal by Howell et al (1991) has suggested that down-slope or oblique grooves can also be used for erosion control, particularly in difficult ground where erosion risk is high, and some loss of material is acceptable (Figure 6.3). The advantages of these approaches are that fairly natural drainage systems are established, but by keeping the density of grooves high, individual gullies do not get excessively eroded.

Technical gaps

There appears to have been no evaluation of the benefits of surface moulding techniques under British conditions. An assessment could compare erosion rates on moulded and unmoulded slopes, and compare effectiveness with that of glue and geotextile techniques.

7 PATH CONSTRUCTION

7.1 Aggregate paths

Aggregate paths are mainly suitable for use on mineral soils, where there is firm sub-grade material. Simple excavation of a path base is followed by infilling with an appropriate fill material. No reinforcing is required although a filter geotextile may help to prevent the surface becoming clogged with fines.

Angular quarry graded material is the most suitable fill since it will pack dowh firm and solid. Often, though, material from local sources such as borrow pits or streams will be used. These materials may be satisfactory, but problems can arise if there is too high a proportion of rounded gravel, or too much or too little clay present; these combinations make poor path surfaces. A solution can be to mix in a proportion of angular material or clay to improve the properties of the mixture. Mixing can, however, be difficult and time consuming, particularly at remote sites.

A variation is to form a wearing surface with stones or rock ("cobbling"). This can be very durable, but has to be carefully laid and consolidated, as protruding angular material can be both unpleasant to walk on and even dangerous.

Effective drainage is important to prevent scour and loss of finer surfacing material. It should be possible to build in a camber or shedding slope, but in practice this appears to be difficult to achieve and sustain.

Figure 7.1 Laying a box-section geotextile path (Pentlands).

7.2 "Floated" aggregate paths

Aggregate paths can be rafted or floated on soft ground or peat by laying them on geotextiles, to prevent them sinking. The earliest such use of geotextiles in path construction was about 20 years ago with Terram. Although this material is a good filter textile (preventing fines flooding the surfacing) it lacks tensile strength, and some of the early trials were not successful, as the resultant paths tended to slump and sag. In recent years there has been recognition that there are still problems at some sites, particularly on steep slopes and on sites with very high water tables, where path slumping , loss of surface material or slippage of the textile reinforcing can occur.

The long term performance of floated paths has so far only received limited monitoring although many paths have now been laid, apparently successfully, in difficult conditions on soft peat and clay. The scale of path ranges from machine-laid tracks up to 2.5 m wide in the Three Peaks to very modest narrow footpaths at sites like the Grey Mare's Tail in Dumfries-shire.

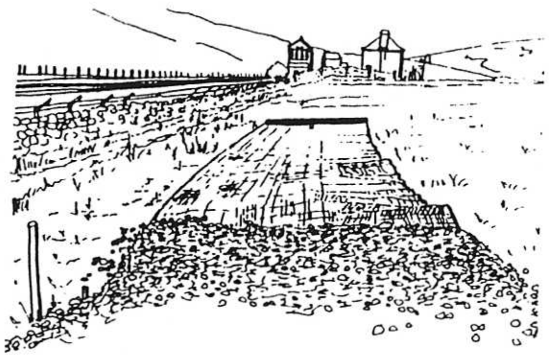


Figure 7.2 Building a 2.5 m wide limestone aggregate path on a geogrid over deep peat at Ribblehead (Yorkshire Dales)

Although geotextile paths can be laid quickly and relatively cheaply when good fill and surfacing materials are readily available, they need some care in design and construction, and good finishing, to produce an informal alignment.The availability of information on existing methods and sites is decidedly patchy; the suggestions for laying goetextile in the BTCV handbook are seriously out of date. Although professional engineering advisers for geotextile manufacturers and suppliers have taken an interest in footpath and ground restoration applications, in general they have not seen a large enough market in countryside management to address the issues of this relatively small-scale application in detail. However the range geotextiles and grids goes on expanding and diversifying rapidly; continuing appraisal and experiment with new materials, as they appear should be a priority.

Trials with sheeps wool as a geotextile substitute suggest that is more expensive, heavier, more difficult to handle, and significantly less effective than artificial membranes.

7.3 Soil cement paths

Soil cements have been used in various parts of the world, notably in trials in bog areas in Tasmania, but we are not aware of any extensive applications in the UK. The Tasmania trials indicate that it is possible to establish stable self-draining surfaces that need not be too formal in appearance, but the path created tends to be hard on the feet for walkers over longer distances, can present problems of colour, and may be brittle under frost. The need for transport to remote sites of materials and machinery to mix and pack the surface is likely to limit the range of possible applications. Nevertheless the scope for hardening chemical treatments of this sort should be kept under review. This topic is further discussed as a method of reinforcing soils, in Section 12.2.3.

7.4 Stone pitching

Pitching is an ancient technique for establishing hard-wearing paths or roadways on steep or broken ground, based on setting and packing stones into a mineral base. Pitching creates a series of small stone steps and is usually distinguished from cobbling, which involves packing stone to give a smooth surface plane to the ground. The stones are laid with flattest face uppermost to form a stepped surface that rises smoothly (without abrupt changes of gradient) and with each stone set so as to shed water downhill and to the side of the path. Gaps between stones can be packed with soil and seeded. One leading practitioners suggests the larger the stones the better. There are local variations of pitching in many different parts of the world. To some extent its detailed form and style are dependent on the local geology, though the fundamental principles are universal. When well executed, it offers very high stability and durability. It is virtually the only reliable technique so far discovered for heavily-used paths at gradients over 15 degrees; carefully built it can provide a good surface up to twice that gradient.

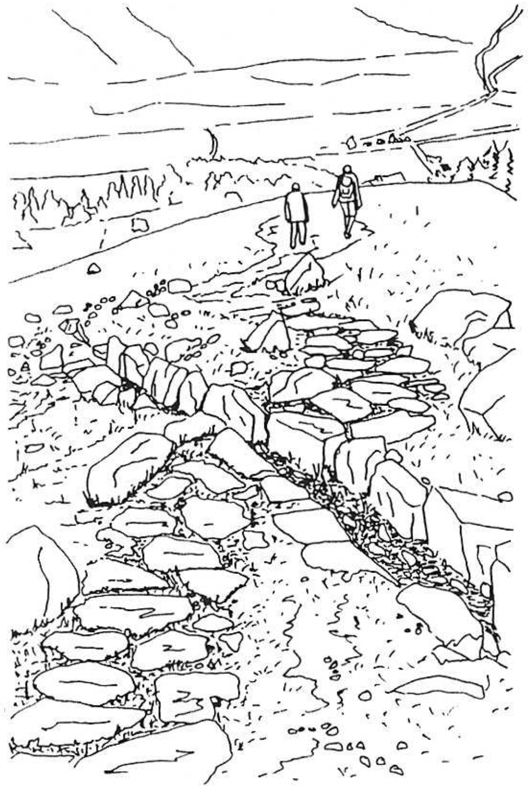


Figure 7.3 Finely executed recent stone pitching in Langdale. Note the use of rocks on the path margins to deter lateral spread, and the revegetation of the whole width by seeding and turfing.

Much excellent rock-pitching can be seen in the Lake District (particularly on National Trust paths) where it has been the technique of choice on upland paths for about fifteen years. More limited sections of pitched path have been built in the Peak District and on some Scottish mountain paths The technique is particularly valuable in hill country by virtue of being almost impervious to erosion by water, and in allowing integral provision for drainage across the path and off its surface.

Because of the need to collect large amounts of rock and the importance of sound construction, pitching tends to be slow, labour intensive, and expensive; it requires a level of skill that is not quickly acquired, so that it is not an easy technique for volunteers to develop. But the high costs of construction need to be set against the very long, low-maintenance life expectancy of a good pitched path. Practical advice on pitching is available from the National Trust in Lakeland, but there does not appear to be much published information.

7.5 Stone slab paths

The laying of stone slabs or flags is, like stone pitching, a revival of a traditional approach. The Romans built stone slab paths and roads (for example at Doctors Gate in

Derbyshire) and the stone "trod" paths through fields in the Yorkshire Dales (such as around Hawes) are attractive features, possibly dating from the time of enclosure.

In the last five years there has been a revival of interest in slab paths, and

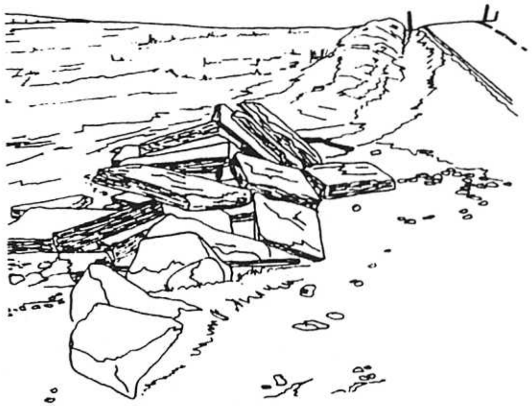


Figure 7.4 10 cm stone slabs offloaded by the roadside (Snake Pass, Derbyshire).

recent development work has focused on their use on soft ground. Quite long stretches (>1 km) of stone slabs have been laid across peat in parts of the Pennine Way (particularly in the south) and in Northumberland and elsewhere. The special advantages claimed for this approach are ease of laying, high durability, low maintenance and a very attractive, vernacular appearance.

Little published unformation is available on the technique, as the use of this method is rapidly evolving, and long term evaluation is so far incomplete.

On the Pennine Way, initial trials involved the use of newly quarried stone, but a substantial supply of old mill flooring has since been utilised, with substantial savings. Supply is not considered a limiting factor at present, and quarried supplies should still be available in the longer term. Slabs 10 cm (4") thick are preferred to thinner (6-8 cm) material, as the heavier slabs have considerable inertia and hardly

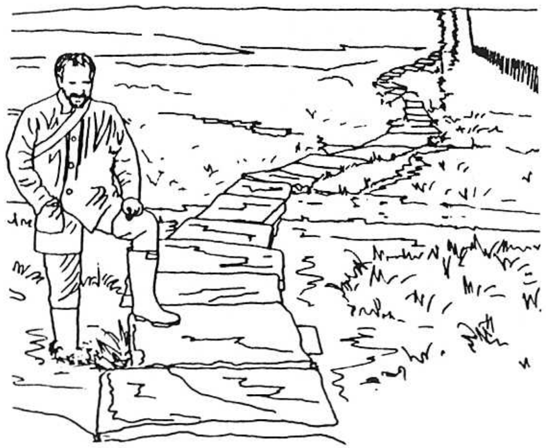


Figure 7.5 Slabs laid directly onto a mat of vegetation (Northumberland).

Figure 7.6 Stone slabs laid onto amorphous peat (Devil's Dyke, Derbyshire).

move in use. One tonne of 10 cm thick stone is sufficient for about 5 m of path and the same weight of 6-8 cm slabs will provide about 7 m of path. For comparison, a 1.2 m wide gravel path could require about 0.75 tonnes of aggregate, a substantially greater weight than in the case of slabs. Individual slabs vary in width from about 50-80 cm, and the irregularity of sizes gives the resultant path a natural broken edge and a very pleasing appearance.

Where slabs are laid onto a fibrous mat of peat or vegetation, or directly onto a mineral base, no reinforcing will be required. Where the route is over wet amorphous peat, recent practice has been to lay the slabs onto a base of chestnut paling about 1.5 m wide bound with polypropylene cord. In a few locations, slabs have been laid onto a base of aggregate, but this appears to be overspecification and should not be required at most types of site.. Except at very wet locations the evidence is that direct laying onto bare peat is satisfactory; there have been few instances of sinking or loose slabs. However, it should be noted that several years of observation (preferably of paths with contrasting specifications) are needed to confirm that there are no serious drawbacks to this approach.

On the Pennine Way, a steel cradle has been developed for transporting slabs by helicopter (T. Philpin, *pers. comm.*). This type of delivery minimises handling, and when undertaken on a large scale makes slab paths very competitive in price with other approaches, as well as comparatively rapid to lay. The price of laid slabs is broadly similar to that of good quality boardwalk, but has much higher durability and probably lower maintenance costs.

7.6 Boardwalk

7.6.1 Outline

Boardwalk is a well established technique for creating an acceptable walking surface across dificult ground. Possibly the oldest documented path in Britain, the "sweet path" through a bog in the West Country is a type of boardwalk, made from split logs.

Boards for the walking surface can be laid either across or along the route. In either case they normally rest on bearers to tie the structure together and to help spread the load. Many boardwalks are built on site, particularly where the ground is uneven or the route circuitous, but pre-fabricated sections or rafts are sometimes delivered to site by vehicle or helicopter. Boardwalk is relatively more temporary than most path surfaces in that it can be lifted and removed fairly easily and without leaving much damage. Sections need to be checked regularly for wear and tear since, more than most path techniques, it manifestly implies a public safety obligation on the manager. For similar reasons it should be surfaced with chicken wire or tar and gravel chips where there is a risk of slippiness.

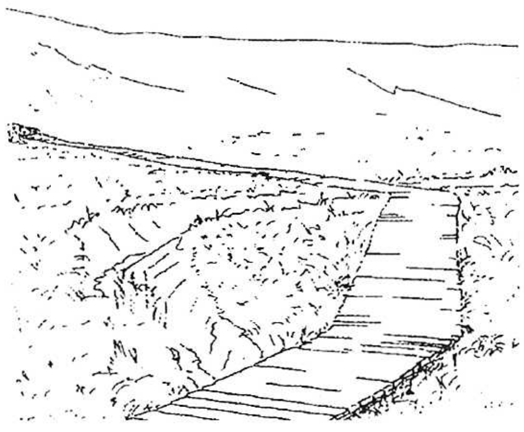


Figure 7.7 Well sited low ground profile boardwalk (Yorkshire Dales)

7.6.2 Suitable locations for installation

Boardwalk is an excellent solution for paths through wet sites of high ecological interest as it avoids any interference with lines of drainage. It can also be successful in woodland and coastal settings. Although it does not offer a pleasant walking experience over long distances, it has nevertheless been used in quantity in some remote areas such as the Pennine Way in the Cheviots, where there is a shortage of local materials for alternative approaches.

7.6.3 Technical details

Sound detailed specifications for boardwalk and associated timber techniques are given in the BTCV Handbook (Agate 1983). Similar detail is given in path management handbooks for the US Forest Service (USDA 1985) and South Africa Department of Environment Affairs (Humphrey undated).

All Boardwalk and similar timber paths should be built as close to the ground as possible to minimise visual impact, with gentle curves to reduce linear intrusion.. There is no need to overspecify construction. Within limits, the narrower it is the better so long as it is compatible with levels of use. Installation can be readily undertaken by volunteers but careful alignment and close supervision of construction are needed to ensure a high standard of finish.

There are relatively few technical problems with boardwalk, although there is still scope for innovation. Plastic roll-out horticultural paths might, for example, be worth further development.

7.7 Machine-built paths

Machines are widely used to transport materials for path construction (see also Section10, use of machinery), but in the present context machine-built paths are those where the bulk of the excavation , placement of materials and finishing are by mechanical means. The first extensive trials of this approach were undertaken by the Countryside Commission for Scotland, in the early 1980s on parts of the West Highland Way and recorded on video. The economies of operation were immediately apparent, and the technique has since been widely used, for example on Aonach Mor ski resort paths, on the Pennine Way, in the Southern Uplands and in the Yorkshire Dales.

The principal of the method is that vegetation is stripped along the line of the proposed path, subsoil is dug out from one side and mounded to form a walking surface while surplus topsoil is placed where the subsoil was removed. The final profile is usually a raised path surface, with a ditch to one side. A high level of skill is required of the machine operator. Machines used for the work range from mini excavators to large Hymac types. Small machines can be airlifted to remote sites, but large machines have the advantage of requiring comparatively little movement on site because of the large reach and capacity of their buckets.

The method is mainly appropriate on mineral soils or on peats less than 0.5 m deep. The subsoil should not contain a high proportion of clay, or the dressed surface will be unsuitable for walking. Site investigation of subsoils prior to machine operations is highly desireable.

Figure 7.8 Machine-constructed path on mineral soil in a peat grough (Devil's Dyke, Derbyshire).

7.8 Comparison of different techniques

It is difficult to compare techniques directly because site conditions such as accessibility, soil type, or available materials restrict the range of methods that can actually be used at any particular site. Neverteless some broad comparison of contrasting methods can be attempted using very general criteria (Table 7.1).

Several points emmerge. More techniques are available for mineral soils than for wet ground or peat. Only two methods, stone slabs and boardwalks necessarily rely on imported materials, although several other methods may require some importing where local materials are unsuitable.. Only one approach relies heavily on geotextiles, although again, other methods may sometimes use these materials. The labour requirement of all the hand construction methods is moderate to

Table 7.1 Comparison of different types of path construction

Path type	Suitable soil type	Use geo-textiles	Use local materials	Labour needed	Excavation needed	Skill	Relative cost	Visual intrusion
Aggregate	mineral	no	yes/no	high	moderate	moderate	moderate	low
Floated aggregate	peat or soft mineral	yes	yes/no	high	moderate	moderate	high	low-moderate
Soil cement	clay/mineral	no	yes	high	moderate	?	moderate	low
Stone pitching	mineral	no	yes	very high	moderate	high	high	very low
Slab	any	no	no	moderate	slight	low-moderate	moderate	low
Boardwalk	any	no	no	moderate	slight	low-moderate	moderate	moderate
Machine-built	mineral/ shallow peat	no	yes	low	substantial	high	low	moderate

high but pre-construction and airlifting can greatly reduce the amount of work on site in the case of boardwalk and slabs. Machine construction is much the cheapest method at suitable sites, even though some hand finishing is usually required.

Stone slabs and boardwalk involve the least site preparation, and only moderate levels of skill, although careful siting and supervision are still essential.. Most methods have fairly low visual intrusion if carefully installed (particularly stone slabs and pitching, which have a strong vernacular feel). Boardwalk and machine construction are probably the most intrusive in practice, but much depends on siting, finish and the skill of the operatives involved.

7.9 Technical gaps

Most of the methods described are fairly well proven, although in the case of floated paths, slab paths, soil cements and machine construction, monitoring is needed to indicate long-term performance and maintenance requirements. A technique that is low in initial cost but high in maintenance rquirements may be poor value in the long term, particularly if funds for maintenance are limited.

An area where further development and testing is needed is in the use of mats and surface geotextiles laid directly onto soils or vegetation to reduce wear and provide a partial wearing surface (see also Section 12, reinforcing soils and vegetation). At present there seems to be no satisfactory material to fill this role, although various trials are or have been underway in the Yorkshire Dales and on the Pennine Way with mats and nettings of plastic and natural fibres. Results are not yet available.

This section is concerned with techniques for canalizing use as a means of containing overuse. There are two main types of problem:

(1) controlling total numbers of users,

(2) controlling their distribution.

8.1 Controlling numbers

Overt and covert methods of manipulating numbers of visitors include adjusting the size and location of car parks, publicity (or the lack of it), charging and systems of permits. The latter techniques are usually only possible on private ground. These approaches are peripheral to this review, but there are good discussions in Brown et al (1985) (USA) Fishwick (1985) (UK) and van der Ploeg (1990) (Holland).

8.2 Controlling distribution

Methods of canalizing the distribution of uses within a site are of three main types:

* way marking of chosen routes/areas

* discouraging use of other routes/areas

* landscaping to minimise path spread.

8.2.1 Way marking

Many different ways of marking routes are used, ranging from cairns, through painted rocks to concrete blocks. Ideally the marker should indicate both the route, and the direction. In Britain a majority of sites are now marked using the Forestry Commission system of painted route posts, which are simple, informative and unobtrusive in most types of habitat. Posts are usually painted dark matt colours (green, brown or black) with actions highlighted in a primary colour.

8.2.2 Discouraging use of alternative routes

At many sites, there have been alarming changes in the extent and

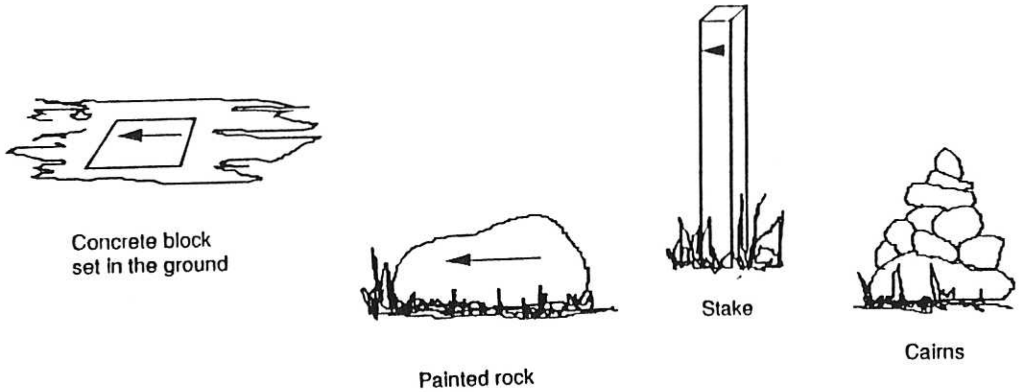


Figure 8.1
Waymarkers

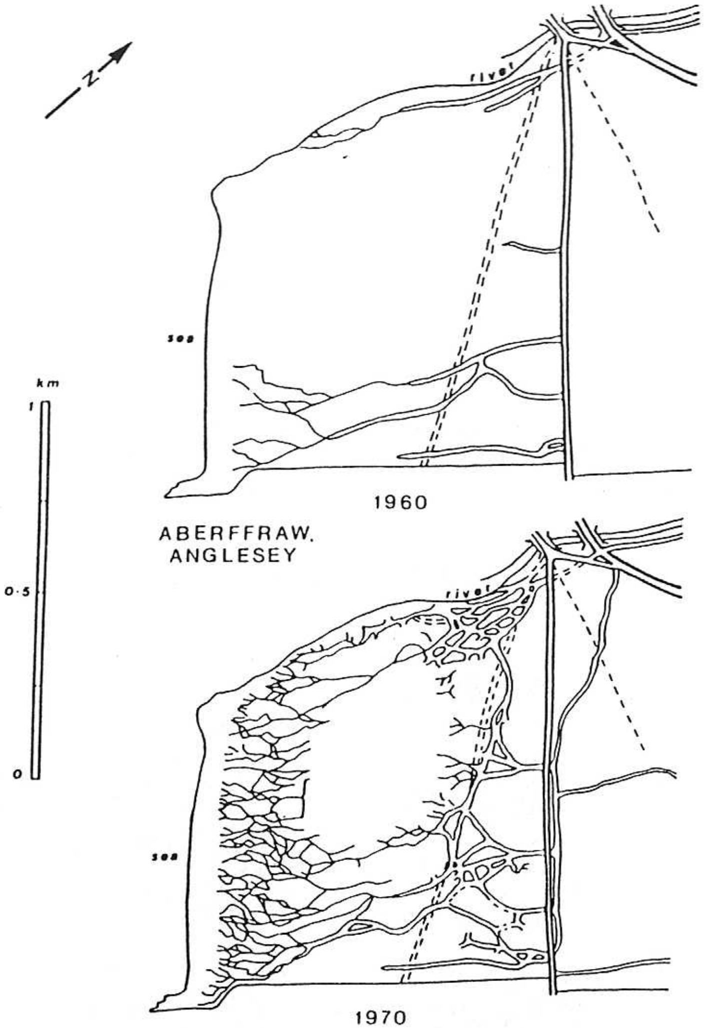


Figure 8.2 Changes in path density on Aberffraw dunes, North Wales, over a 10 year period (Liddle 1973)

braiding of footpaths. Liddle (1973) provides a good example for sand dunes at Aberfraw (Figure 8.2). In these situations, it is desirable to close some routes or at least reduce use, so that recovery can take place. Closing paths is probably easiest in woodland, where quantities of dead wood are often available for use as barriers or to obliterate the route, and where only short sections of path can be seen by users. It is much more difficult to close a route across, for example, moorland where long sections may be visible, and there is little material available for physical blockage.

There has been little systematic study of the effectiveness of different methods of closing paths, but a study in birch woodland by Bayfield and Bathe (1982) provides some indications of visitors responses to six contrasting techniques (Figure 8.3). The methods compared were rope, barbed wire and plank barriers, arrows, logs and brushwood. Only one technique, the

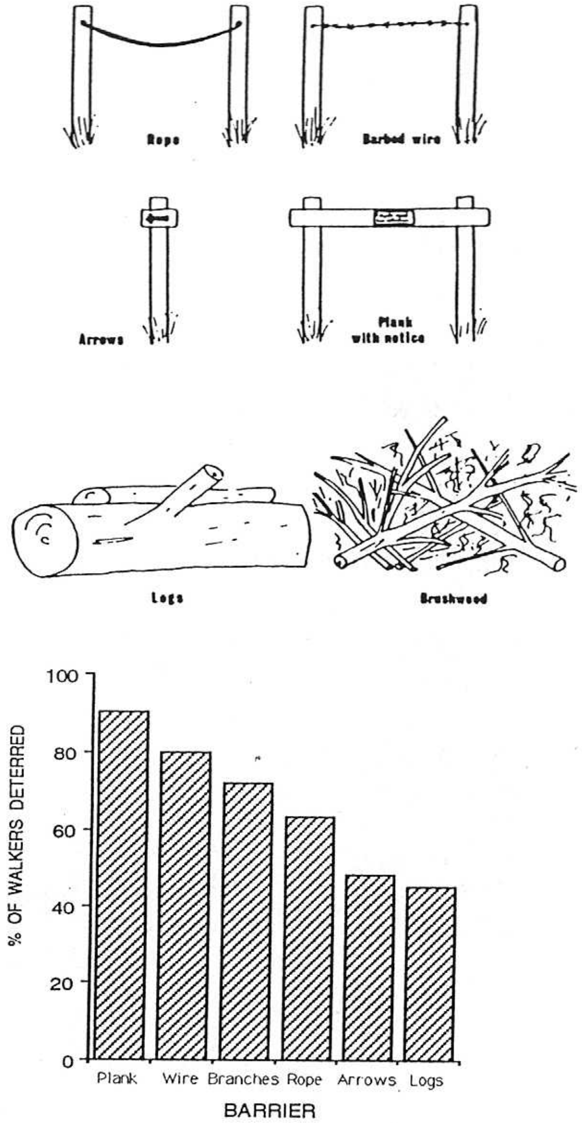


Figure 8.3 (above) Types of barriers used to close paths and (below) proportions of walkers deterred (Bayfield & Bathe 1982)

plank, included a notice ("path closed for restoration"). The most effective method was the plank with notice, but even this method only deterred about 90% of visitors. In more open habitats, path closure is likely to be more difficult. In general, from the experience of managers of a wide range of habitats, completely stopping use of existing routes is very difficult, and even very low levels of use are normally sufficient to keep a route open.

8.2.3 Landscaping to contain use

The guiding principle for landscaping techniques to help minimise route deterioration is to ensure that use of the route in question is the easiest and most desirable option for user. This means ensuring :

(1) that the route follows a clear line for users;

(2) there are no places where short cuts can develop (Figure 8.4);

(3) the surface of the path is always better for travel than adjacent ground. To this end, it is useful to provide a clear edge to the path or trail with turfs

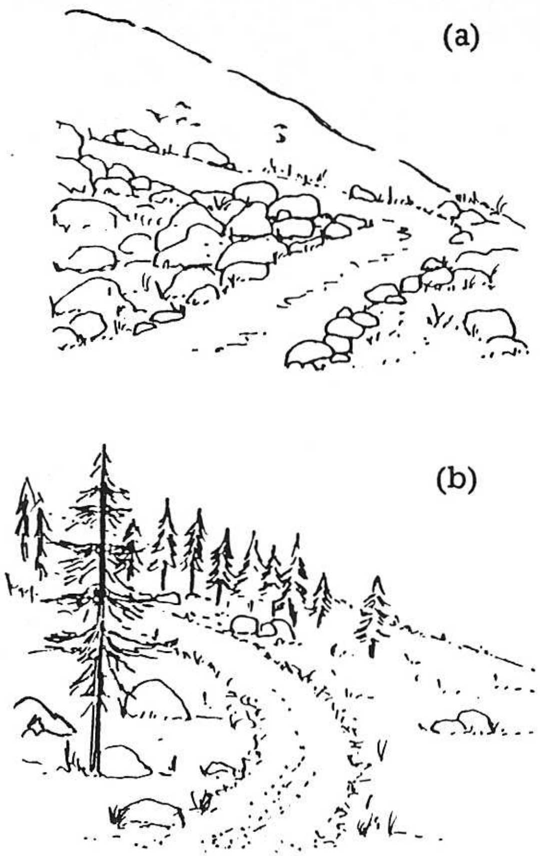


Figure 8.4 (a) Use of rock debris on the corner of a switchback turn to prevent shortcutting. (b) smooth turn designed with the same objective. Redrawn from USDA (1985)

or rocks. Landscaping of cut or fill slopes should wherever possible involve placing rocks, or fallen timber or other natural obstacles to help prevent the development of parallel routes. Planting clumps of bulky species such as rushes can serve a similar purpose once they are established. Example of suitable species include: *Juncus* spp.(rushes) *Deschampsia cespitosa* (tufted hair grass) *Sarothamnus scoparius* (broom) *Ulex spp* (gorse) *Salix* spp (willows and sallows) *Calluna vulgaris* (heather) *Ammophila arenaria* (marram grass) *Rubus* spp (brambles), most trees and shrubs, and most tussocky grasses. Suitable species will vary from site to site.

Temporary fencing may be required to permit satisfactory establishment. Recreation managers report, however that token fencing in the form of a single strand of baler twine or similar is sufficient to contain use at most sites.

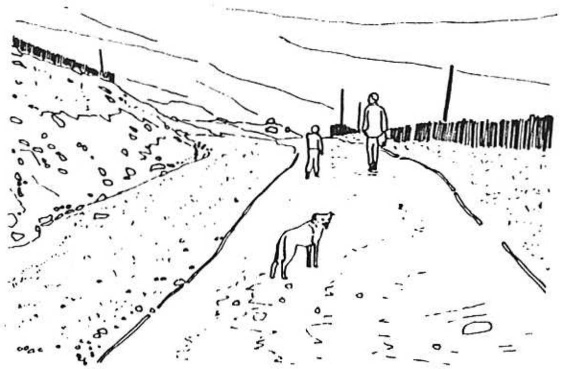


Figure 8.5 Use of tapes to control the lateral spread of walkers on Cairn Gorm.

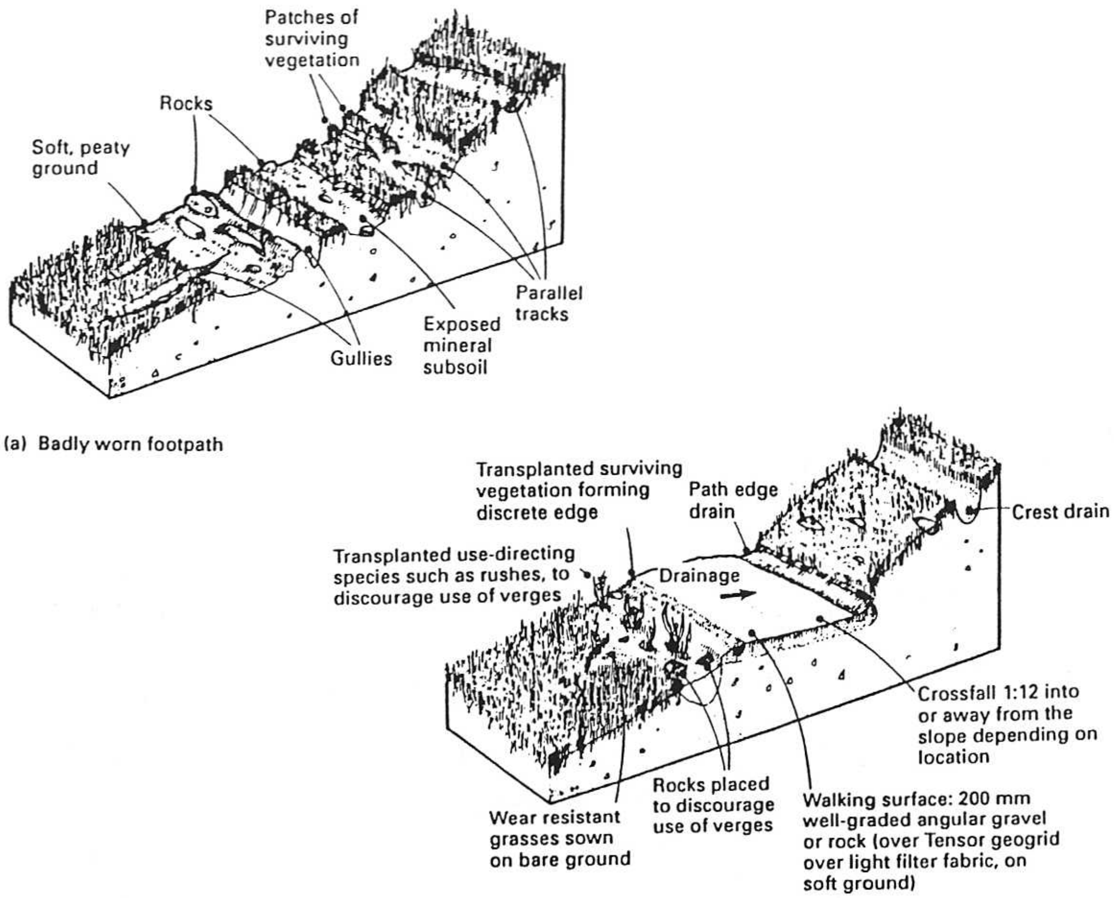


Figure 8.6 Landscaping paths to canalize use and minimize deterioration (CIRIA 1990)

On Cairngorm coloured tapes on the edges of tracks have effectively reduced lateral path spread and disturbance of seeded margins.

8.2.4 Technical gaps

There is little information available on methods of reinstating unwanted paths. The techniques required would probably require a combination of revegetation, soil replacement and user canalization methods, and might be better tackled by means of well-described case studies rather than a programme of research trials.

9 DRAINAGE

Outline

Taking ground management across all environments, drainage is perhaps the single most important factor to be dealt with. Waterlogging of ground can cause very widespread damage as visitors seek to avoid wet areas, while even modest scour along a path can progressively erode the best constructed surfaces or steps. The sites with the worst damage on footpaths are almost invariably those with major drainage problems.

The basic techniques for drainage management on paths, being fundamental to good practice, are well established and adequately documented in existing published advice. See for example the path handbook by Agate (1983) and the Countryside Commission for Scotland management handbook for ski areas(1989). To a degree, however, the detailed application of these techniques depends more than in most ground management on observation and experience. The principle that the site area, rather than the path itself, should be drained generally holds good, though it can be a counsel of perfection in mountain environments or in peat areas.

Traditional types of drain include open drains and french (stone-filled) drains. Recent innovations are various types of slot drains, wrapped in filter geotextile. These drains may be suitable for some types of lowland situation, but managers of upland paths report that the filter textiles are easily clogged by peat debris and silt.

Much of the detail of drainage work relates primarily to the style of the path, its intended use, and the nature of its environment. Thus (for instance) open ditches and cross-drains may have some value as barriers to mountain bikes or trail bikes, though conversely, they may present a serious barrier to wheelchairs and even to families with small children. The degree of maintenance likely to be available is another important consideration which may determine whether open cross-drains should be preferred to piped or built culverts.

An important issue in drainage is the problem of anticipating and handling the extreme rainfall or snowmelt event. Simplified engineering formulae are available to calculate runoff (e.g. in Agate 1983), but for accurate application they require a degree of ground survey that will seldom be possible or justifiable for path management purposes alone. A more constructive response is simply to install drainage crossings at frequent intervals, and to build crossings so that storm flows can if necessary overwash the path without causing acute damage. Agate's own comment "that culverts must always be bigger than you expect" is appropriate.

Technical gaps

Although drainage clearly has an important role in strengthening soils against wear, there has been little formal study to compare different methods and effects of different types of site conditions

10 USE OF MACHINERY

10.1 Introduction

The use of machines for ground management and path repair has increased in recent years partly as a result of the high costs of manual work and the lack of skilled labour. Plant hire is often attractive to managers who may not have problems or resources that allow the employment of their own specialist staff.

Experience in sites from the Three Peaks Project to the West Highland Way, and on a range of Forestry Commission projects, indicates that the base cost of machine construction of paths can be a fraction - as low as 10% in some cases - of the cost of construction by hand. That does not, however, allow for the costs of hand-finishing which may very significantly reduce the differential.

However, practically all machine work involves the likelihood that the powered vehicle, whether on wheels or tracks, will create impacts over and above the original ground damage - not to mention temporary intrusion in what is often perceived as wild country. To limit these impacts often requires a higher degree of planning and care in operation than in conventional machine construction work, and possibly a high degree of manual finishing to achieve an appropriate style. For these reasons the most effective machine work in path construction to date tends to have been on low ground and in forested areas; results on open hill country have been less satisfactory. Nonetheless there is considerable financial pressure to achieve acceptable machine results in upland and moorland.

To date the use of machines in path work has fallen into two categories:
(1) path construction involving earth-moving, and
(2) path laying involving the importation of surfacing material.

Obviously there is often an overlap, but the two can usefully be treated separately here.

10.2 Use in path construction

Fundamentally the techniques of path construction by powered digger are scaled-down versions of those used in the construction of forest roads; most of the work done to date has been carried out by contractors skilled in roads work.

The best results have been achieved where a cross-slope provides sufficient cut for good surfacing material and a gradient for a lateral ditch on the uphill side of the walking surface. A skilled operator can conserve and re-use much of the local vegetation cover. In these circumstances a conventional excavator with a 2.5 m wide trackbase, using a wide bucket, can work an alignment to leave a path only a metre wide behind it. With suitable local materials it is possible to achieve several hundred metres a day of path base.

The direction of working is important to ensure that the machine does not have to travel back over its own work.

In the UK it is usually practicable to run a machine between two points of access, but in Tasmania small machines have been helicoptered into remoter country so that they can work out towards the roadend. It may be well worthwhile to take a machine overland to the furthest possible point and then work backwards along the desired path line. Through drainage is usually by piping, though with hand-finishing, open cross-drains can be built.

Although scaled-down excavators with a metre-wide trackbase are now in common use with contractors, current indications are that there are few advantages in deploying smaller machines unless local site conditions limit the use of the larger versions. On soft ground, the ground pressure of a full-size excavator is not greater because of its wider track area, while it offers much more power to handle boulders or peat and a wider radius of reach. However, mini-excavators can be useful in ditching and other smaller operations Different effects will be achieved with the use of different sizes and styles of digger bucket; it is helpful to find a sympathetic contractor willing to experiment.

Figure 10.1 Path construction with a Hymac excavator

The use of machines can reduce the construction period, and so allow rapid ground recovery. But inevitably, the line produced by machine tends to lack the informality and irregularity of a naturally evolving path; in open country its visual effect can be decidedly unnatural. There is, therefore, a critical need for care in alignment, to avoid excessive regularity of line and width, and for good finishing.

Experience suggests that excavator construction is much less useful on deep peat,where even the widest tracked machines can become bogged, and where it may not be possible to bring in good mineral material within the machine's radius of reach.

10.3 Transporting materials

A variety of tracked and low wheel pressure all-terrain vehicles have been used for the transport of materials in path management trials. Since this usually involves repeated passes over the ground, it can generate substantial damage depending on local conditions. Argocats and similar vehicles with tracks or low-pressure tyres may break up the sward, particularly where they need to make frequent turns, and do not have a high load carrying ability in any case; in both Pennine Way Project and the Scottish Footpath Management Project, their impact was found to be seriously detrimental.

However the path being constructed can itself function as the route for these vehicles. In the Three Peaks project the need to use vehicles was accepted at an early stage, and the main paths were constructed to a standard width to accommodate wheeled dumper trucks. In some situations this might produce an unacceptably wide and regular alignment. More work is needed to establish whether a path laid to a width of two metres or more could subsequently be drawn in by manual finishing to a narrower and more sinuous line.

A smaller-scale solution has been the use of powered carriers, running on a base of plastic tracks under a metre in width, and originally designed for large garden or estate use. These are now used extensively by Pathcraft Ltd in Scotland for the local transport of surfacing material, and have proved capable of dealing with very rough terrain, though the specification could be improved if there were more demand for this application. These carriers can certainly save much time and very strenuous effort in carrying stone and gravel by hand.
Tracked carriers can also negotiate stone-built cross-drains without inflicting damage, so can operate along a path to the "trailhead".

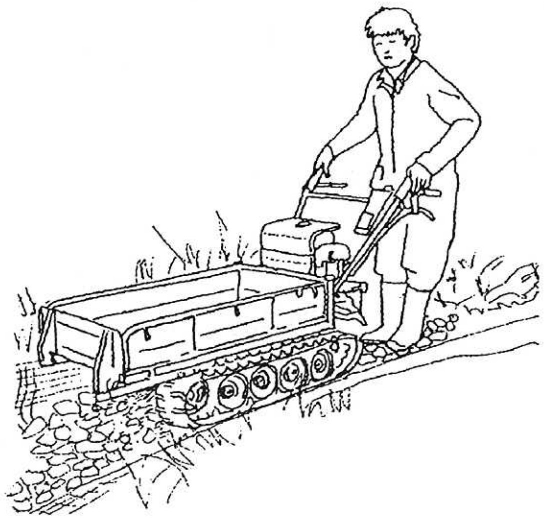


Figure 10.2 Honda tracked carrier.

Multi-wheeled Argocat-type machines and even dumper trucks have been used in a similar way in Three Peaks for path restoration work. However, large vehicles like dumpers need a substantial path width to operate on, which is a considerable drawback. It should be noted that the use of any vehicle on a geotextile-based path tends to compact the surfacing materials and to create incipient surface drainage problems.

Another solution used on the Pennine Way in the Peak National Park and elsewhere is a small trailer towed by a four-wheeled motorbike. This combination has been found to be easy to load and unload, and to be relatively fast and manoeuverable.

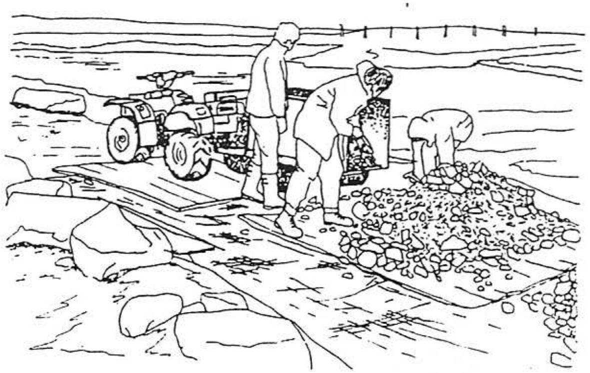


Figure 10.3 Loading a four wheel motor bike and trailer combination. (Snake Pass). Note the use of boards and geotextile to protect the ground.

Damage to soils and vegetation is considered to be lower than with multi-wheeled Argocat -type machines.

Forms of powered carrier based on conventional two-wheeled barrows have been found to be unsatisfactory and in some cases difficult to handle.

There is little advantage in using ATVs for transport of personnel to work sites. As in transporting material, these vehicles can cause a good deal of damage if used for repeated trips over the same ground, especially if it is waterlogged or frozen. On rough terrain, it will often be faster to walk. On the other hand it may well be justifiable to make one or two journeys to help in getting tools and equipment to remoter sites.

Air transport

Helicopters have been used in various upland and island sites, usually for transporting prefabricated boardwalk or path surfacing materials; but in the Lake District and the Peak District they have carried up large volumes of soil and other materials for ground restoration and landscaping. The cost of commercial hire ofhelicopters is high - typically over £300 per hour for a small machine - and may be prohibitive unless path work can be integrated with other local work. The Services are often willing to help, but will tend to dictate their own timetable and will usually restrict their assistance to a one-off or an occasional effort to avoid the perception that they are undercutting commercial operators.

In either case careful organisation of materials and handling is vital to maximise the benefits and to ensure the safety of all concerned. Substantial manpower is needed to allow fast turnaround or materials The use of helicopters is, however, excellent for morale and for publicity for path work - effects that should never be underestimated.

11.1 General principles

11.1.1 Introduction

Given time, almost any bare soil surface will be revegetated by natural colonisation. Studies of bulldozed hill roads in the Cairngorms show that even at >1000 m, vegetation of spoil is almost complete after about 30 years, (Bayfield et al 1984). In less inhospitable locations, a majority of bare ground sites are probably colonised within five years, and some in two or three.

Even these rates are, however, unacceptably slow for most recreation sites, where the aim is to reinstate bare or damaged surfaces as rapidly as possible, to minimise both erosion and visual intrusion.

In the past it has been acceptable to merely provide some kind of vegetation cover, any kind of vegetation cover. During the last decade however, planners and managers have begun to demand higher standards of revegetation, involving use of native species, and landscaping schemes that try to blend damaged areas to the surrounding ground. Specifically the *nouvelle cuisine* of reinstatement aims to:

- use appropriate native species;
- use local or native strains where available;
- create vegetation pattern ("geometry") similar to intact ground
- create ecologically diverse stands of vegetation
- prepare surfaces for planting that blend with surrounding landforms
- integrate engineering, vegetation reinstatement and landscaping management of damaged sites.

Some of these objectives are difficult to achieve, and there are frequently time, cost or technical constraints on implementation. There are consequently few well documented examples of these principles in practice. Nevertheless these objectives provide good criteria against which new schemes can be judged, and similar guidelines are likely to provide a pattern for the future.

11.1.2 Strategy

Before selecting the individual techniques that will be required, it is necessary to have a clearly defined site vegetation strategy. This will be largely determined by the overall character of the site, and the broader aims of management. Factors that are particularly influential include:

- soil type and fertility
- size of any seed bank
- vegetation type and patterning
- severity and extent of damage
- landforms, drainage and other site factors
- type and management of use.

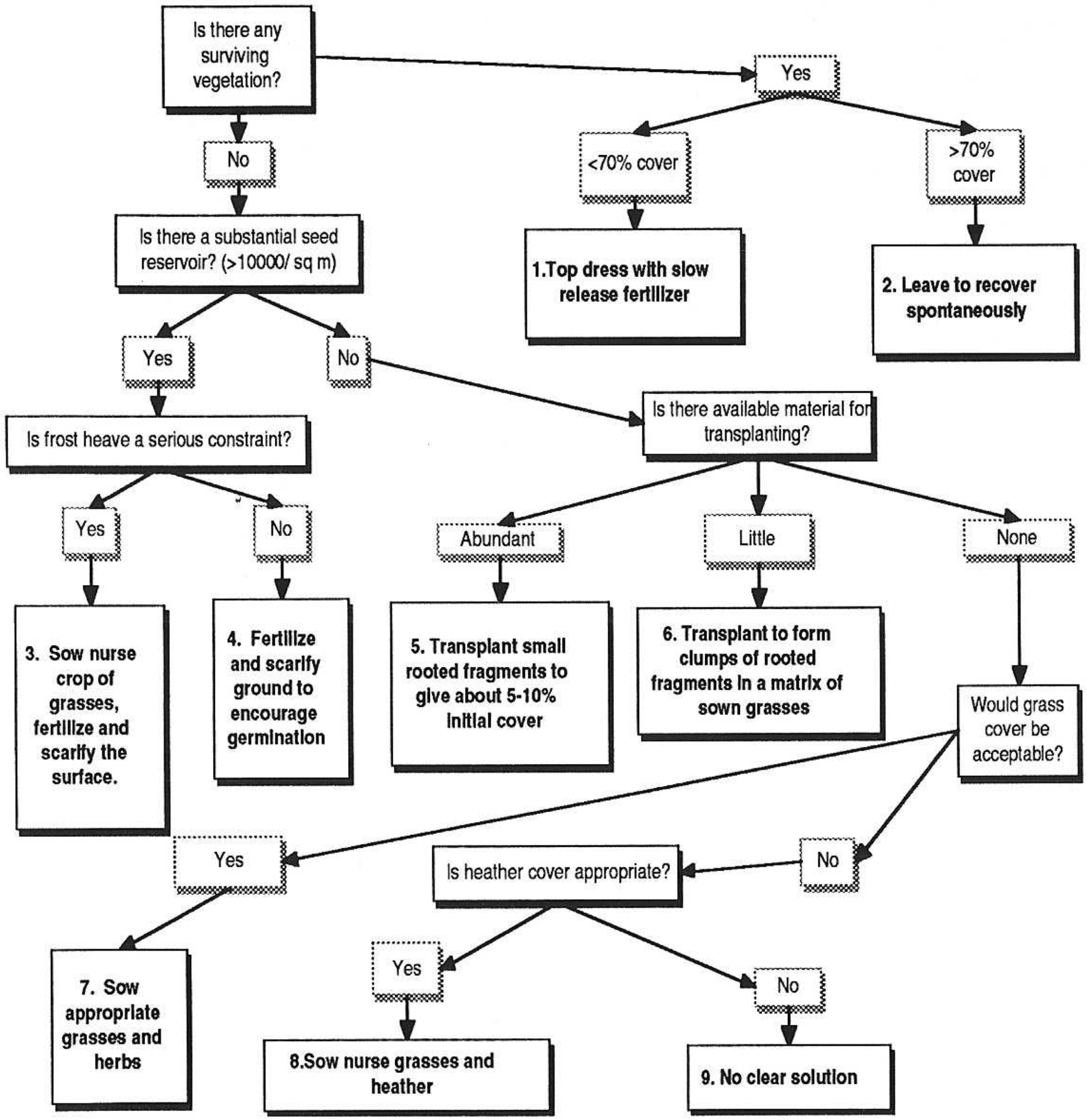


Figure 11.1 An example of a decision guide to revegetation for sites on the southern Pennine Way (ITE 1988)

For individual environments it should be feasible to construct decision guides based on key site features, to indicate the most appropriate approaches. Few such guides are available, but an example is given in Figure 11.1 for sites at the southern end of the Pennine Way.

11.1.3 Tactics

Even when the overall site strategy is clear, several different approaches may be needed within a single site, to suit the severity of damage, level of continuing disturbance and other factors. Most sites are very patchy in this respect, and require thorough site evaluation (Section 3).

In the case of a reconstructed path, for example, the path surface (if seeded), would require to be sown with trample-resistant species, whereas adjacent damaged ground, on which disturbance would now be relatively low, should be reinstated with species appropriate to the surrounding ground, and probably with only low or moderate resistance to trampling (Figure 11.2).

Ground bare of vegetation will

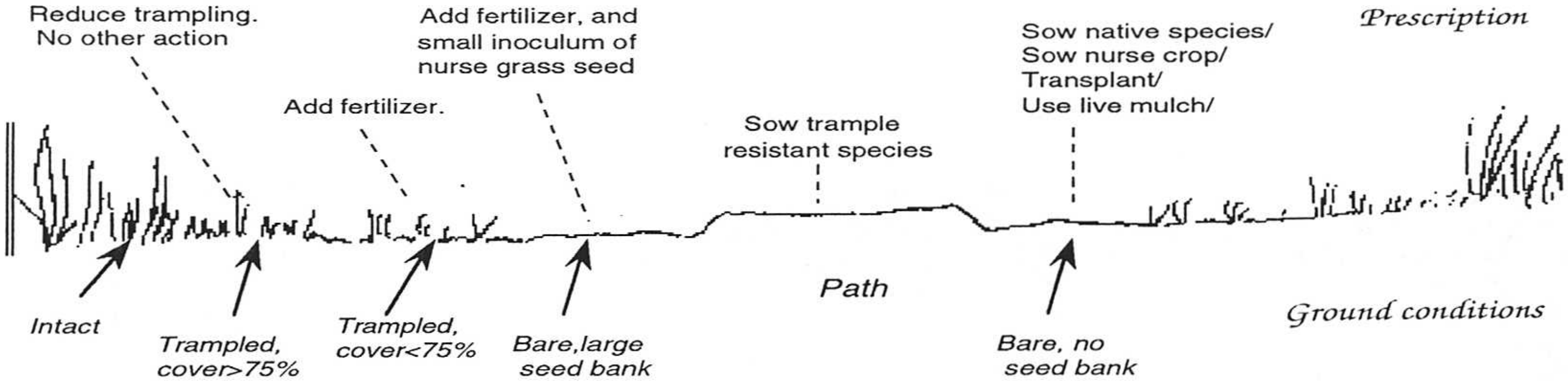


Figure 11.2 Revegetetion tactics depend on site conditions and amount of damage. Details of individual techniques are given in the text

require substantial intervention in the form of seeding or transplanting, although where there is a large seed bank, this may reduce the input required. Partially bare ground will also need less treatment, and where cover is high, rapid spontaneous recovery is likely without any further treatment provided the level of further disturbance is at a low level.

Techniques for revegetation, follow below, and details of approaches for vegetation reinforcement are given in Section 12.

11.2 Transplanting

The techniques described here are all ways of re-using existing plant resources. They include movement of intact vegetation in the form of turves or larger "clods", stretching or dividing clumps of vegetation, bare root transplants and taking cuttings. Special techniques for trees and shrubs are outlined later.

11.2.1 Transplanting habitats

A near ideal way of reinstating a damaged habitat is to transplant similar material from elsewhere.

There have recently been examples of whole habitat transfer, involving habitats as diverse as woodland (Down & Morton 1989), marshland (Helliwell 1989) and magnesian limestone grassland (Park 1989) all involving moving large blocks of vegetation and soil to new locations. Care is needed to ensure that the blocks are replaced either in the same juxtaposition as they were cut, or at least so that the broad patterning of vegetation remains similar. The trials undertaken so far (which include part of an SSSI, at

Thrislington) indicate that relocation is both technically and biologically feasible.

Whole habitat relocation is likely to be rare at recreation access sites, but small scale relocation, particularly during the course of engineering work, may sometimes occur. A sequence of strip-build-replace is commonly used at pipeline sites (ACLU 1990) where the technique is termed "clodding" (Figure 11.3).

This method is particularly good for delicate habitats and wet or stony ground where cutting turves would be difficult. The main drawbacks are the need for heavy machinery, and for skilled operators, capable of replacing clods to form a level surface and without too many gaps. In practice some hand finishing is desirable to pack gaps with topsoil or peat, and level off protruding edges. Material for packing gaps should be from similar ground, and not imported topsoil that could contain weed seeds and be of different fertility to the clodded material.

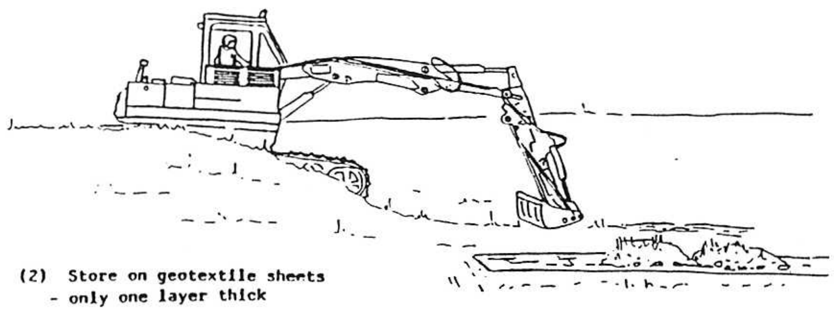


Figure 11.3 The clodding technique as used in pipeline construction

11.2.2 Turfing

Turfing is a small scale version of clodding, and is one of the most rapid and successful means of revegetating damaged ground. Turves can be cut by machine but are more likely to be hand cut at most recreation sites. A spade may be used, or the special tool termed a turf float. Turves can be as small as 0.3 x 0.3 m or up to 0.3 x 1.0 m. The small size is best for turf which is poorly consolidated. After lifting, turves can be "boxed" (cut to uniform thickness in a simple wooden frame) to make them easier to lay. In stony soils, however, this may be impractical. Turves should ideally be laid as soon as possible, but can be stored for up to 4 weeks in spring or 2 weeks in summer (Webb & Rose 1981). They must not be allowed to dry out, as they will shrink, and establishment is impaired. There are three main patterns of planting, close turfing, spot turfing and stretched turfing.

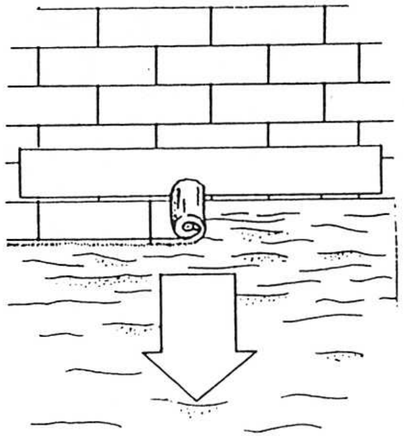


Figure 11.4 Turf laying. Work proceeds in the direction of the arrow (Hope 1990)

Close turfing

This involves completely surfacing with turf. Turves are laid brick fashion

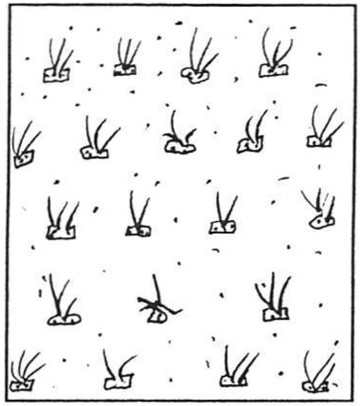


Figure 11.5 Grid pattern for spot turfing

(staggered) as this ensures an even knitted sward. Any gaps should be packed with local topsoil, but seeding should not be required unless the gaps are substantial. To avoid trampling damage during laying, boards should be placed on turf in the working area. The main drawback to this method is finding sufficient appropriate material. It is important to match the turf to site conditions. Thus mire turf will not do well on a dry slope, and neither will heather turves succeed if transplanted above their altitudinal limit.

Spot turfing

This method is often adopted when the turf is in short supply, or close turfing is too expensive. Turves are planted on a grid, with gaps from 15 cm to 1 m between turves, depending on the amount of material available, and the type of vegetation. The gaps can be reduced by using a larger number of smaller turves. The minimum size would be about 10 cm x 10 cm for grassy vegetation, and about 20 cm x 20 cm for dwarf shrubs . Gaps can be sown with suitable grass.

Stretched turves

This is a popular method in the tropics, where closely-knit turf is uncommon. Turves are pulled apart to up to twice their original area, by hand or by the use of a pair of forks back to back. The stretched material is laid as for close turfing, but with soil worked into the surface to fill the numerous gaps.

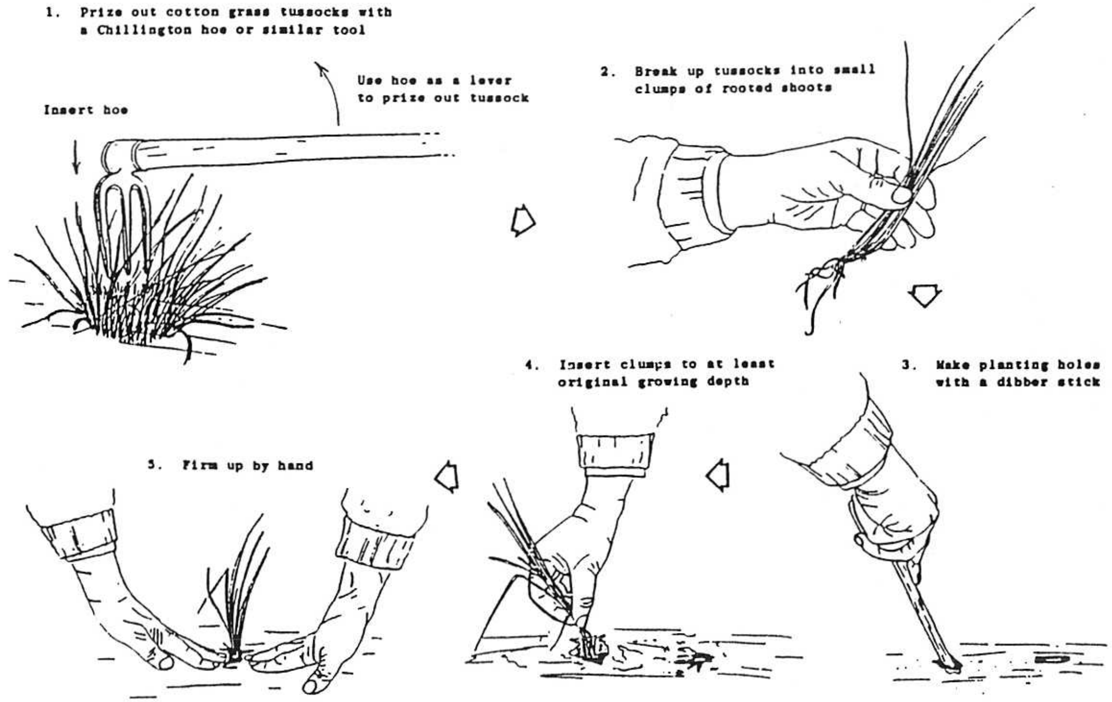


Figure 11.5 Transplanting bare root clumps of Eriophorum vaginatum *(cotton grass) (ACLU 1990).*

11.2.3 Bare root transplants

Many species can be transplanted directly from intact ground by extracting small clumps with a Chillington hoe or similar tool then pulling the clump apart to a large number of rooted fragments. If undertaken carefully, little damage will be done to the source area. Tussock species such as *Nardus stricta*, *Deschampsia cespitosa* and *Juncus effusus* are particularly suitable, and creeping species such as *Ammophila arenaria* and *Eriophorum angustifolium* also transplant readily in this way (Figure 11.5).

In studies for the Countryside Commission for Scotland, Yorkshire Dales National Park and Peak National Park, ITE have been screening upland species of vascular plants and bryophytes for transplanting and have undertaken field trials with a limited range of species in Scotland, the Dales and in Derbyshire (Bayfield & Miller 1987; Bayfield 1991; Bayfield et al 1991).

Details of planting dune grasses are given by Ranwell and Boar (1986) and for planting waterways by CIRIA (1990).

Table 11.1 Pros and cons of transplanting methods

	Pros	**Cons**
Clodding	Suitable for difficult ground and wet sites that cannot be turf-stripped Immediate high cover achieved	Requires heavy machinery and skilled operators
Close turfing	Immediate high cover achieved	Heavy labour requirement Needs abundant supply of turf
Spot turfing	Less turf needed t han for close turfing	Seeding of gaps may be required
Stretched turfing	Rapid cover from limited supplies of turf	Topsoil also needed. More vulnerable to drought than other turfing methods
Bare root transplants	Good way of creating patches of pattern or colour	Care needed in extracting material to avoid creating more damaged ground
Pot transplants	Rapid means of providing large plants	Very costly.

Bare root direct transplants can have high survival provided they are not allowed to dry out during preparation and there is not a drought after planting.

11.2.4 Pot grown transplants

Most native species can be propagated from seed or cuttings in pots,for transplanting into suitable locations. Because of the high labour and transport costs this method is usually confined to sites where there is a severe shortage of suitable material locally, or where it is desired to rapidly create colour or texture. Pot transplants have for example been used in road schemes to give rapid wildflower cover (Wells et al 1990), and have been used experimentally for heathland restoration (Environmental Advisory Unit 1988).

In practice large pot plants do not always readily transfer into the field, and mortality can be high (Wells et al 1990).

11.2.5 Pros and cons of transplanting methods

All transplanting techniques have the advantages of providing a greater or lesser degree of instant cover, and of being able to use local material (where available) appropriate to the site. All the techniques also have the disadvantage of having a relatively high labour requirement, and are usually more costly than corresponding seeding methods. Advantages and disadvantages of individual techniques are shown in Table 11.1

11.2.6 Technical gaps

There is only limited information on the suitability of individual species for transplanting. Existing information needs to be collated, and further species screened. Development trials with transplants should be undertaken to time and cost these approaches and to compare results with those from seeding.

The Countryside Commission for Scotland commissioned one such trial, on moss-rich heather moor during 1991-2.

11.3 Live mulching

11.3.1 Outline

This method consists of planting damaged ground with a mixture of topsoil, moss or plant litter and plant fragments (some rooted) cut from intact ground with a sharp rake or similar cutting instrument. The material ("live mulch") is spread on the area to be reinstated, at a rate of 1-3 litres/m^2, and lightly worked into the surface. It is then gently consolidated to ensure good soil-mulch contact. Live mulch can provide seeds, topsoil, mosses, vegetative fragments of mosses and vascular plants, all of

Figure 11.6 Cutting live mulch by hand with a multi-bladed hoe

which can potentially contribute to plant cover. In addition the mulch provides a small element of shelter to the soil surface.

The composition of live mulch varies widely from plant community to community. Mulch cut from *Rhacomitrium* heath contains little but *Rhacomitrium* moss and a few fragments of *Deschampsia flexuosa* (wavy hair grass) whereas mulch from birch woodland can contain quite a wide range of grasses, herbs, mosses and viable seeds.

Recent studies of live mulch from different habitats show that the yield of material varies quite widely as well as the composition. In most cases extraction causes little damage; a light dressing of compound fertiliser speeds up the process of recovery without any obvious deleterious effects on species composition (ITE study for Countryside Commission: report in preparation).

The vegetation cover achieved by dressings of live mulch increases with the rate of application, but the most rapid cover is achieved by the use of a combination of live mulch plus sown grasses. This combination provides quick cover (>70% in a season) and relatively high species diversity. Results obviously vary from habitat to habitat, but live mulch has been shown to provide species not available commercially such as *Luzula multiflora*, *Galium saxatile* and *Junus squarrosus*, *Sphagnum* species and *Hylocomium splendens* that are generally secondary rather than primary colonists of bare ground (Table 11.2) (Bayfield et al 1990).

The technique is most successful when ground conditions permit ready rooting. A severe drought can kill much of the living material present before it can get established.

11.3.2 Pros and cons

Overall, this is an interesting technique that offers a simple way of providing local material without requiring turf cutting or extraction of clumps of vegetation. Disadvantages relate mainly to the relatively large amount of effort required to collect the material and apply it, and the vulnerability of the live material to desiccation.

Table 11.2 Cover of main categories of vegetation at Red Moss, Yorkshire Dales, on bare peat sown with grasses plus live mulch or grasses alone. The differences are highly significant (analysis of variance).

	Seed + live mulch	*Seed alone*
Heather	*t*	-
Grasses	*56.4*	*44.9*
Sedges & rushes	*8.9*	*2.9*
Heath bedstraw	*1.3*	-
Mosses	*14.2*	*1.5*
Bare ground	*28.0*	*42.7*

Advantages

1 Highly appropriate material from nearby intact ground.

2 Contains propagules of mosses and vascular species not available commercially as well as seeds

3 No capital expenditure required

4 Little damage to extracted areas

5 The material has a slight mulching effect on the soil surface

Disadvantages

1. Laborious to collect. No machine extraction at present.
2. Living components of the mulch are very prone to desiccation
3. The volume of material extractable per square metre varies from site to site
4. Not very suitable for dry sites
5. Satisfactory partial burial is time consuming and requires skill

11.3.3 Technical gaps

The main technical gap is the need to develop a suitable machine for extracting live mulch and demonstrating the practicality of the approach on a larger scale. Use so far has mainly been on small research plots at upland sites.

11.4 Seeding

Seeding is probably the most widely used method of reinstating damaged ground at recreation sites. The issues covered in this section include the selection of appropriate seeds mixtures, methods of sowing, and the use of species as nurse cover or as permanent contributors to vegetation.

11.4.1 Selecting seeds mixtures

The selection of seeds mixtures is not a precise science, and the novice can be forgiven for thinking there are almost as many mixtures as advisors. Certainly seeds rates can vary by a factor of at least 10, and the numbers and proportions of species are almost equally flexible. There are, however, a few guiding principles for mixtures for recreation sites.

1. The seeds mixture should be matched to site conditions: paths and heavily used areas will need trample resistant grasses, whereas little used areas can be seeded with species similar to intact adjacent ground; potentially including a broad spectrum of semi-natural species.

2 At sites of high nature conservation importance, it is desirable to sow local provenances of seed, but these are more expensive than ordinary stock varieties.

3 Not all the species that one might like to sow are available commercially. In 1990 for example, no *Deschampsia flexuosa* was available because of a crop failure. It is generally preferable to sow a restricted range of species rather than substitute inappropriate species that may be aggressive and persistent.

4 Where it is hoped to produce an open sward that can be colonised by forbs and cryptogams it is important to avoid sowing species such as *Festuca rubra* that produce a dense, smothering cover.

5 Sowing forbs to create wildflower swards requires careful species selection, and appropriate management. Establishment is generally rather slow, and it may be several years before flowering occurs. The seed is relatively expensive, and germination can be erratic.

6 The proportions of species in a

sward rarely matches that sown. Some species such as *Deschampsia flexuosa* have poor establishment and need proportionally higher seed rates than more successful species such as *Agrostis capillaris*. Discrepancies in establishment result from variations in germination rate, early survival and competitive ability between species; each of these factors can vary with site conditions.

7 Small seeded species such as bents (*Agrostis* spp) are usually sown at much lower rates than large seeded species such as ryegrass (*Lolium perenne*).

8 Seeds merchants tend to advise higher than necessary seed rates. 15-35 g/m^2 can be appropriate for lawns and golf courses, but 5-10 g/m^2 is more usual for recreation sites.

It can be seen that the number of factors influencing mixture composition is large, and there can be several broadly acceptable mixtures even for a single site. In practice, however, most managers either take specialist advice or use one of the commercially available mixtures, or one of the published specialised mixtures.

Detailed information on commercial amenity mixtures is available from seeds merchants such as British Seed Houses and John Chambers. Lists of wear-tolerant species are produced annually by the Sports Turf Research Institute, and mixtures for specific habitats are provided in various papers, reports and books. Mixtures for coastal dunes are, for example, given by CIRIA (1990) and Ranwell & Boar (1986), for uplands and heathlands by Environmental Advisory Unit (1988) and Bayfield & Miller (1988).

A handbook for sowing wildflowers on trunk roads and motorways by Wells et al (1992) provides general purpose mixtures for a wide range of site types and a simple key to selecting an appropriate mixture (Figure 11.7). The authors note, however, that there has been little systematic testing of mixtures under field conditions, and that the success or failure of a mixture can depend critically on site conditions and on the management of the sward. This is a general criticism of seeds mixtures; they have rarely had detailed testing under field conditions.

Wells et al have also developed a software package that permits the selection of wildflower species appropriate to different regions of the UK, and to suit various combinations of site conditions. This was intended for tailoring mixtures to specific sites.

11.4.2 Use of Nurse species

Nurse species are sometimes included in mixtures in order to provide quick cover, and shelter for slower-growing species. Suitable nurse species should be rapid-growing, but not produce so much cover that other species are stifled, and short-lived, permitting other species to replace them after a season or two. Classic nurse species are Westerwolds ryegrass and barley, which are annuals. For most recreation sites these species look very odd in the first season because of their tall habit and bright green colour and are consequently not often used. More common is perennial ryegrass (*Lolium perenne*) (which does not persist long in infertile soils) and Yorkshire fog (*Holcus lanatus*) which is not very frost tolerant, and so is suitable for exposed sites.

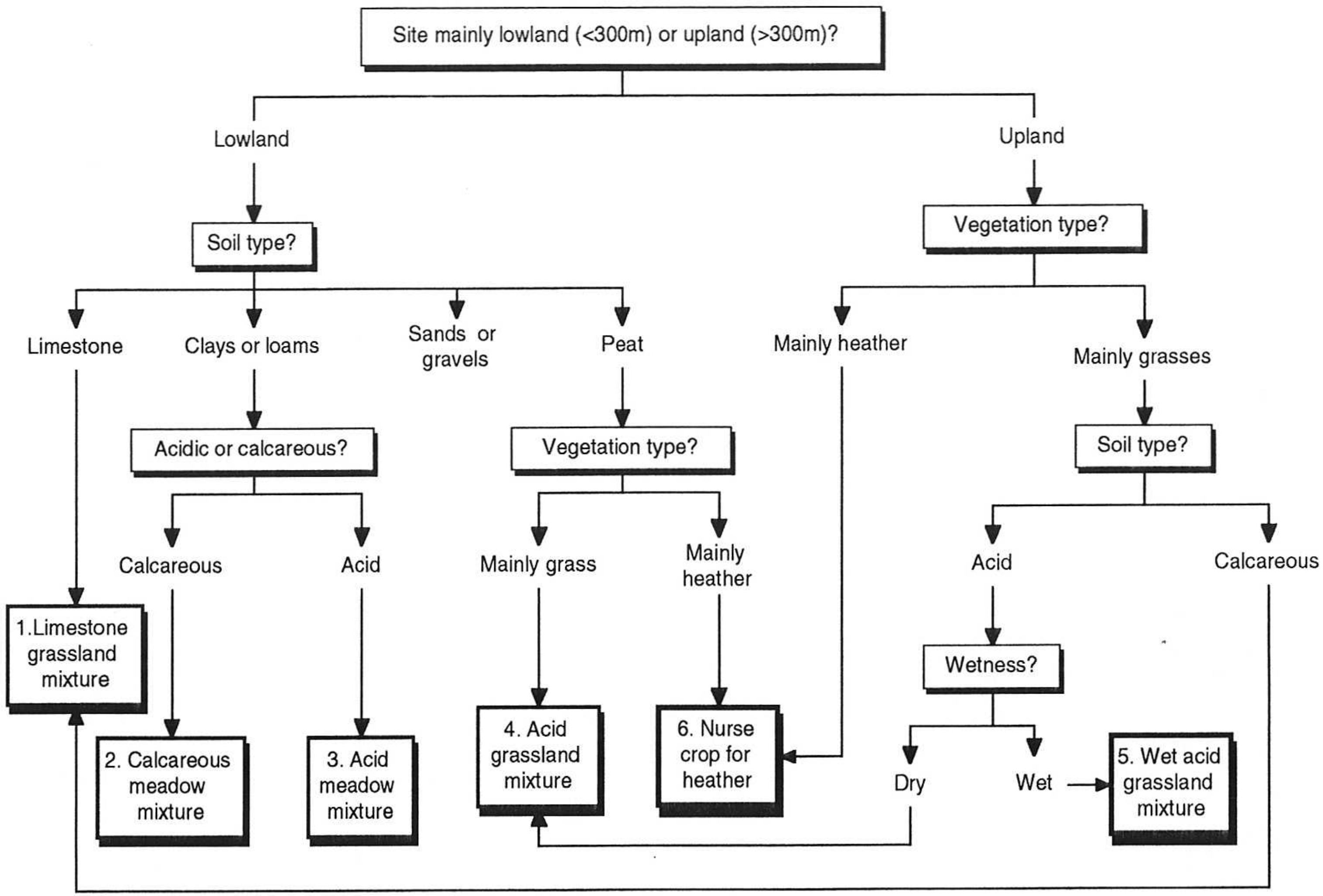


Figure 11.7 Example of a decision key for selecting wildflower mixtures . Details of the mixtures are given in Wells et. al. (1992).

Sites being reinstated with heather nearly always need a nurse crop because of the small size and vulnerability of heather seedlings. *Agrostis* species are commonly used, but red fescue (*Festuca rubra*) meadow grass (*Poa pratensis*) and others have been used successfully (Environmental Advisory Unit 1988). Heather seedlings gradually replace the grasses over a period of 5-8 years (Bayfield 1980).

For more rapid-growing species the advantages of sowing a nurse crop are less clear cut.

Trials in the Three Peaks, for example, involved three contrasting grass mixtures for use on upland mineral soils. Cover produced with and without a nurse crop of Yorkshire fog (*Holcus lanatus*) was assessed. The trials concluded that although the nurse species gave a slight boost to total cover in the first year, there was generally lower total cover in the second and third year than on plots without the nurse species (Bayfield et al 1991). Similarly, high altitude trials at the Lecht in NE Scotland, used several contrasting nurse species including *Poa annua*, *Lolium perenne* and *Holcus lanatus*. The grass mixtures established satisfactorily during the first season, but failed to indicate any advantage in having nurse species in the seeds mixtures.

Unfortunately few detailed trials of this kind have been undertaken. There is a need for further experiments on the use of nurse species to give clearer guidlines as to when and where they are beneficial, and which species are most useful.

11.4.3 Sowing

There are three main methods:

* drilling: direct placement of seeds in the soil

* broadcasting: dry spreading seeds

* hydroseeding: spreading seeds in a water slurry, usually with other ingredients such as fertilisers and tackifiers.

Drilling is only practical on large areas of fairly level ground (and stone free soils) suitable for tractor-mounted drills ; such areas are uncommon at recreation access sites. There are few examples of drilling at UK sites.

Broadcasting sowing is the most commonly used method and can involve hand sowing, or the use of various types of backpack or tractor mounted seed spreaders. Care needs to be taken to ensure even spreading of seed. With very small seeds it is useful to mix the seed with sand or fine sawdust to make it easier to see gaps or dense patches. Ground to be sown is best raked and roughly levelled to form a seedbed prior to sowing. After seeding, rolling or some other method of light compaction will help partially bury seeds, and keep the surface moist.

Hydroseeding is a relatively large-scale operation like drilling, but is better suited to sloping and rough ground. Little surface preparation is needed, although establishment will be improved if the surface is raked and levelled. Hydroseed slurries are sprayed on to areas to be seeded from a vehicle-mounted nozzle or using extension hoses. The slurry typically includes:

- seeds
- soluble and slow release fertilisers

Table 11.3 Advantages and disadvantages of seeding methods

	Drilling	Broadcasting	Hydroseeding
Topography and terrain	Slopes<15°, good terrain necessary	Slopes <20°, unless by hand; can cope with rough terrain	Any terrain, up to 40m reach with spray (depends on wind), up to 200m reach with hose
Obstructions	Limited; seed drill needs a clean site	Few limits	Few limits
Season and rainfall	Limited by high soil moisture	Limited to warm moist season; incorporation of mulch extends season	Limited to warm moist seasons; mulch extends season
Soil texture	Not stony soil, difficult on heavy soils	Rough surface allows seeds to fall into cracks with better microclimate	Rough surface improves microclimate, but any soil if mulched
Seed rates	Low rates are sufficient	Higher rates to allow for losses during establishment	High rates on poor quality soils to allow for losses during establishment
Seed sizes	Can only cope with uniform sizes	Any seed sizes; mixtures well mixed beforehand	Any seed size can be accomodated
Seed distribution	Uniform, in rows	Variable, random	Variable, random
Seed establishment	Most effective method	Variable, improved by incorporation	Variable, improved with a mulch
Fertilizing	Usually a separate operation	Separate operation	Usually included in slurry, but can reduce germination
Mulching or **incorporation**	Not needed	Desireable; separate operation	Mulch required, can be in same operation
Equipment	Seed drills	Hand, backpack or tractor equipment	Specialized hydroseeding sprayer
Relative cost	Inexpensive on easy	Cheapest on suitable areas	Cost effective on rough terrain
Difficulty and logistics	Straightforward; normal agricultural equipmant	Very easy; normal agricultural machinery	Specialized equipment, rapid application

- peat or woodpulp mulch
- tackifier (soil stabiliser or glue).

Most of the ingredients are insoluble, and have to be kept in suspension by agitation prior to spraying. Rates of 2-4 litres/m^2 are usual, with a solids content of about 10%.

Although this is essentially a large-scale technique requiring special equipment, it has been quite widely used at ski resorts such as Cairn Gorm, and has been tested on parts of the Three Peaks footpath network.

Advantages and limitations of the three seeding methods are given in Table 11.3.

Mulch is often included with hydroseed slurries. It can also be applied after broadcast sowing as a separate operation. Chopped straw, peat or paper pulp are the usual materials, and they need to be held to the soil surface with a tackifier or light netting. Mulch has the advantage of conserving soil moisture and providing some shelter for establishing seedlings. If applied too heavily however, it can smother the seedlings. Mulches of straw and grass cuttings have been used at the Cairn Gorm ski resort and larch branches used in trials by the Moorland Restoration Project (Tallis & Yalden 1983). Heather brash has been used both as a mulch and source of seeds by the National Trust at Kinder. In each case the trials suggested that mulches were beneficial to plant establishment.

There is also a range of mulch mats available commercially that are quite commonly used on road cuttings for erosion control. Mats consist of a layer of straw, coire or other mulch material sandwiched between two layers of light plastic or hessian netting. Examples include "Greenfix", "Bon Terra" and "Terramat". The mats are rolled out on site and pegged down with long metal staples. The mats can be applied over seeded ground or can be supplied with seeds incorporated in the mulch.

Advantages include very uniform mulch thickness, and fairly easy application. Drawbacks include high cost and weight, and the need for fairly uniform ground surfaces. Mulch mats seem to have been rarely used at recreation sites.

11.5 Use of soil seed banks

Types of seedbank

Most soils contain a proportion of buried viable seeds and these are a potential source of plant material. Some of the best known examples of buried viable seeds are weeds of arable fields. Salisbury (1964) for example, quotes densities of about 20,000/m^2 poppy seeds. Some soils at semi-natural recreation sites can, however, have much higher densities of more than half a million seeds/m^2, (Miller & Bayfield 1989).

Recently ACLU (1990) surveyed sites along the route of the Northwest Ethylene Pipeline from Grangemouth to Stanlow and produced buried seed statistics for a wide range of habitat types (Table 11.4). The data showed that the largest numbers of seeds were contributed by rushes and ericoids (heathers), followed by dicotyledons, with grasses the least important group numerically. Species composition varied widely from community to community and also from site to site. A survey of seed banks in the Three Peaks by Miller & Bayfield (1989) indicated that seed banks declined with altitude and with increasing disturbance by trampling. As in the ACLU study, rushes were the most important contributors. Species that were notably under-represented included cotton grass (*Eriophorum vaginatum*) mat grass (*Nardus stricta*) and sedges (*Carex* spp).

Methods of stimulating colonisation from the seed bank

Addition of fertiliser appears to stimulate colonisation of bare ground by plants from the seedbank. Fertiliser may stimulate germination (Roberts 1972), but more importantly it can improve establishment and early growth. Many of the seeds that

*Table 11.4 Mean buried seed populations (seeds/m² x 1000) in habitats along the Shell Northwest Ethylene Pipeline (ACLU 1990). n = number of sites recorded. t = 0.1-0.5k. *based on a single site*

	(n)	Grasses	Dicotyledons	Rushes	Ericoids
Tall herb communities: species - rich	(5)	3	11	25	-
Tall herb communities: species - poor	(5)	t	4	11	t
Herb-rich meadows	(6)	5	20	4	-
Improved pastures	(14)	9	23	56	6*
Neutral grassland	(7)	13	28	4	1
Tufted hair grass grassland	(4)	8	5	216	3
Matgrass grassland	(14)	3	2	72	22
Dry acid grasslands	(10)	8	7	84	23
Wet acid grasslands	(16)	4	17	63	12
Dry heaths	(17)	t	21	3	65
Wet heaths	(11)	3	3	11	42
Grassy heaths	(7)	2	3	77	42
Cotton grass communities	(8)	t	t	8	29
Rush-dominated communities	(8)	14	9	333	14
Sedge communities	(4)	3	124*	85	12
Sphagnum bogs	(5)	1	t	58	52
Bracken communities	(3)	1	27	7	6
Woodland	(21)	4	11	33	2
Hedges	(2)	9	14	148	-
Scrub and weeds	(6)	8	8	21	-
Mean:		5	17	66	17

germinate from seed banks make little growth in their first season and die from needle ice damage during the winter. Fertilised plants make sufficient growth to be more resistant to this kind of damage. Miller et al (1991) found that the number of young plants produced from the seed bank of peat soils increased with the rate of fertiliser application. The heaviest rate (86 g/m² of 7:7:7 NPK) was the most effective, although there was some dieback of relatively soft leaf material on the plots over winter.

After three growing seasons cover was almost complete on all fertilised plots, but was less than 40% on unfertilised plots. The authors found that other treatments, such as scarifying the surface and adding lime, was of little benefit, although the addition of alginure encouraged some species where the soil was prone to desiccation. More extensive trials suggested that in practice only partial cover could be achieved in a single season. A moderately large seed bank (>20 k seeds /m²) and a damp or wet site were the optimum conditions for this approach to be effective. Protection from grazing might also be required.for heather colonisation.

Advantages and disadvantages of using soil seed banks

Pros

* One application of fertiliser may be all that is required for seedling establishment.

* No seed or cultivation needed..

* Low cost.

Cons

* Only partial vegetation cover may be achieved in a single season.

* Rushes are most likely to colonise the area.

* Fencing may be needed for heather establishment.

* Vegetation cover is likely to be patchy.

* Dry sites and high altitude sites respond less well to this approach than wet and low altitude sites.

* A moderately large seed bank is required.

Examples of use

Conservation of topsoil in order to utilise seed banks is widely practised, but there are few documented examples of fertiliser being used specifically to stimulate the seed bank, apart from the Yorkshire Dales studies.

Technical gaps

Further trials would be justified to demonstrate the practical value of this approach under a range of site conditions.

The techniques described here are aimed at increasing the trafficability of vegetation and soils. They involve physical reinforcement of surface vegetation by more durable materials, improvement of soil bearing strength by drainage and various strengthening agents, and increasing vegetation resilience by the use of fertilisers.

12.1 Methods of reinforcing surface vegetation

These techniques involve providing durable reinforcement materials at the vegetation surface to withstand much of the traffic wear, and so improve vegetation survival. These approaches are usually only employed at heavily used locations, where vegetation would otherwise be eliminated. Materials employed range from natural stone, wood, and concrete to plastics, depending on circumstances and availability.

12.1.1 Stone mosaics

Surfaces consisting of 60-80% stone permit good vegetation survival in the interstices. Such mosaics are very durable, and blend in well around buildings, on footpaths, and other heavily used areas. The principal drawbacks are the heavy labour requirement and the need for large supplies of suitable rocks.

12.1.2 Stone/concrete slabs

Vertical stone or concrete slabs serve a similar function to rock vegetation mosaics. This method is used by Historic Scotland to reinforce turfed entrances.

12.1.3 Plastic grids and grasscrete

Plastic and concrete honeycomb surfacing is widely used for rural car

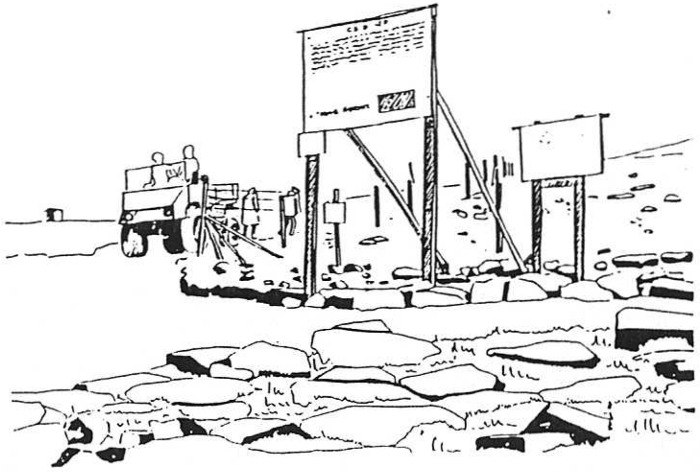


Figure 12.1 Rock-turf mosaics created around the Top Chairlift Station at Cairn Gorm, Scotland

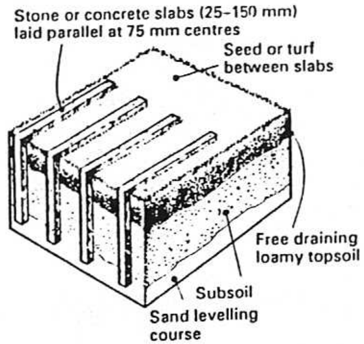


Figure 12.2 Stone slabs used to reinforce heavily used turfed entrances

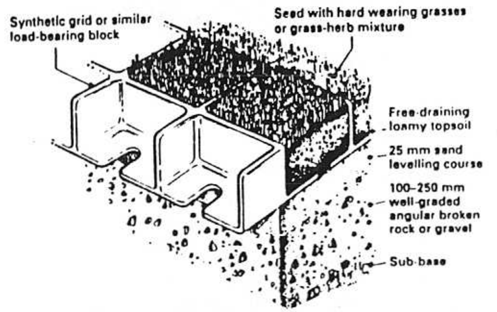


Figure 12.3 Plastic surface reinforcement for car parks and footpaths. Similar installation applies to perforated concrete slabs

parks and occasionally for heavily used paths. The USDA Forest Service recommend these types of materials for trails to be used by motorbikes, particularly on switchback curves. The reinforcement is laid on a firm base of well drained aggregate or similar material, and the honeycomb filled with topsoil and seeded. The main drawback to this approach is the high cost of site preparation and materials

12.1.4 Boardwalks

Ground level slatted boardwalks permit vegetation growth between the slats. This approach is cheaper than those listed above, and has the advantage that the reinforcement can be lifted or relocated if necessary. Widely used at ski resorts to reinforce queuing areas.

12.1.5 Surface geotextiles

It should be feasible to lay a surface geotextile netting or mat directly on to vegetation to reduce the impact of use. Heavy-duty mats for use by vehicles are available. "Mammothmat" for example is a composite of steel rods and plastic netting. It is, however, very heavy and expensive, and over-specified for most recreation sites. The Yorkshire Dales National Park have tested the use of a flexible plastic netting (Fortrac) which has a mesh size of about 2.3 cm. Although the mesh appeared to confer some degree of protection to vegetation it was too flexible to be fully effective (Bayfield et. al. 1990).

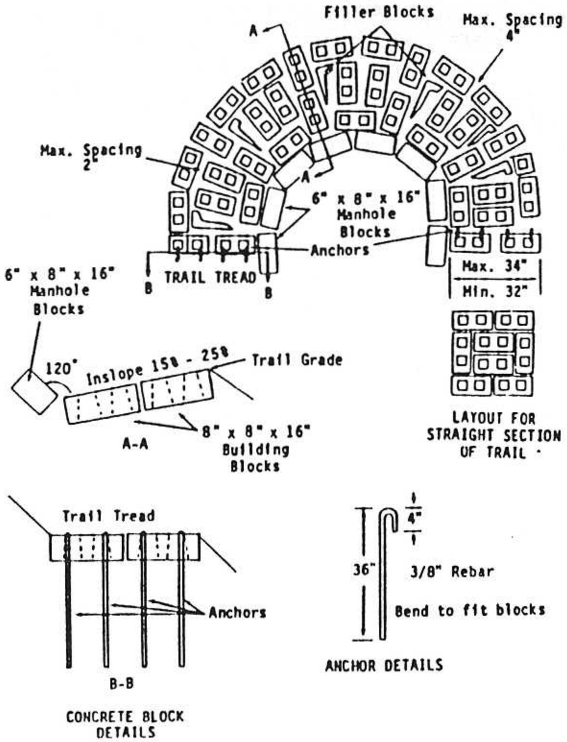


Figure 12.4 Details of perforated concrete block armouring for motor bike trails (USDA 1985)

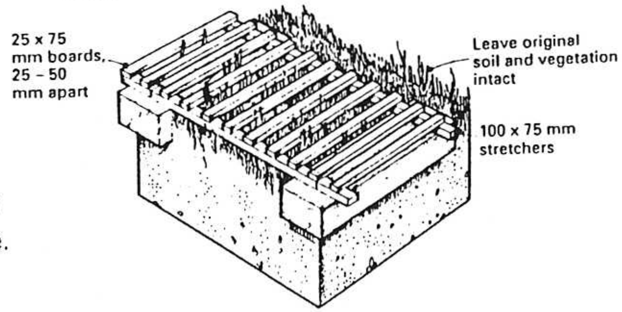


Figure 12.5 Slatted boardwalks permit vegetation growth and can be lifted or relocated

At present there appears to be no geotextile available that has the combination of rigidity, ease of laying on uneven ground and lightness that would be ideal for vegetation reinforcement purposes.

12.2 Soil reinforcement

These techniques aim at increasing soil trafficability by strengthening soil structure or by improving drainage characteristics.

12.2.1 Subsurface geotextiles

Geotextile netting placed just below the soil surface can strengthen soil by spreading the pressure exerted by traffic that could otherwise cause deformation or damage to soil structure. Suitable geotextiles should be relatively inelastic, and fairly strong (breaking strength >10 kN/m^2), with a fairly large mesh size (>1 cm). Suitable types include geogrids such as SSI used for road reinforcement, and more flexible types such as Fortrac, provided that they do not stretch significantly under load. These geotextiles are often used for mineral path construction (see section 7) but they can also be used for vegetated paths.

One of the longest established examples is on Arthurs Seat, Edinburgh, where Scottish Heritage rebuilt an eroded footpath in 1980 by levelling the path profile, pegging a polypropylene and wire ("Wiretex") geotextile to the surface, and seeding with ryegrass. The path was fenced off until the grass was well established.

The geotextile was rapidly covered by vegetation, and has been very successful in preventing further erosion. The wiretex is still in place. The vigour of the ryegrass is maintained by spring and autumn dressings of fertiliser.

12.2.2 Mesh elements

A fairly recent innovation in geotextile engineering is the development of soil strengthening by the inclusion of small pieces of plastic mesh (Box 3). The mesh size is carefully chosen to interlock with soil particles, and with adjacent meshes. In effect the meshes simulate the strengthening action of roots. The meshes typically have mesh openings of 1 cm x 1 cm, and are used at a density of 0.1- 0.2% of soil volume (Andrawes et al. 1986). The mesh elements, which are about 2.5 cm x 2.5 cm in size, are mixed into surface soil on site or are delivered pre-mixed with topsoil or other surfacing material. The composite has higher load - bearing and wear-resisting properties than untreated soil, and is recommended for paths, slope failure repairs, and reinforcing sports turf and general recreation areas. However, this technique does not seem to have been used much in the UK at recreation sites. Obvious drawbacks are the difficulty and expense of thoroughly mixing the mesh with surface soil. This makes it mainly suitable for sites where fairly extensive earthmoving is envisaged.

12.2.3 Soil cements

There are a number of chemical additives that can be mixed with soil to increase its wearing strength. Both hydrated lime and portland cement can be used for conventional soil cements, which are mixtures of soil and a binding agent. The proportion of cement may be 1:10 to 1:50 depending on the type of soil and the likely traffic. Soil cements do not appear to be in common use at recreation sites, possibly because of the difficulty of predicting the strength and properties of the resultant mixture. In the USA, soil cement paths are used very successfully in Arches National Park, using mixtures of sand and cement. The sand is reddish in colour and cement paths made with it blend in very well with the surrounding semi arid desert landscape. Similar sand cement paths have been used in Guernsey (I McEwan *pers.comm.*) for coastal dune paths.

In recent years a number of polymer additives have been produced for mixing with soils; these appear to work best with clay soils. There is little hard information about these chemicals in a recreational site context, apart from an unsuccessful trial by the Yorkshire Dales National Park (YDNP undated) with a Swiss product called Solidry.

Using a rotavator, the Solidry was mixed with a peat clay substrate to produce a firm walking surface . However during the winter the surface became soft again, apparently as a result of frost action.

Unfortunately the trial was abandoned before being fully analysed so it is not clear whether substrates with different proportions of peat and clay were equally affected.

12.2.4 Grassed gravel ("Gazon-gavier")

Replacing topsoil with gravel or aggregate is one of the most commonly used ways of creating paths. The gravel is freely drained and durable, but is largely inhospitable to plant growth (although gradual colonisation from the edges of the path is likely).

A Swiss specification ("gazon gavier") suggests how gravel surfaces can be made more suitable for vegetation. The addition of topsoil to the surface layer of gravel can permit satisfactory establishment by wear resistant grasses, for rural car parks, road verges, and paths [Union suisse des professionels de la route (undated)] .

The specification calls for a basal layer of 15 cm or more of untreated aggregate that will be frost-resistant. This is surfaced with up to 15 cm of aggregate mixed with up to 25% of fertile topsoil, and sown with wear resistant plant species.
For example:

Lolium perenne 50%
Festuca rubra 30%
Festuca ovina 15%
Medicago lupulina 5%

This approach appears to have been rarely attempted in the UK.

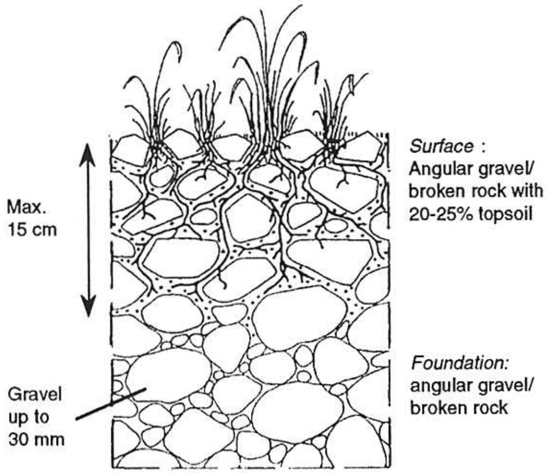


Figure 12.6 Grassed gravel specification

12.2.5 Drainage

Drainage of trafficked surfaces improves the bearing strength of soils. Traditional methods include open drains, pipe drains, mole drains, sand slots and gravel filled ("french") drains (section 9). Lightweight plastic slot drains are also available, but some managers report that they are easily blocked, particularly in peaty soils.

Technical gaps

Drainage is routinely used to stop run-off eroding paths and other recreational areas such as ski pistes. However, drainage can also improve surface durability, but this function has received little detailed study, and trials to compare the effectiveness of different methods in contrasting locations could be instructive. Such studies would be particularly valuable for locations with drainage difficulties, such as peat bogs, where there are often severe wear problems due to the softness of the (wet) substrate.

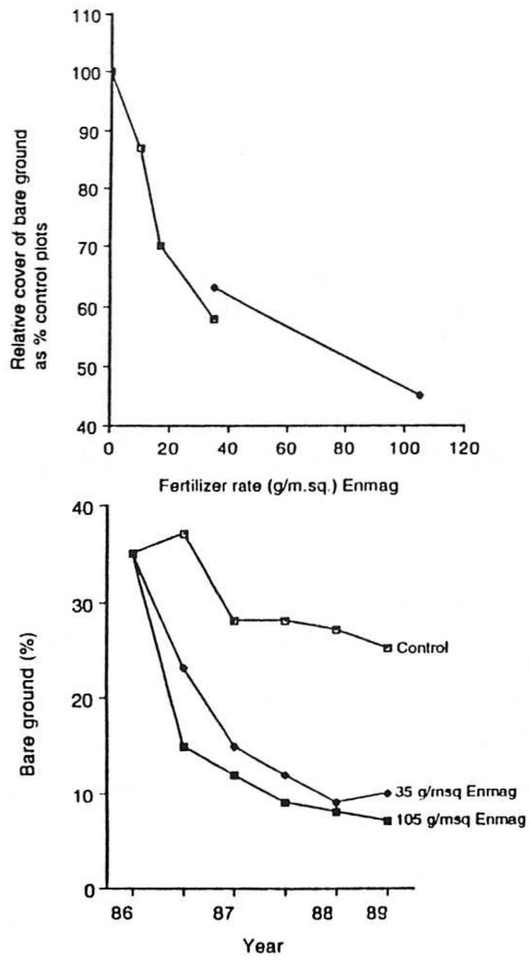


Figure 12.7 (above) Effect of increasing fertilizer rate in reducing bare ground on trampled paths.
(below) Persistence of the effect of fertilizer over three seasons (Bayfield et. al. 1989, 1990)

12.3 Increasing vegetation resilience with fertilisers

Amenity and sports turfs are routinely treated with fertilisers to compensate for the damage done by wear, and the removal of nutrients by regular cutting (Hope 1990). The slow release fertiliser ENMAG is marketed specifically for trampled turf.

Fertilisers are less often used for rural recreation sites, but recent trials suggest that worthwhile improvements in vegetation resilience can result from fertiliser dressings at some types of site. Trials in the Three Peaks area and in the Peak National Park have shown that substantial reductions in bare ground can result from moderate applications.

On cottongrass grassland, a cost effective application rate was 70 g/m^2 of Enmag which gave a reduction in bare ground of about 50%. The effects of a single application were found to persist for several years. In this community not all species increased in cover. Species that increased included *Festuca ovina*, mosses, *Juncus effusus* and *Carex nigra* whereas *Trichophorum cespitosum* and

Eriophorum vaginatum were unaffected.

The effectiveness of fertiliser on other upland plant communities was not always the same. Dramatic improvements were noted on cottongrass mire at the Snake Pass [reduction of bare ground of about 80% (Bayfield 1991)] but there were only modest improvements on heath rush (*Juncus squarrosus*) grassland, and little or no benefit on mat grass (*Nardus stricta*) grassland in the Three Peaks (Bayfield et al 1990).

Large scale applications of fertiliser have been tried in the Three Peaks with mixed results. Associated improvements, which involved provision of board-walks on some sections, resulted in more concentrated use of the fertilised ground. This obscured any apparent benefits from the fertiliser application.

Overall, these trials suggest that the use of fertiliser may be a valuable management tool at some types of site. Further work is needed to identify which plant communities can benefit, and to provide clear guidelines as to when this form of treatment should be used.

Factors to be considered will include:

- the fertility of the soil (only infertile types of site are likely to show much benefit)
- the plant community (responsive or unresponsive)
- any possible interactions with other management techniques that might change thedistribution or concentration of use.

There appears to be a general recognition among UK recreation site managers, that the amount and quality of monitoring of such characteristics as user numbers and impacts is poor. Much of the effort expended has not been sufficiently related to management problems and objectives.

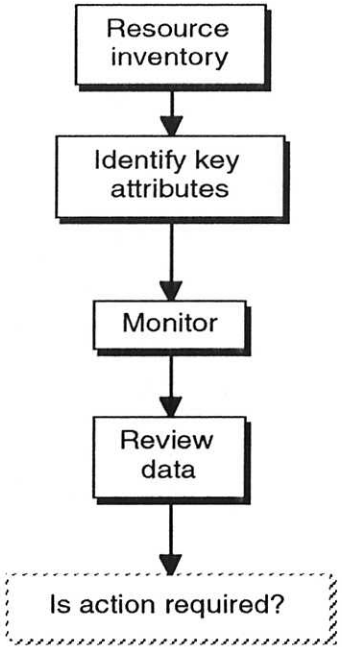


Figure 13.1 Open ended monitoring framework

The value of monitoring information to management action and assessment is in fact not widely appreciated, and there are comparatively few sources of information available for guidance.

13.1 Frameworks for monitoring

The aims of monitoring are *a priori* to provide a time-related data base of information relevant to management decision making. The data should indicate when action is required, and the effectiveness of any action taken. Regular review of data and of the relevance of the monitoring procedures are essential.

Many monitoring schemes are open-ended in the sense that no action is considered until the data are reviewed (Figure 13.1). This type of framework may be suitable when there are no clear management problems, or possible courses of action are unclear. Monitoring can serve a more powerful function

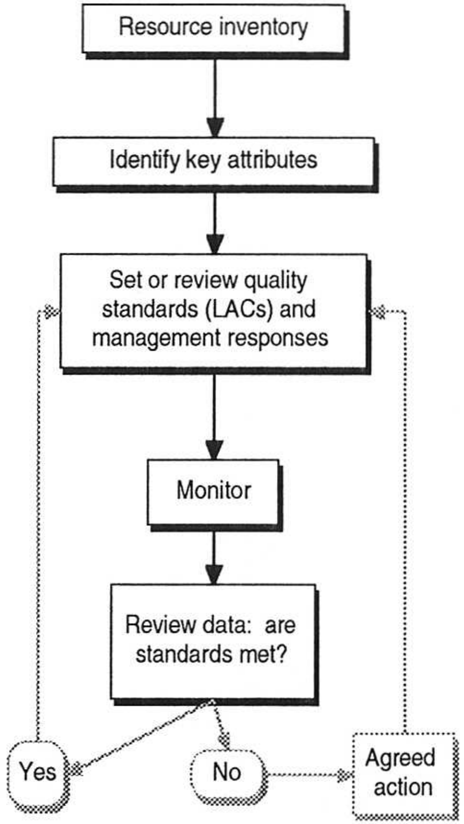


Figure 13.2 A monitoring framework incorporating quality standards and agreed management responses

however, if it can be structured to include agreed quality standards, and the actions that should follow if the quality standards are not reached (Figure 13.2). With this type of structure, monitoring can automatically trigger action without requiring a period of consultation and consideration of possible alternatives, which usually results in procrastination.

This approach to monitoring is based on the USDA Forest Service LAC ("limits of acceptable change") system (Stankey et al. 1985) in which LAC values are the quality standards, set for each situation by a monitoring group representative of interested individuals or agencies. LAC values can be set for almost any known attribute from vegetation cover to numbers of users.

An example from the UK is the monitoring scheme operating at the Aonach Mor ski resort. This involves LAC values for attributes as diverse as vegetation damage on pistes, erosion patch sizes, litter density and queuing times for ski tows (Bayfield et al 1988).

13.2 Methods of monitoring levels of use

13.2.1 Total use

Numbers of visitors can be monitored by direct counting but this is usually too time consuming for routine recording. Indirect counts such as car park tickets or car numbers, sales of nature trail booklets have sometimes been used, but careful calibration of observations against actual numbers is required. The most widely used methods are automatic counters, which can be set up across roads for vehicles, and on stiles and gates for pedestrians.

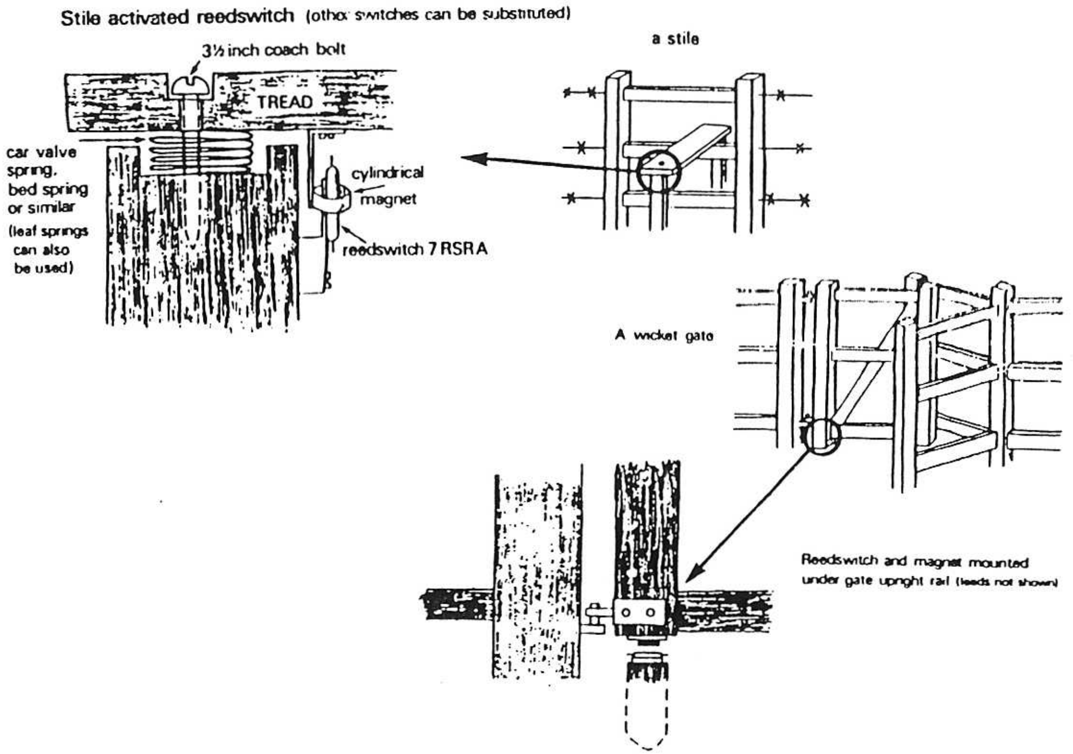


Figure 13.3 Automatic counters for gates and stiles (Tourism & Recreation Research Unit 1983)

Simple mechanical and electro-mechanical counters such as those illustrated in Figure 13.3 are widely used, for example in the Three Peaks, Peak National Park, Cleveland Way and Pennine Way Coordination Project. These systems are cheap but need regular maintenance. Many of the examples in use are badly designed, and so conspicous that vandalism is a frequent occurrence. Good examples should be almost undetectable; a stile can be expected to creak a bit when stood on, but not to move with a metallic clunk and have conspicuous hinges and wires and boxes etc attatched. Such counters invite interference.

More sophisticated counters include *pressure pads, and photoelectric and infra-red counters* which can count people crossing their field of view. An early example of the latter type of counter was described by Bayfield and Pickrell (1971). Three recent reviews (Center for Leisure Research 1992; Dales,1992; Philpin, 1992,) provide an up to date catalogue of available types, and the equipment available is undergoing fairly rapid evolution.

Pressure mat counters are relatively expensive, and require careful siting. Readings are taken with a remote hand -held unit. These counters are in use on Pembrokeshire Coast paths. A related system from North America uses a buried induction loop to of count people. The Countryside Commission for Scotland have an induction loop counter under trial at the Falls of Bruar.

Infra red counters work either by the breaking of a reflected beam, or by detection of changes in background temperature created by someone passing within range. A very effective development of the latter system has been produced by the British Waterways Board for pedestrian counting (British Waterways Board undated). Examples are installed on the Kennet and Avon Canal, Tring Reservoirs and elsewhere. This type is also in use by North York Moors National Park, the Countryside Commission for Scotland, Durham County Council and the Pennine Way Coordination Project. These counters are rarely detected by the public, and need little servicing.

Yet another type of detector counts people using an *accoustic beam* . An

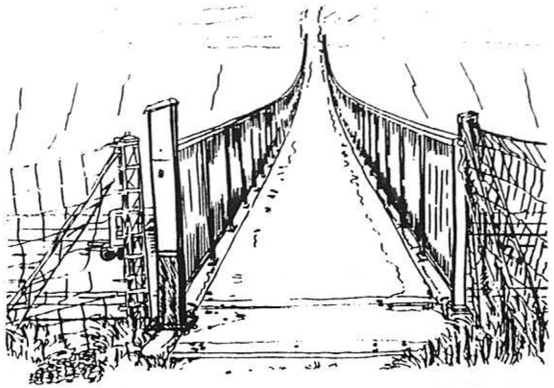


Figure 13.4 Infrared counter installed in a post at the end of a bridge over the M62. The counter is in the post on the left.

example of this type is the Schmidt counter which has a range of about two metres so has to be placed across a narrow entrance. One of these counters is also being evaluated at Falls of Bruar.

Recording results from counters can be done manually or by automatic data logging of results with totals provided hourly, daily or as required. Several such systems are available commercially, and can be left unattended for weeks or even months at a time. There is actually a danger of such systems providing too much information for management to utilise effectively. Nevertheless, the cost of a data logging system will often be justified for remote locations, very heavily used sites, or where a very detailed record of use is required.

Advantages of automatic counters:

- low cost and simple to run;
- can give hourly, daily or longer-term counts;
- operational manpower requirements low.

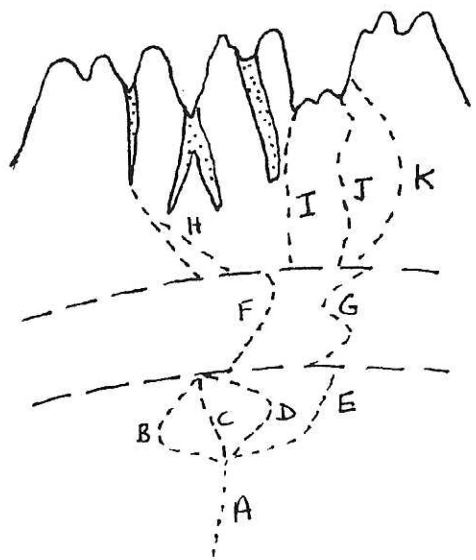
Disadvantages:

- prone to mechanical or electrical failure;
- require calibration against direct counts;
- require skilful design and fitting to avoid detection and vandalism.

Most types of counters are best located at points where use is concentrated. Careful location is necessary to ensure the survey points are really representative of site use. For example, counters at either end of a bridge can give quite different levels of use if a proportion of visitors walk to the middle of the bridge to admire the view and then turn back.

Box 4 DIRECT COUNTS OF VISITOR DISTRIBUTION

EXAMPLE: Stac Polly footpath study, 1972 (Nature Conservancy (unpublished))
Below: sketch map of the hill from a fixed survey point



This study was concerned with seeing which paths were most used, and whether the proportion of walkers off paths varied between uphill and downhill travel.

Counts were from a fixed point, using binoculars, at 15 minute intervals. The results showed that paths A,C,F and J were the most heavily used, and that the proportion of walkers off paths was similar in both directions

13.2.2 Dispersed use

Frequently, information is required on user distribution. There are three main techniques: direct counts, aerial surveys and interview surveys.

Direct counts

This approach is effective at locations where substantial portions of the site can be seen from vantage points (especially mountain and moorland sites). The usual procedure is to draw a freehand sketch of the site from each vantage point, or to use a photograph. Routes or segments of the view are then superimposed on the sketch or photo, and counts of people in each compartment are undertaken at prescribed intervals (Box 4)

Advantages of direct counts:

- detailed information can be produced on distribution, types of users and activities

Disadvantages:

- time consuming
- visibility dependent.

Aerial surveys

Aerial surveys can be conducted from light aircraft, or with cameras mounted under balloons (Duffield & Forsythe 1972) or on model aircraft. Light aircraft are the most expensive option, but have the advantage of letting the observer position photographs more precisely than the other techniques. Experiments have shown that oblique aerial photos give the most useful results.

Advantages of aerial surveys:

- low manpower requirement for field work;
- large areas of ground can be covered in a short period of time;
- photographs give very precise location information.

Disadvantages:

- flights are very dependent on suitable weather
- data analysis can be time-consuming
- large items such as vehicles are much easier to distinguish than people
- there may be legal restrictions on-flying over some types of land.

Interview surveys

A widely used technique is to ask visitors where they have been as they leave a site, either as a stand alone exercise, or as part of a wider survey. If necessary, users can be shown maps of the area to help them describe their visit. Details of methods are given by Tourism and Recreation Research Unit (1983).

Alternatives to the interviewing of users are to give them a questionnaire to fill in and post back, or to issue self reply questionnaires at site entrances. Self-reply questionnaires have recently been used successfully on the Pennine Way. Some of these techniques have been used quite commonly in wilderness areas of the USA (Stankey& Baden 1977)) but less often in Britain. There is a fairly extensive literature in the States on the effectiveness of different methods. Stankey & Schreyer (1985) provide a review of recent practice.

Advantages of interview surveys:

- detailed information about activities and attitudes can be obtained as well as distribution data
- not weather dependent

Disadvantages:

- time consuming method
- some users may refuse to answer
- some users may be uncertain where they have been
- mainly suited to sites with well
- defined geography

13.2 .5 Technical gaps

There are no substantial gaps.

13.3 Vegetation change

13.3.1 Techniques

Methods of botanical analysis are outlined in standard texts. The objectives in monitoring at recreation sites are usually to record changes in:

*species composition
*cover
*vegetation/habitat geometry (patch size and height).

At some locations fëatures such as flowering abundance may be of special significance. For most purposes, recording species composition height and cover can be satisfactorily undertaken in permanent quadrats or along fixed transects. Some modifications of normal botanical practice can, however, be useful for conditions at recreation sites.

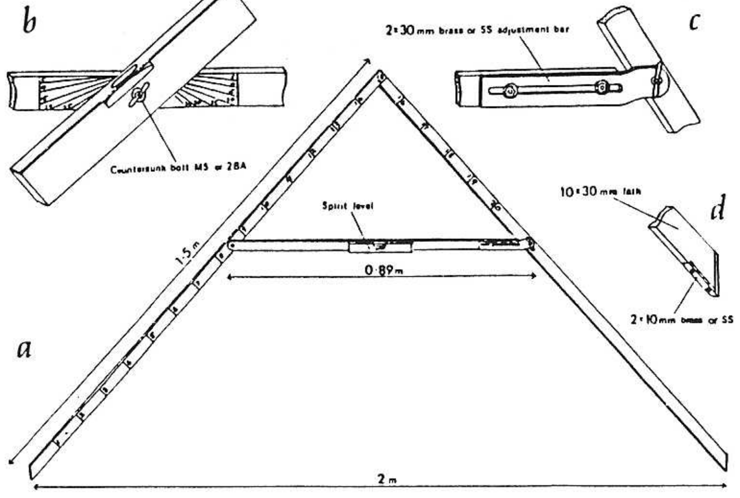


Figure 13.4 Construction details of the two metre A frame (Bayfield 1988)

1. The risk of disturbance or vandalism of marker pegs is comparatively high at recreation sites, and it is good practice to use existing markers such as fence posts, trees or buildings from which to locate transects or quadrats.

2 . Many sites tend to be quite extensive but with very localised areas of damaged ground. Rapid survey techniques are required, to cover large tracts of ground. One such method is the step-pointing technique developed in New Zealand by Cunningham (1978). This method consists of marking a line or point on the toe of each shoe (or inserting a coloured mapping pin) and recording species touched by step points as sample areas are crossed. This approach permits rapid sampling of quite large areas by simply walking randomly across them, and coding the

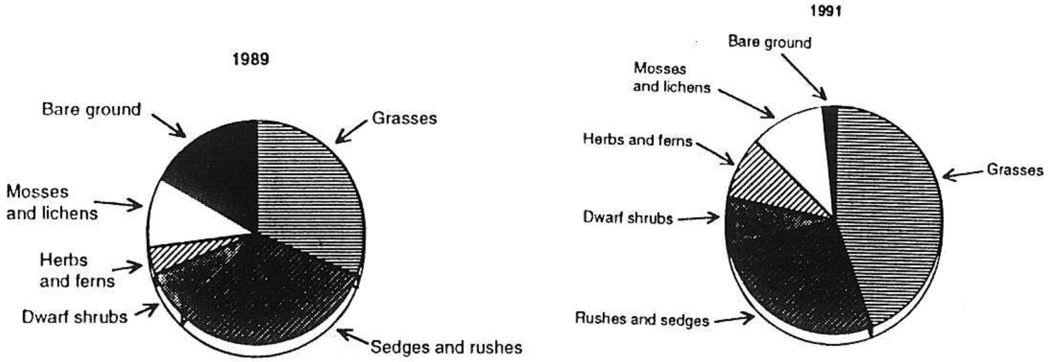


Figure 13.3 Summary of vegetation changes between 1989-1991on a ski piste at Aonach Mor based on step point obaservations (Bayfield et.al. 1991)

species intercepted.

3. For individual patches of damage, more detailed observations of dimensions and severity may be required. Photography from fixed points is a useful method. Measurement of depth of erosion from a horizontal bar may be useful for comparative purposes (see section 13.4 for techniques for footpaths).

4 A simple technique for locating permanent sample points and for general location purposes is the two metre A frame (Bayfield 1987). This device is used like a pair of oversize dividers with 2 m between points, for rapid measurement of distances. It is much easier and faster to use than a distance wheel or tape measure over broken terrain. The frame can also be used to estimate angles of slope.

13.3.2 Technical gaps

There are no substantial technical gaps, but there is little guidance available at present on selection of appropriate methods. Each type of site tends to have its own particular problems and requires a unique solution.

13.4 Recording route wear

13.4.1 Approaches

Route wear takes the form of widening, multiple tracks and deepening by compaction and erosion. On footpaths the most obvious changes are generally in width. In contrast, horse tracks both get wider and conspicuously deeper, due to the relatively heavy penetrations and loosening of surface soil by hooves. Vehicle tracks tend to cause rutting and erosion rather than widening.

Methods of monitoring need to address the type of wear occurring, and as usual, the methods and detail of recording should be regularly reviewed to ensure that they are still appropriate as changes take place

The approaches that can be adopted range from those that are closely related to path maintenance requirements to those that are more focused on the detail of impacts. Examples of the former include the systems of logging trail conditions and prescription details described by the US Forest Service Trails Handbook (USDA1985) Humphrey (1985) and the Forestry Commission (1991). These mainly descriptive types of survey record for example:

1. damaged culverts
2. Locations of hazard trees
3. Overgrowing scrub

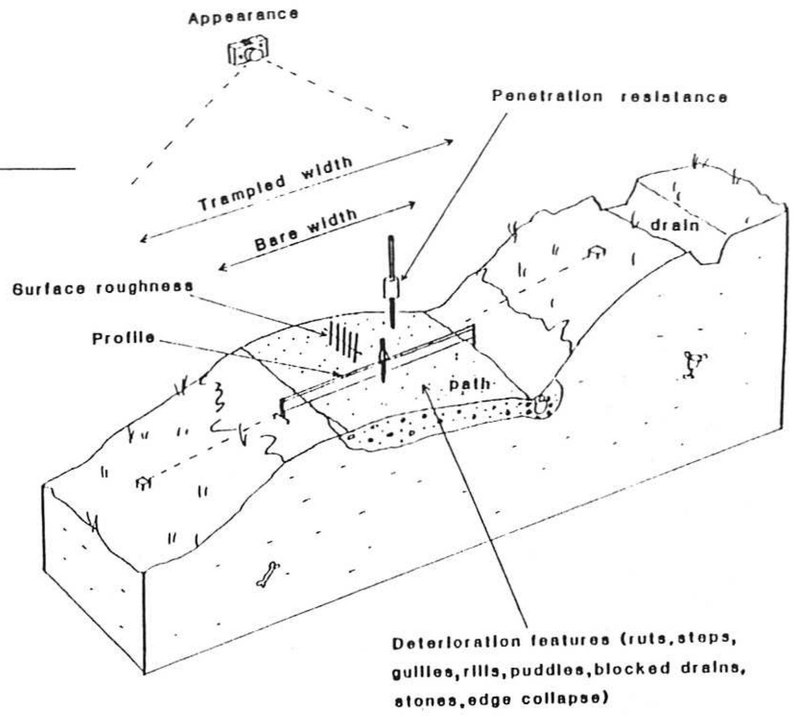


Figure 13.5 Some techniques for measuring path condition

4. Eroding backslopes
5. Missing signs
6. Subgrade failures
7. Retaining wall failures
8. Landslips
9. Trail surface erosion.

Locations of individual deficiencies are noted, with appropriate prescriptions.

Few detailed measurements are required, but this type of log is sufficient to pinpoint problem areas and a regular update shows the conditions of the route over time.

A much more detailed approach has been used by researchers more interested in impacts; for example, in studies of the processes of erosion, and of the susceptibility of different soils and vegetation (Figure 13.5).

Some of these approaches are desribed in more detail below

13.4.2 Techniques for measuring changes in path widths

Original Pennine Way survey method

One path recording technique that has been widely in Britain, is the rapid survey approach used to measure the condition of the Pennine Way in 1971 (Countryside Commission 1973), and subsequently updated in the Three Peaks Project Monitoring Handbook (Bayfield 1988).

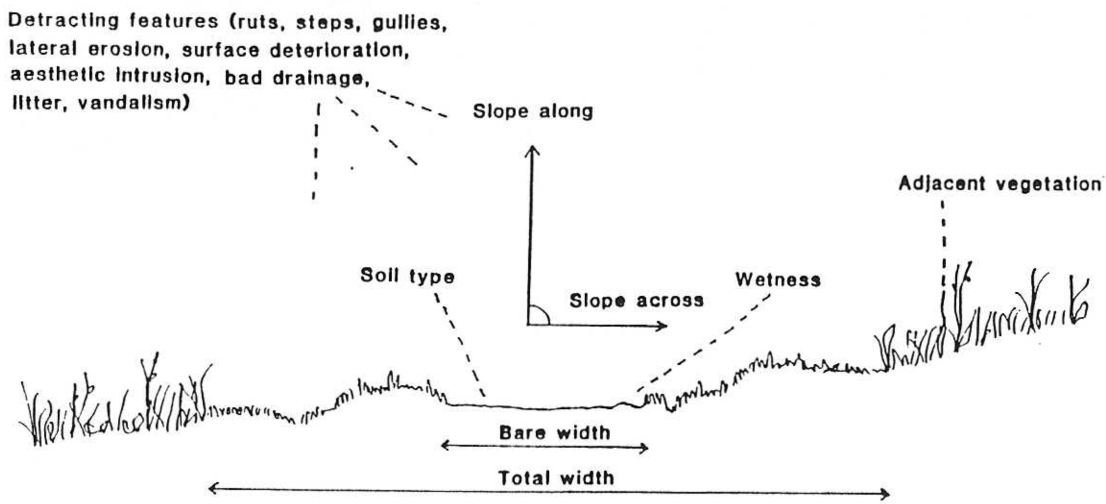


Figure 13.6 Path characteristics recorded in the original Pennine Way survey method (Countryside Commission 1973,

This method is more detailed than the USDA trail log approach. It involves recording path widths, bare ground, and site characteristics such as vegetation, slope, and presence of various detracting features such as steps, ruts or gullies (Figure 13.6). This type of analysis can provide a very detailed baseline description of a path network, which permits the identification of worn sections and indicate relationships between wear and site features such as vegetation, soil types, drainage and slope.

When this method was used in the Three Peaks Project every tenth survey point was marked permanently for repeat sampling purposes, to reduce the work required to annually monitor the 64 km route network.

Simple width recording

A simplified version of this approach may sometimes be appropriate. For example, on Aonach Mor, annual recording of path condition involves recording only path total and bare widths (ITE 1991). This provides a mean wear value for each path which can be compared with set LAC values, and also pinpoints areas of heavy wear (Figure 13.7).

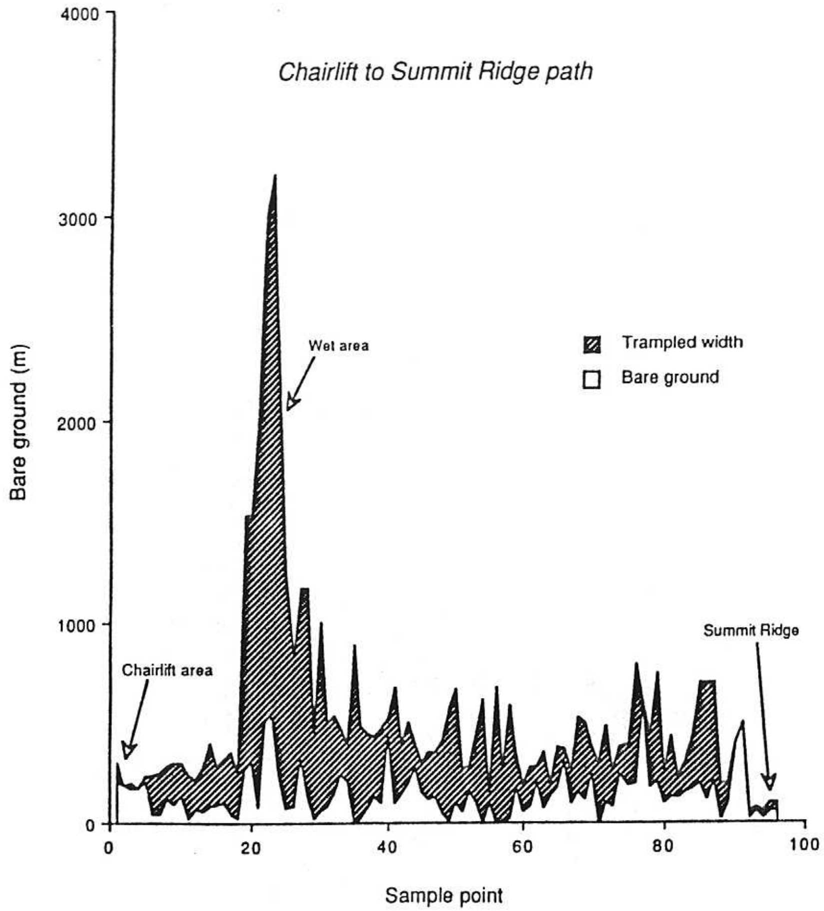


Figure 13.7 Example of bare and trampled width data for the Aonach Mor Chairlift to Summit ridge path in 1991. The sample points were 20m apart (ITE 1991).

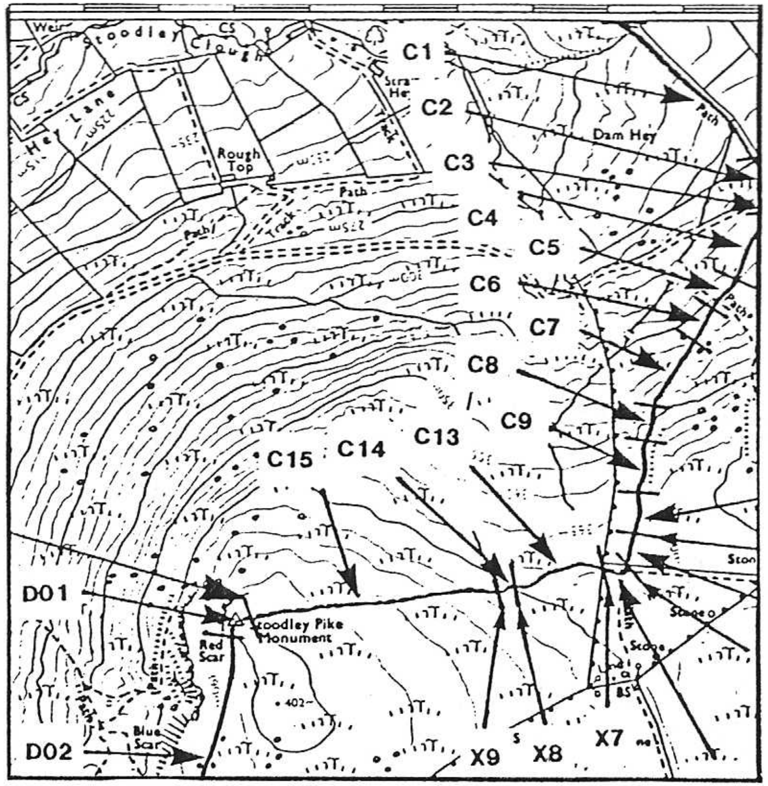


Figure 13.8 Example of part of a survey sheet of the Pennine Way at Stoodley Pike Monument, coded to show boundaries of sections with relatively uniform conditions (C1,C2 etc) and crossings(X7 etc).

Revised Pennine Way survey method

In 1989 the Pennine Way Coordination Project adopted a method of survey that was more management orientated than the original approach (Philpin 1990, Pennine Way Coordination Project 1990). This protocol draws on features of both the trail log and original Pennine Way methods. Recorders survey the route and measure bare and worn widths, with damage categorised into one of 20 classes. Drainage, soil, terrain and other features are recorded, as are details of crossings, obstructions and other management features. Instead of measuring at random or fixed intervals, new records are only made when some aspect of the route changes This has the advantage of picking out sections with uniform management requirements. The new method is apparently not as rapid to record as the old, but is more directly related to management needs. The whole Pennine Way has been logged.

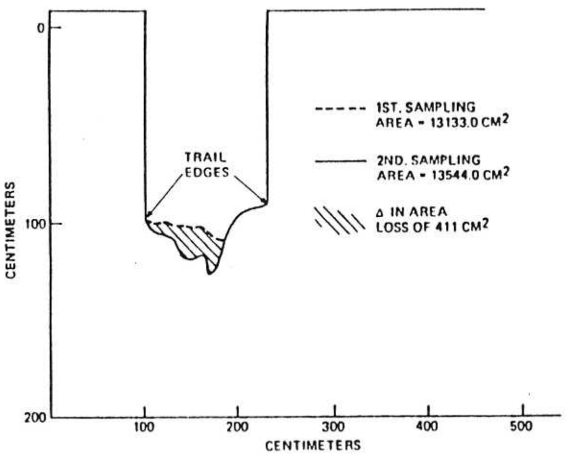
13.4.3 Surface erosion

Depth

As Humphrey (undated) points out, a rough estimate of depth of erosion on paths can be gained by measuring the height of intact pedestals of vegetation. More precise measurements can be obtained by measuring depths to the surface from a straight profile bar (Coleman 1981, Bratton et al. 1979). This method is usually used at permanent transect points with the bar positioned on or adjacent to marker pegs. A drawback is that paths vary so much in width that a very long bar may be needed.
A collapsible model may be found useful, or alternatively a taut cord or wire may be substituted (Leonard & Whitney 1977).

Surface roughness

Another useful characteristic of path surfaces is their roughness. A technique for estimating roughness is with another form of profile bar, similar to a point quadrat frame, but with heavier pins (Figure 13.7). This device has a simple clutch to lower



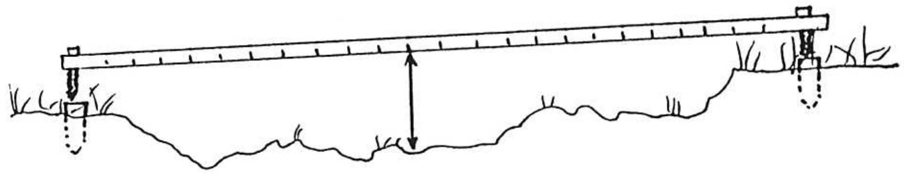


Figure 13.8 (Above) Use of a profile bar to measure the changes in profile across a path. The bar should be at the same angle when repeat measurements are made. (Above right) Example of calculation of the material lost through erosion

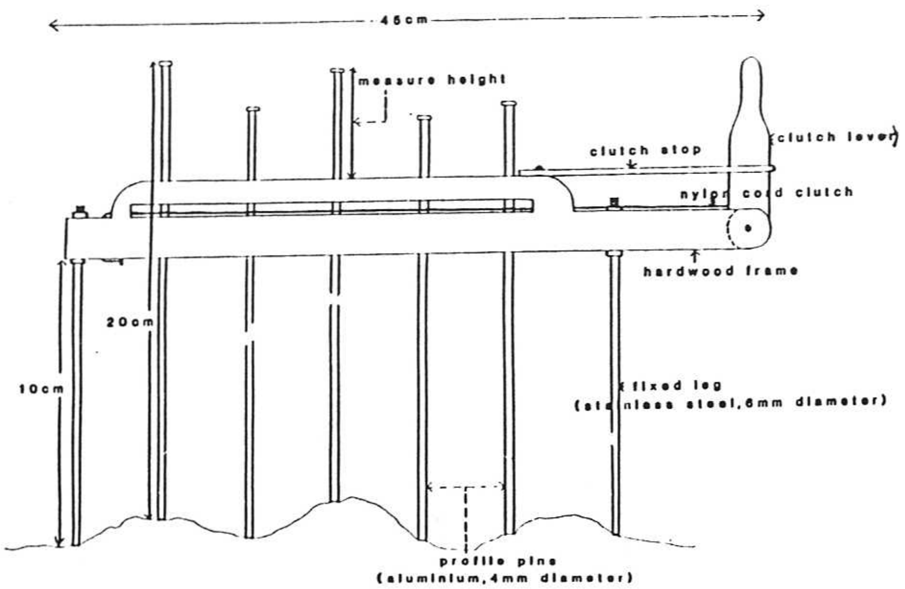


Figure 13.9 Path surface roughness guage. The profile pins are released to touch the ground, then locked in place with a cord clutch so that the instrument cAn be picked up to measure individual pin heights. The guage dimensions can be built to suit the type of ground. Based on a concept by Harper et.al. (1965).

and then lock the profile pins. Pin heights are measured and the volumes computed to give a variance value ("surface topographic variance") which indicates roughness. Observations of this kind are a useful way of monitoring deterioration in new path surfaces as well as for unconstructed paths.

Penetrability

Estimates of penetrability have been widely used to show the impacts of trampling. Compacted soils have low penetrabilities and this is usually correlated with low penetration both for gases and surface run-off. Liddle (1973) gives an example of the apparatus involved, and descriptions are also provided by Bayfield (1988) and MacIntyre (1991). Essentially, penetrometers measure the depth that a rod or spike penetrates the soil when hit with a precisely measured blow from a falling weight. Another related technique is to measure the resistance of soil to shear using a shear vane apparatus (Figure 13.9). This measures the force required before the vanes (inserted into the soil) twist. A drawback to these techniques is that a relatively large number of samples are required, and results can vary substantially with soil moisture content.

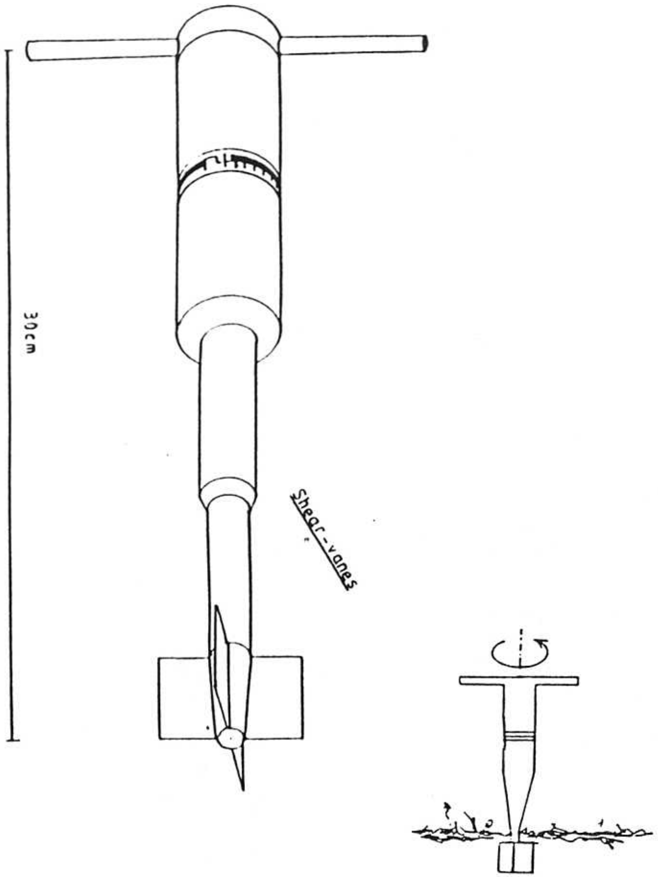


Figure 13.10 Shear vane apparatus (MacIntyre 1991)

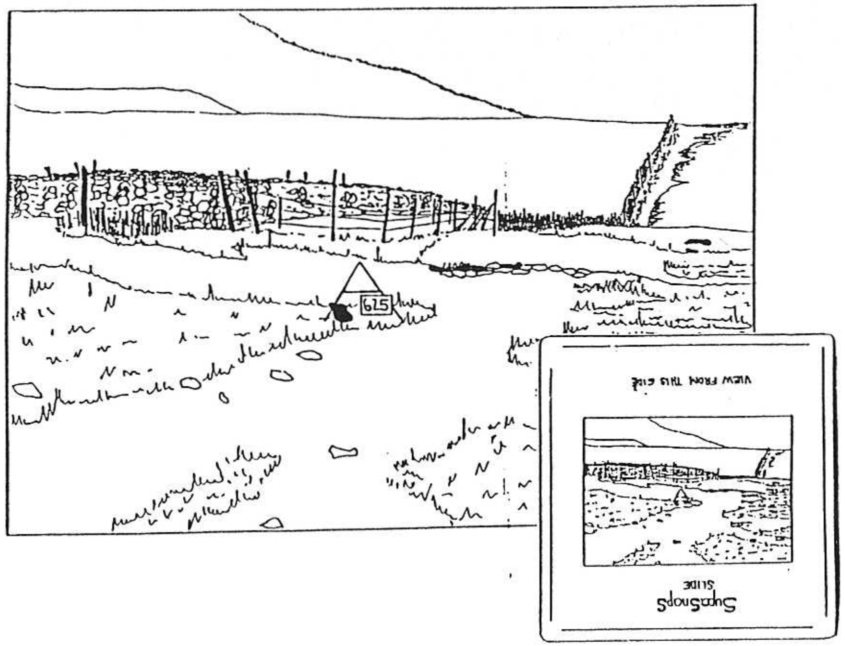


Figure 13.11 Path photography from a fixed point. The view includes a numbered board to indicate the site reference and to provide a scale. The field of view should be checked against a reference photograph

Appearance

Photographic recording from fixed points is very useful for indicating path conditions.

The fixed points can be rocks, fence posts or even unmarked points located by pacing or by measurement with an A-frame from easily recognised features. It is useful to have a copy of the original photographs when repeating the recording, in order to ensure the field of view is constant (Figure 13.11).

13.4.4 Summary of pros and cons

Choosing the right technique or techniques is likely to be heavily dependent on site characteristics, time available, and the objectives of monitoring. Table 13.1 summarises some of the pros and cons of individual methods of route assessment.

In practice a combination of approaches will be appropriate. Humphrey (1985?) (Natal Forest Service) for example advocates two tier monitoring system of (1) periodic scientific monitoring of path profiles at permanent transects coupled with (2) a general questionnaire similar to that used in the USDA trial log system.

Table 13.1 Pros and cons of techniques for assessing trail condition

	Pros	Cons
Trail logging	Directly relevant to manag-ement problems. Very quick	Largely subjective
Pennine Way survey method	Detailed but rapid survey provides a good baseline resource survey	Too detailed for some situations No detailed depth information.
Simple width recording (e.g. Aonach Mor)	Rapid method	No erosion depth information
Erosion depth recording	Precice estimates of eroded material lost	Time consuming Impractical for large footpath networks
Surface roughness recording	Quantifies gradual changes	Simpler subjective recording may often be preferred
Penetrability recording	Quantifies otherwise unseen changes	Time consuming. Large number of samples needed. Results affected by soil moisture.
Photography	Quick and cheap	Weather dependent

13.5 Landscape changes

Photographic recording is about the only effective method of monitoring landscape changes.

There are three main approaches, ground photography from fixed points, vertical aerial, and stereo oblique aerial photography. All three methods give results which can be compared quantitatively over time. Less satisfactory are casual photographs from unfixed locations and mono aerial photographs, as these are difficult to repeat with reliability.

Ground photography has been discussed in relation to paths in the previous section. It is cheap and easily repeated. Aerial photography has the advantages of potentially providing precise ground measurement. Vertical stereo pairs can be related to map contours and ground control features by means of a stereo transferscope.

Stereo oblique photographs have the advantages of giving a much better impression of sloping ground than vertical imagery, but more ground control may be required, and photo-interpretation is more costly.

In practice the high cost of aerial photography usually precludes its use for regular recording, but a set of reference aerial photographs can provide an excellent baseline record, which can subsequently be given detailed analysis as and when required and supplemented with ground photographs.

Table 13.2 Advantages and disadvantages of photographic techniques for recording landscape change.

Type of photography	Advantages	Disadvantages
Fixed point, ground level	Cheap and easily repeated. Not very weather dependent	Difficult to convert to ground measurements.
Stereo vertical	Good ground measure-ment capability.. Suitable for balloon and model aircraft as well as fixed wing and helicopter use.	Poor definition of steep slopes. Expensive. Very weather dependent. Photo-interpretation moderately costly in time and equipment.
Stereo oblique	Good ground measure-ment possible. Good definition of sloping ground. Less weather dependent than vertical photography as lower altitudes are required.	Expensive. Fairly weather dependent Photo-interpretation very costly in time and equipment. Not suitable for balloon or model aircraft use

Part 3: SYNTHESIS

Although most of the problems discussed in this report can occur at almost any type of recreational site, some problems are especially prevalent in particular environments.

14.1 Mountains

Mountain areas in Britain can be arbitrarily defined as ground above 300 m. They are used not only by walkers, mountain bikers and vehicles but also by skiers, and specialist users such as rock climbers, gem hunters and bird watchers (Table 14.1). Control of users movements is difficult because much of the ground is open in character, and users tend to be resentful of overt canalisation in semi-wilderness areas. Erosion problems are often locally severe because of steep slopes, high rainfall and fairly erodible soils. Recovery is poor because of the short growing season and infertile soils. Route siting is problematic because much of the ground has high viability, and route construction is difficult because of the need to get staff, equipment and materials to remote sites. Often there is a shortage of suitable construction materials on site. Although some sites, such as many in the Lake District, have an ample supply of suitable rock, others have little or none. A high standard of drainage provision is essential because of sudden floods and high rates of surface run-off. Many of the problems outlined above can be solved by good working practice with the techniques outlined in this study. There remain, however, a substantial number of problems of route selection, canalisation, path construction, reinstatement and implementation for which further research and development are needed.

14.2 Moorlands

Moorland areas have many of the problems of mountain areas, although they are generally less visible from a distance, and where there is high cover of heather this tends to reduce the spread of users away from paths (Haffey 1979). Drainage, particularly of peaty areas, is often problematic, and vegetation reinstatement, although not quite as difficult as on mountains is still slow and uncertain because of poor soils and climatic constraints.

14.3 Bogs

Bogs are mainly used by walkers, on route to somewhere else. Both vegetation and peat soils are easily damaged by trampling (Slater & Agnew 1977), and the living surface layer or acrotelm (Ingram 1982) crushed. Use of bogs is, however, easily contained by construction of boardwalks, and vegetation recovery is generally fairly rapid provided partial vegetation cover remains; there is often a substantial seed bank of rushes, and transplanting and live mulch techniques can be used successfully.

Use of extensive upland blanket bogs can also be tackled by floated aggregate paths, but there is scope for more trials of drainage and fertiliser to increase vegetation and soil resilience.

Table14.1 Problems in managing damage at recreation sites in different environments. Types of use: W, walkers; H, horses; M, mountain bikes; V, vehicles; B, boats; S, skiers

	Mountain	Moorland	Bog	Dune	Grassland	Woodland	Waterways
Type of Use	WMS	WMHV	W	WV	WH	WHVM	WB
Path construction	✔	✔	✔	✔			
Route selection	✔	✔					
Drainage	✔	✔	✔				
Vegetation erosion	✔	✔	✔	✔			✔
Soil erosion/ damage	✔	✔	✔	✔			✔
Canalising use	✔	✔		✔			✔
Reinstatement	✔	✔	✔	✔			
Other problems	High visibility of use			Wind erosion			Riverbank erosion by wash

14.4 Dunes

Problems at coastal sand dune sites are mainly caused by uncanalised use by walkers and vehicles (Liddle 1973, Ranwell & Boar 1986, Boorman & Fuller 1977), although horses are occasionally a problem. The solution is nearly always to proscribe vehicles, contain car parking, and build formal paths of boardwalk, sand cement, or bark (Leatherman et al 1978). Sensitive areas of dune are often fenced off, and blowouts and otherwise damaged areas revegetated with marram, or other species, and erosion minimised by use of brash or soil glues to provide surface protection (Ranwell & Boar 1986, Countryside Commission for Scotland 1987).

14.5 Grassland

Grasslands are a broad category which covers predominantly grass habitats such as downs, upland grazings and meadows. Grassland is, however, present to some extent in many other types of habitat, and it tends to be favoured for recreational purposes (Haffey 1979, Goldsmith et al 1970). In general the damage to grassland by recreational use is relatively small, vegetation resilience is fairly high and reinstatement straightforward. It is important, however, to ensure that as far as possible use of fertilisers and reinstatement work do not substantially alter the ecological character of a site; for example by replacing bent-fence grassland with ryegrass. This can be avoided by careful choice of species, taking care not to use fertiliser except in appropriate situations, and where feasible adding amenity herbs and grasses to create patterns as well as cover (Wells et al 1989).

14.6 Woodland

The major problems of recreational access to woodlands stem from the general dampness of the ground. Woodland soils are slow to dry out because of theshelter provided by trees. Consequently footpath surfaces are easily damaged and can be difficult to keep in good condition. One approach is to open up paths by cutting back trees to let drying occur more rapidly.

Horseriders are perhaps more frequent users of woodland than most other habitats, and can cause quite a lot of damage to rides. This is one reason why the Forestry Commission separate footpaths and bridle ways.

Advantages of woodland are that there is usually an adequate supply of timber for engineering purposes. In addition, although woodland vegetation is fairly easily damaged by trampling, recovery is often rapid except where completely bare ground has been created. Irving (1985) gives examples of the use of brush to reduce penetration of plantations, poles to close rides to vehicles, and encouraging growth of brambles to restrict use away from prescribed routes.

14.7 Waterways

Most of the focus of this report has been on land-based recreation, but at the land-water interface around lakes and on river and canal banks there can be heavy recreational use and erosion problems are common. Construction of reinforced paths and sections of bank are often needed to reduce the problems of erosion by trampling. Damage from boats takes the form of increased sediment suspension, and erosion of vegetation by direct abrasion and wave actions (Table 14.1)

Most of this damage can be controlled by canalisation of use; restricting speeds of boats, types of craft, or areas they can use (Eaton 1986, Van der Ploeg 1990). Provided there are not extraneous limiting factors such as eutrophication, revegetation of banks and shallow waters by transplanting and seeding is relatively straightforward and rapid (Eaton 1986, Bickmore & Larard 1989).

15. PRACTICAL CONSTRAINTS

Techniques for ground repair are only one of the practical issues facing most managers, and one that often does not loom large in the process of decision-making about ground management. In most cases, even when the manager is aware of the full range of techniques available - and for reasons already outlined (2.4), relatively few managers have that wider awareness - a number of practical constraints will limit choice.

15.1 The range of constraints

Some constraints are inherent in the physical nature of damaged sites, but others stem from the organisational structures and funding processes typical of much current work on ground damage.

There are five key aspects, closely interrelated. They are discussed in the order they usually emerge in the *ad hoc* management process:

15.1.1 Retrospectiveness

This may not seem a very attractive term, but it encapsulates the fact that in present circumstances the great majority of work done on ground damage is repair, and often emergency repair at critical sites, rather than work preparatory to public use of a site or even work to pre-empt likely damage. Action (and particularly the allocation of resources for action) is usually triggered by acute damage. This means that there is very rarely any scope for desirable forms of management such as selection of an optimum alignment or a more trafficable vegetation type. Too often the manager must deal with ground damage where it already occurs, with little opportunity for realignment.

This problem is perhaps most acute in mountain environments. Existing desire-line paths are often very steep and subject to water erosion, but it can be difficult both to establish a more stable alignment that will be used, and to reinstate the damaged area - not least while visitors continue to use the site. There may also be legal obstacles to moving paths which are rights-of-way. Further practical difficulties may stem from the fixed location of source carparks or target visitor attractions. This of course is part of a wider truth (demonstrated for instance in the Tarn Hows restoration work) that in some cases long-term solutions to ground management problems may require fundamental reassessment of the wider resource and its use - countryside management in a broad sense, rather than (or as well as) site management.

15.1.2 Organisational structures

Much work in dealing with recreation ground impacts has been either short-term or focused on a relatively local area, but usually both. This partly stems from the great variety of actors involved in the provision and management of recreational land in the UK, compared to some other countries where there is a more unified system. This tends to lead to difficulties of communication; to diverse practice and much reinventing of basic techniques in different areas (or even in the same area, due to staff changes); and to some degree of professional rivalry.

Three broad contrasting types of organisational approach can be distinguished. The first is that often seen where local authorities are engaged in site management. This has too often been characterised by intermittent funding and staffing, or by medium-term but semi-independent staffing under MSC and related programmes. This approach, usually centring on capital projects of fixed duration, tends to inhibit the formulation of sustained work programmes, the development of permanent management expertise, or the application of experimental techniques.

It has also tended not to be particularly sensitive to the need for maintenance, monitoring, or high-quality landscaping and vegetation treatments. This is especially so where commercial contractors are involved in competitive tendering for ground management works. Contractors cannot afford experiments which may not work, and few have the time or inclination to look for new techniques; they will essentially carry out work as specified. Experience suggests that it can be hard to achieve high-quality detailed finishing. The capacity to provide good specification for contracted-out path work is also underdeveloped at present.

At the other end of the spectrum is the activity of land holding or land managing agents such as the Forestry Commission, the National Park authorities in England and Wales, or private conservation owners like the National Trusts and the County Naturalists Trusts. While many of these agents have long-running commitments to ground management, sometimes supported by sustained management staffing and permanent labour forces, they are typically highly site-specific in their approach. Some have no need (or at least perceive no need) to develop a range of techniques for different situations; in fact it can be difficult to persuade managers in these agencies to adopt or even to consider new techniques when their current methods are well proven by practice. This is especially so when they are under financial pressure. Further, some of the agencies in this sector rely heavily on volunteers, whose capacity to implement highly technical solutions is often very limited.

The third, mainly recent approach is the ad hoc crash project where major problems have been identified, such as the Three Peaks and Pennine Way projects. These are usually funded by the national agencies in substantial part or in whole. Strongly experimental in approach, they have been the main sources of new techniques in recent years. Ironically, however, there can be an internal conflict between the need to achieve substantial repairs and the experimental objectives. This has tended to result in a failure to carry through technical trials to the stage of full evaluation and published advice. While the funding for these projects has allowed the development of considerable expertise, it has usually been vested in a single Project Officer with many calls on his or her time; the moving-on of that officer can then result in a substantial loss of accumulated technical understanding and diagnostic skill.

15.1.3 Management and labour skills

The lack of skilled and experienced workers, both at the managerial level and on the ground, is a substantial constraint on the application of new and complex techniques. The short-term nature of much work carried out by local authorities and other agencies means that it is often implemented by professional officers whose primary skills and commitments lie elsewhere. In those circumstances it is unrealistic to expect staff to develop the diagnostic skills needed to assess sites and specify techniques. The lack of resources often means that there is only a single officer with responsibility in this field, with little time to pursue new techniques.

The perception of all ground repair work as manual labour requiring little skill is highly persistent, and underpins the common tendency to apply unskilled job creation employees to the work. This prevailing view makes for low levels of pay and of status, militating against the development of specialists in the field and of a career structure leading on to middle and senior management. In fact this kind of environmental work is really a craft calling for considerable judgement of sites, a sophisticated choice of techniques, and a good deal of finesse in application to satisfy users and external agencies. This applies a fortiori to vegetation restoration and landscaping techniques, which tend to be disproportionately time-consuming and fiddly; most path workers (including most managers) prefer work that produces solid, durable, and immediately conspicuous improvements.

These comments apply still more stringently to volunteer workers, who still contribute a significant part of the total effort in ground repair and footpath management. Most experienced managers agree that while volunteers can play an important role in support of professional workers, they have a limited capacity to undertake technical work in terms of skills and the short time-span of the usual volunteer task. The need for training and supervision will often more than outweigh the relatively low cost of the manpower delivered. To that extent all new techniques need to be appraised in terms of the skills required for implementation.

15.1.4 Funding

Funding is central to the problems of ground management. A gross shortage of resources is exacerbated by intermittent and short-term funding in a field where sustained inputs are essential. High-quality work is expensive; even the best work needs maintenance; and the distinction between capital and revenue funding, especially for grant aid from national agencies, often means that ground or path repairs simply need to be re-repaired after five or ten years.

The pressure for competitive tendering has made life considerably more difficult, by creating a need for specification which is very detailed, very complex, and calls for a range of skills which are not generally available. There are strong arguments for fostering specialist contractors who can deliver the full range of techniques at the right level of quality.

15.1.5 Site factors

Remoteness is probably the most constraining single factor in ground management. Besides adding substantially to costs, it can limit the use of machinery and the application of bulky or weighty materials such as jute mesh or quarry gravels.

A range of site sensitivities also apply. Some stem from visitor concern for landscape and recreation values; the British Mountaineering Council policy on footpath management sets high standards for the exclusive use of natural materials and local vegetation in upland sites. In SSSIs the Nature Conservancy Council can exert strong constraints on vegetation treatments, on the opening of borrow pits or the use of stream gravels, and even in some cases on shifting boulders. Path work in SSSIs is frequently viewed as a potentially damaging operation to be controlled, rather than as positive environmental management.

16 THE WAY FORWARD

This part summarizes earlier sections and highlights research gaps and the need for well documented management trials, and more effective monitoring. Suggestions are made for improving the communication of ideas and information about new and ongoing trials.

16.1 Priorities

Gaps and needs have been categorized as low, medium or high priority.

Low priority areas are those where the technology gap is small or of relatively little importance to management practice. Route planning, toxicity testing of soil glues, use of rock-turf mosaics and many problems of individual environments are in this categorie.

Medium priority is ascribed to solving problems that could improve management practice in the longer term but where there is a modest fund of information available already.

Table 16.1 Summary of research and development needs and priorities identified in erosion control technology for recreation access areas

Area	Subject	Priority (L/M/H)	Research trials	Development trials	Survey	Communication
Resource assessment:	Trampling sensitivity	H	*		*	
	Impacts of different types of use	M	*		*	
	Impacts of mountain bikes	M	*			
Route selection and lanscaping:	Route planning and design	L				*
Soil erosion control:	Comparison of geotextile nettings	M	*	*		
	Toxicity testing glues	L	*			
	Effectiveness of ridging	M		*	*	
Path construction:	Floated paths	M				*
	Stone pitching	M				*
Canalizing use:	Materials and methods	M				*
Use of machinery:	Path construction	M		*		*
	Planting vegetation	M	*	*		

Impacts of different types of users, comparison of erosion control nettings and many aspects of pathengineering and revegetation fall into this group. In some cases the need is for communication of existing information rather than research or development.

High priority is confined to subject areas where there is a substantial information gap that appears to be inhibiting management action. There are only a few areas in this group. They include studies of the relative sensitivities of different soils and vegetation to disturbance, the development of geotextile reinforcement of vegetation surfaces, use of drainage to reinforce vegetation, and the general lack of communication of ideas and experience.

Four approaches to tackling research and development needs are suggested.

Research trials would be fully replicated scientific studies in the laboratory or in the field that aimed at developing or testing techniques. Usually such trials would involve a large number of comparisons, and

Table 16.1 (Continued)

Area	Subject	Priority (L/M/H)	Research Trials	Development trials	Survey	Communication
Vegetation reinstatement:	Turfing	M		*		*
	Transplanting	M	*	*		*
	Seeding mixtures	M	*	*		*
	Soil seed banks	M		*		*
Vegetation reinforcement:	Rock mosaics etc.	L				*
	Geotextiles	M/H	*			
	Drainage	M/H	*	*	*	
Monitoring:	Frameworks	M				*
	Methods	M	*	*		*
Problems in particular environments:	Mountains	H	*	*		
	Moorlands	M		*		*
	Coasts	L				*
	Woodlands	L				*
	Grasslands	L				*
Practical constraints:	General	M				*
Communication:	Techniques trials and monitoring	H				*

would be followed by development or management trials to test the most successful techniques.

Development trials in the sense used here mean trials in which only a small range of treatments or techniques would be compared, but with costs and implementation details examined in more detail than in research trials. Development trials should still be rigorously designed and recorded, so that the results can be documented, and reliably interpreted by others.

Survey involves collating and recording information from existing experience, sites or trials. For example, a survey of sites where slope ridging had been undertaken would be helpful in evaluating this little known technique.

Communication of ideas and experience could be of immediate value for a high proportion of the areas of research or development need that have been identified. Erosion control at recreation access areas has not generally had a high profile in the scientific press, although there are a few noteable exceptions. Much of the available information is in the form of contracty reports that have a limited circulation, or internal reports that rarely emerge from filing cabinets. There is a need to recognise that much of this information could be important, and to find a suitable vehicle for its communication.

16.2 The skills required

Much of the work in this field has developed in an *ad hoc* manner. Although there are obvious exceptions, many projects large and small, have suffered from a lack of careful planning. There are three main elements to research and development:
* design;
* implementation;
* communication.

Failures have often been due to poor experimental design, resulting in a trial that either cannot be interpreted at all, or which lacks any statistical confidence limits. Good design requires expert advice. Project officers, for example, should not be expected to test techniques or do development work without access to backup advice from a specialist. Suitable specialists could be provided by Universities or Polytechnic colleges, the Research Councils and some independent consultants, although the latter probably have less experience of experimental design and testing.

Large projects concerned with managing impacts of recreation should be multi- disciplinary. The design stage at least should involve obtaining suitable advice on:
* landscaping
* engineering
* ecology
* sociology

To date there have been few truly integrated studies in this field.

Implementation seems to be rarely a major problem, and is most efficiently undertaken by staff on site, possibly with specialised advice or supervision where necessary.

The time required to communicate results has often not been adequetely taken into account. It is not generally realised that supervising staff running management or research trials should be allocated 10-50% of their time for analyzing and writing up their results.

This should be anticipated at the planning stage and in job descriptions. Some major management trial initiatives that have achieved substantial progress on the ground have failed to realise their full potential by not communicating or recording their results adequately.

16.3 Possible initiatives

16.3.1 The need for an overview

Some site managers, such as the National Trust in the Lake District, have systematic programmes in place for survey and monitoring of ground damage on their property. Similar surveys have been carried out under the CCS Footpath Management Project for heavily-used path systems in parts of Scotland. The Countryside Commission has undertaken the same kind of base survey for the Pennine Way. Other land managers like the Forestry Commission operate local systems of path condition survey, which vary in intensity between Forest Districts. Such inventories allow an assessment of the total scale of ground damage, forward programming of work, financial planning, and a review of techniques. They offer the best hope of moving away from the *ad hoc* approach that has prevailed in this field for too long.

These local surveys could be expanded into an inventory and overview of area problems, and ultimately aggregated into a national perspective akin to the rights-of-way condition study in England and Wales. This would help to establish the long-term funding need (both capital and revenue) to assist the national agencies in seeking appropriate levels of sustained funding from central Government. This inventory should also be matched by a survey of current work on ground management, in enough detail to record the main techniques and labour approaches being tried out.

16.3.2 Vegetation and soil sensitivity studies

The dearth of comparable information on the sensitivity of soils and vegetation to damage could justify a substantial research and development project. This would provide a national data base of sensitivity information for a wide range of site conditions, plant communities and soil types. This could be tackled by a combination of site surveys and experimental trampling of small plots. The work would need to extend over several years, and might be best undertaken by a University Department or one of the Research Councils.

16.3.3 Integrated research-development-management projects

There is a case for an integrated demonstration project to tackle a major recreation problem area.
This would also involve an ongoing monitoring system providing feedback for decision making and technique evaluation. Such a projects would aim to demonstrate the value of multi-disciplinary inputs, and should have a high element of quality assurance in the form of project management, clearly defined objectives, and full documentation at all stages. Overall direction should be the responsibility of a consultant, or middle to senior management, probably in conjunction with a steering group from interested agencies. Experience suggests that leaving major projects to a lone, fairly

junior or inexperienced project officer is not an effective solution.

16.3.4 Developing individual techniques

It is important to continue to develop new techniques and to screen materials and approaches. A variety of screening and development programmes are underway by Universities, the Research Councils, consultants and suppliers of materials and equipment. Techniques should continue to be tested and developed as part of ongoing programmes or in relation to specific problems. New initiatives should, however, be considered for high priority areas, such as (1) high altitude revegetation, and (2) the use of drainage to reinforce soils and vegetation.

16.3.5 The need for improved communication

There is an urgent need to re-establish and develop a national system for communication of techniques and practice along the lines of the Footpath Information Network, but with a broader coverage of ground management issues: something like a specialised version of the old Recreation News. The need for an active editor, free from other pressures and with time to chase up contributions or even to undertake site visits and write them up, implies national support, preferably jointly by the key agencies.

There is probably even an international demand for a good communication service of this sort, ideally including current awareness reviews to point to useful academic and practical publications, as well as technical notes. In fact a good-quality, regularly-appearing newsletter with a modest but specialised circulation could even generate some advertising revenue or support through sponsorship.

In order to provide an accessible account of current techniques there is a case both for a *manual of techniques* and for loose-leaf type *information sheets.* A manual would have the advantage of also providing an overview, and of drawing attention to the need for structured approaches to technique selection, implementation and evaluation. It could potentially be made available more rapidly than a large number of separate sheets. However, it could have the drawback of becoming dated within a few years.

Individual sheets could be more portable for field use than a manual and be potentially more readily updated. On the other hand, the organisation required to keep a series of leaflets up to date and distributed to existing users would be considerable, as the Countryside Commission for Scotland have found with their current series. Few individuals aquire a full set of leaflets so lack a broad perspective on the range of approaches possible.

Training is another priority area. The national agencies should certainly be working to promote higher levels of awareness of ground management issues and techniques in current college courses. But there is also a need to reach out to existing managers at all levels through practical workshops dealing with different aspects of the subject, and particularly to reach the middle management in local authorities and agencies where lack of expertise is sometimes an easy excuse for lack of action.

17 REFERENCES

ACLU (1990).Northwest Ethylene *Pipeline Phase II Ecological Survey. Volume 1. Main report and site reinstatement prescriptions.* Aberdeen Centre for Land Use, Aberdeen. 69 pp.

AGATE, E. (1983). *Footpaths - a practical handbook.* British Trust for Conservation Volunteers.

AITKEN, R. (1985). *Scottish mountain footpaths. A reconnaissance review of their condition.* Countryside Commission for Scotland, Perth. 97 pp.

ANDRAWES, K.Z., McGOWN, A., HYTIRIS, N., MERCER, F.B. & SWEETLAND, D.B. (1986). *The use of mesh elements to alter the stress-strain behaviour of granular soils.* Third International Conference on Geotextiles, 1986, Vienna. 839-844.

BARKER, D.H., BAYFIELD, N.G. & YAH, K.C. (1989). *Bioengineering erosion control and slope stabilization. State-of-the-art report with particular respect to West Malaysia and Singapore.* Geostructures Consulting, Edenbridge. 28 pp.

BATES, G.H. (1935). Vegetation of footpaths, sidewalks, cart tracks and gateways. *Journal of Ecology*; 23, 470-487.

BAYFIELD, N.G. (1973). Use and deterioration of some Scottish hill paths. *Journal of Applied Ecology*; 10, 634-644.

BAYFIELD, N.G. (1979). Recovery of four montane heath communities on Cairngorm, Scotland, from disturbance by trampling. *Biological Conservation,* 15: 165-179.

BAYFIELD, N.G. (1980). Replacement of vegetation on disturbed ground near ski lifts at Cairngorm Mountains, Scotland. *Journal of Biogrography*, 7, 249-260.

BAYFIELD, N.G. (1983). *Effects of extended use on footpaths in mountain areas of Britain.* In: The ecological impacts of outdoor recreation on mountain areas in Europe and North America. Ed. N.G. Bayfield & G.C. Barrow. Recreation Ecology Research Group, Wye. 100-111.

BAYFIELD, N.G. (1987). The two metre A-frame - a simple measuring device for rapid ecological survey. *Aberdeen Letters in Ecology*; 1, 1-2.

BAYFIELD, N.G. (1990). 1990 *Progress report: Snake Pass revegetation and fertiliser trials.* ITE Report to Peak National Park. Institute of Terrestrial Ecology Banchory.

BAYFIELD, N.G. (1991). *Progress report: Snake Pass revegetation and fertiliser trials.* Report to Peak National Park. Institute of Terrestrial Ecology, Banchory 6 pp.

BAYFIELD, N.G. & MILLER, G.R. (1989) *1988 vegetation reinstatement trials.* ITE Report No. 6 to the Yorkshire Dales National Park Three Peaks Project. Institute of Terrestrial Ecology, Banchory.

BAYFIELD, N.G., MILLS, D., McGOWAN, G. & PATERSON, I.S. (1990). *Vegetation reinforcement trials: 1986-80.* Report No. 7 to Yorkshire Dales National Park. Institute of Terrestrial Ecology, Banchory. 26 pp.

BAYFIELD, N.G., BARKER, D.H. & YAH, K.C. (1992). Erosion of road cuttings and the use of bioengineering to improve slope stability. *Singapore Journal of Tropical Geography* (in press).

BAYFIELD, N.G. & BATHE, G.M. (1982). Experimental closure of footpaths in a woodland National Nature Reserve in Scotland. *Biological Conservation;* 22, 229-237.

BAYFIELD, N.G., & McGOWAN, G.M. (1990). *Re-establishment of mountain and moorland vegetation: Laboratory screening trials* 1988-9. Report No. 2 to the Countryside Commission for Scotland. Institute of Terrestrial Ecology, Banchory.

BAYFIELD, N.G., McGOWAN, G.M. & PATERSON, I.S. (1991). *Monitoring of seeding trials in the Three Peaks, 1991.* ITE Report No 12 to Yorkshire Dales National Park. Institute of Terrestrial Ecology, Banchory. 20 pp.

BAYFIELD, N.G., McGOWAN, G.M. & PATERSON, I.S. (1991). 1990 *Progress report: trials of revegetation techniques at the Lecht, Aonach Mor, Cairn Gorm and Ben Nevis.* Report No 4 to the Countryside Commission for Scotland. Institute of Terrestrial Ecology, Banchory 31 pp.

BAYFIELD, N.G. & MILLER, G.R. (1988). *Restoration of vegetation in the Scottish uplands: a review.* Report to the Countryside Commission for Scotland and the Nature Conservancy Council. ITE Banchory, 75 pp.

BAYFIELD, N.G., MILLS, D., McGOWAN, G. & PATERSON, I.S. (1990). *Vegetation reinforcement trials: 1986-80.* Report No. 7 to Yorkshire Dales National Park. Institute of Terrestrial Ecology, Banchory. 26 pp.

BAYFIELD, N.G. & PICKRELL, B.G. (1971). The construction and use of a photoflex people counter. *Recreation News Supplement.* November 1971, 9-12. Countryside Commission, London.

BAYFIELD, N.G., URQUHART, U.H & COOPER, S.M. (1981). Susceptibility of four species of *Cladonia* to disturbance by trampling in the Cairngorm Mountains, Scotland. *Journal of Applied Ecology*; 18,303-310.

BAYFIELD, N.G., URQUHART, U.H. & ROTHERY, P. (1984). Colonisation of bulldozed track verges in the Cairngorm Mountains, Scotland. *Journal of Applied Ecology*, 21, 343-354.

BAYFIELD, N.G., WATSON, A. & MILLER, G.R. (1988). *Assessing and managing the effects of recreational use on British hills.* In: Ecological change in the uplands . Special publication Number 7 of the British Ecological Society. Ed. Usher, M.B. & Thompson, D.B.A. Blackwell, Oxford.

BICKMORE, C.J. & LARARD, P.J. (1989). *Reconstructing freshwater habitats in development schemes.* In: Biological habitat reconstruction. Ed. Buckley, G.P. Belhaven Press, London. 189-200.

BLOM, C.W.P.M. (1976). Effects of trampling and soil compaction on the occurrence of some Plantago species in coastal sand dunes. 1. Soil compaction, soil moisture and seedling emergence. *Oecologia Plantanum*; 11, 225-241.

BOORMAN, L.A. & FULLER, R.M. (1977). Studies of the impact of paths on the dune vegetation at Winterton, Norfolk, England. *Biological Conservation*; 12, 203-216.

BOORMAN, L.A. (1977). *Sand dunes.* In: The coastline. ed. Barnes, R.S.K. Wiley, London. 161-197.

BRATTON, S.P. (1985). Effects of disturbance by visitors on two woodland orchid species in Great Smoky Mountains National Park, USA. *Biological Conservation*; 31, 211-227.

BRATTON, S.P., HICKLER, M.G. & GRAVES, J.H. (1979). Trail erosion patterns in Great Smoky Mountains National Park. *Environmental Management;* 3, 431-445.

BRITISH WATERWAYS BOARD (undated). Notes on the development and use of the BW pedestrian counter. 8 pp.

BROWN, P.J., McCOOL, S.F. & MANFREDO, M.J. (1985). *Evolving concepts and tools for recreation user management in wilderness: a state-of-knowledge review.* In: Proceedings - National Wilderness Research Conference: Issues, state of knowledge, future directions. Ed. Lucas R.C. USDA Forest Service General Technical Report INT-220 Intermountain Research Station, Ogden. 320-346.

BUITRAGO, J. (1981). *Coastal sand dune disturbance by public pressures.* MSc Thesis, University of Aberdeen.

BURDEN, R.F. & RANDERSON, P.F. (1972). Quantitative studies of the effects of human trampling on vegetation as an aid to the management of semi-natural areas. *Journal of Applied Ecology*; 9, 439-457.

BUREAU OF LAND MANAGEMENT (1980) *Visual Resource Management Program.* Department of the Interior, Bureau of Land Management, Washington. 39 pp.

CANAWAY, P.M. (1975). Turf wear: a literature review. *Journal of the Sports Turf Research Institute*; 51, 92-103.

CENTRE FOR LEISURE RESEARCH (1992). Monitoring visitor numbers at countryside recreation sites. A training manual. Report to the Countryside Commission for Scotland. 142 pp.

CHAPPELL, H.G., AINSWORTH, J.F., CAMERON, R.A.D. & REDFERN, M. (1971). The effect of tramping on a chalk grassland ecosystem. *Journal of Applied Ecology*; 8, 869-882.

CIRIA (1990). *Use of vegetation in civil engineering.* Ed. Coppin, N.J. &

Richards, I.G. Construction Industry Research and Information Association. Butterworths, London. 292 pp.

COLE, D.N. (1985). *Research on soil and vegetation in wilderness: a state-of-knowledge review.* In: Proceedings - National Wilderness Research Conference: Issues, state-of-knowledge, future directions. Ed. R.C. Lucas. USDA General Technical Report INT-220, 135-177.

COLE, D.N. & BAYFIELD, N.G. (1992) A standardized procedure for trampling studies. Biological Conservation (In press).

COLEMAN, R. (1981). Footpath erosion in the English Lake District. *Applied Geography;* 1, 121-131.

COUNTRYSIDE COMMISSION FOR SCOTLAND. (1979). *Vehicular tracks in Upland Scotland.* CCS, Perth

COUNTRYSIDE COMMISSION. (1973). *Pennine Way Survey.* Countryside Commission, London. 78 pp.

COUNTRYSIDE COMMISSION FOR SCOTLAND. (1987). Information Sheet Plants 5.2.2. *Reseeding of dune pastures.* CCS, Perth.

CUNNINGHAM, G.M. (1978). Modified step-pointing, a rapid method of assessing vegetation cover. *Journal of Soil Conservation;* 13, 256-265.

DAN SUN & LIDDLE, M.J. (1992). The morphological responses of tussock grasses and the importance of taller number in their resistance to trampling. *Biological Conservation* (in press).

DOWN, C.G. & MORTON, A.J. (1'989). *A case study of whole woodland transplanting.* In: Biological habitat reconstruction. Ed. Buckley, G.P. Belhaven Press, London. 251-257.

DUFFIELD, B.S. & FORSYTHE, F. (1972). *Assessing the impacts of recreational use on coastal sites in East Lothian.* CRAAG Conference 1972. 37-45. Countryside Commission, London.

EATON, J.W. (1986). *Waterplant ecology in landscape design.* In: Ecology and design in landscape. Ed. Bradshaw, A.D., Goode, D.A. & Thorp, E. 24th Symposium of the British Ecological Society. Blackwell, Oxford. 285-306.

ENVIRONMENTAL ADVISORY UNIT (1988). *Heathland restoration: a handbook of techniques.* British Gas, Southampton. 160 pp.

FISHWICK, A. (1985). *Planning and management responses to recreational pressures in the Lake District National Park.* In: The ecological impacts of outdoor recreation on mountain areas in Europe and North America. Recreation Ecology Research Group Report No. 9. Ed. N. Bayfield & G.C. Barrow. 18-33. RERG Wye.

FORESTRY COMMISSION (1991). *Bulletins and Specifications for forest walk management and monitoring.* B2-B7, 51-13 and C3-C4.

GARLAND, G.C. (1990). Techniques for assessing erosion risk from mountain footpaths. *Environmental Management;* 14, 793-798.

GEOSYNTHETICS WORLD. (1991). 1991 *Directory of available products. Part 1. Europe.* (Geosynthetics World, London. 42 pp.

GOLDSMITH, F.B., MUNTON, R.J.C. & WARREN, A. (1970). The impact of recreation on the ecology and amenity of semi-natural areas: methods of investigation in the Isles of Scilly. *Biological Journal of the Linnean Society*; 2, 287-306.

GRABHERR, G. (1985). *Damage to vegetation by recreation in the Austrian and Garman Alps.* In: The ecological impacts of recreation on mountain areas of Europe and North America. Ed. N.G. Bayfield & G.C. Barrow. Recreation Ecology Research Group, Report NO 9. RERG, Wye.

GRIME, J.P., HODGSON, J.G. & HUNT, R. (1988). *Comparative plant ecology.* Allen & Unwin, London

GRIME, J.P. (1979). *Plant strategies and vegetation processes.* John Wiley, Chichester.

GRIME, J.P. (1983). *Manipulation of plant species and communities.* In: Ecology and design in landscape. Ed. Bradshaw, A.D., Goode, D.A., & Thorp, E. 24th Symposium of the British Ecological Society, Blackwell, Oxford. 175-194.

HAFFEY, D. (1979). Recreational activity patterns on the uplands of an English National Park. *Environmental Conservation*; 6, 237-242.

HARPER, J.L., WILLIAMS, J.T. & SAGAR, G.R. (1965). The behaviour of seeds in soil. 1. The heterogeneity of soil surfaces and its role in determining the establishment of plants from seed. *Journal of Ecology*; 53, 273-286.

HARRISON, J. (1981). Recovery of lowland grassland and heathland in southern England from disturbance by seasonal trampling. *Biological Conservation;* 19, 119-130.

HELLIWELL, D.R. (1989). *Soil transfer as a means of moving grassland and marshland vegetation.* In: Biological habitat reconstruction. Ed. Buckley, G.P. Belhaven Press, London. 258-263.

HOPE, F. (1990). *Turf culture. A manual for the groundsman.* Cassell, London.

HOWELL, J.H., CLARK, J.E., LAWRENCE, C.J., & SUNWAR, I. (1991). *Vegetation structures for stabilising highway slopes. A manual for Nepal.* Dept. of Roads, His Majesty's Government of Nepal and Overseas Development Administration, United Kingdom. 182 pp.

HUMPHREY, B.C.H. (undated, 1986?). *Path Manual. A practical guide for planners and managers.* Department of Environment Affairs, Directorate of Forestry, Conservation Branch, Natal. Pietermaritzburg. ˜90 pp.

INGRAM, H.A.P. (1982). Size and shape in raised mire ecosystems: a geophysical model. *Nature*; 279, 300-303.

IRVING, J.A. (1985). *The public in your woods. An owners guide to managing urban-fringe woodland for recreation.* Packard Publishing, Chichester.

ITE (1991). *Aonach Mor ski area: 1991 environmental audit.Report to Nevis Range.* Institute of Terrestrial Ecology, Banchory, Scotland.

ITE (1988). *The potential for revegetation at four problem sections of the southern Pennine Way.* Report to the Peak National Park and Countryside Commission. Institute of Terrestrial Ecology, Banchory. 31 pp.

JEPPERSEN, J.L. (1987). The disturbing effects of orienteering and hunting on roe deer (Capreolus capreolus. *Danish Review of Game Biology;* 13, 1-24.

KARDELL, L. (1974). *Damage to the vegetation caused by orienteering.* Royal College of Forestry. Research Note No. 4. 48 pp.

LANCE, A.N., BAUGH, I.D. & LOVE, J.A. (1989). Continued footpath widening in the Cairngorm mountains, Scotland. *Biological Conservation;* 49, 201-214.

LEATHERMAN, S.P., GODFREY, P.J. & BUCKLEY, P.A. (1978). *Management strategies for national seashores.* Proc. Symp. on technical, environmental, socio economic and regulatory aspects of coastal zone planning and management. San Francisco, California. 322-337.

LEONARD, R.E. & WHITNEY, A.M. (1977). *Trail transect: a method of documenting trail changes.* Forest Service Research Paper NE-389 North Eastern Forest Experimental Station, Upper Darby, Pa.

LENEY, F.M. (1974). *The ecological effects of public pressures on picnic sites.* PhD Thesis, University of Aberdeen

LIDDLE, M.J. (1988). *Recreation and the environment; the ecology of recreation impacts.* Section 2. Vegetation and wear. AES Working Paper 1/88. Griffith University, Australia. 189 pp.

LIDDLE, M.J. (1989). *Recreation and the environment; the ecology of recreation impacts* S ection 3. Soils and wear. AES Working Paper 1/89. Griffith University, Australia.

LIDDLE, M.J. (1975). A theoretical relationship between the primary productivity of vegetation and its ability to tolerate trampling. *Biological Conservation*; 8,251-255.

LIDDLE, M.J. (1973). *The effect of trampling and vehicles onnatural vegetation.* PhD Thesis, University College of North Wales, Bangor.

MACINTYRE, M. (1991). *The effects of walking and mountain bike use on the erosion of open heather moorland.* Aberdeen Centre for Land Use, Aberdeen. 16 pp.

MEYER, L.D. & WISCHMEIR, W.H. (1969). Mathematical simulation of the process of soil erosion by water. *Transactions of the American Society of Agricultural Engineers*; 12, 754-758.

MILLER, G.R., BAYFIELD, N.G., PATERSON, I.S. & McGOWAN, G.M. (1991). *Restoration of natural vegetation on organic soils from buried viable seeds.* ITE Report No. 10 to the Yorkshire Dates National Park. Institute of Terrestrial Ecology, Banchory. 46 pp.

MILLER, G.R. & BAYFIELD, N.G. (1989). *Seed banks of organic soils at the Three Peaks.* ITE Report No. 5 to the Yorkshire Dales National Park. Institute of Terrestrial Ecology, Banchory. 31 pp.

MORGAN, R.P.C. (1985). *The impact of recreation on mountain soils: towards a predictive model for soil erosion.* In: The ecological impacts of outdoor recreation on mountain areas in Europe and North America. Ed. N. Bayfield & G.C. Barrow. Recreation Ecology Research Group, Wye. 112-121.

MOSS (1991). *Moss. An overview.* MOSS Systems, Horsham. 4 PP.

MOSS, S. (1991). *A study of the correlation between footpath width and vegetation type in the Cairngorm mountains.* MSc dissertation, University of Aberdeen.

MOSS, B. (1986). *Restoration of lakes and lowland rivers.* In: Ecology and design in landscape. Ed. Bradshaw, A.D., Goode, D.A. & Thorp, E. 24th Symposium of the British Ecological Society. Blackwell, Oxford. 399-415.

NATIONAL TRUST (1987). *Kinder, the first five years. (1982-1986).* National Trust, Hope.

PARK, D.G. (1989). *Relocating magnesian limestone grassland.* In: Biological habitat reconstruction. Ed. Buckley, G.P. Belhaven Press. 264-280.

PERRING, F. (1967). *Changes in chalk grassland caused by galloping.* In: The biotic effects of public pressures on the environment. Ed. E Duffey. Monks Wood Experimental Station Symposium 3. Nature Conservancy, Huntingdon. 134-147.

PHILPIN, A.J. (1992). People counters. Unpublished review. 3 pp.

PHILPIN, A.J. (1990). Pennine Way condition survey. Summary report. Unpublished report.

PENNINE WAY COORDINATI9ON PROJECT (1990). Pennine Way condition survey. Area report summary. Countryside Commission, Cheltenham.

PRYOR, P.J. (1985) *The effects of disturbance on open* Juncus trifidus *heath in the Cairngorm mountains, Scotland.* In: The ecological impacts of outdoor recreation on mountain areas in Europe and North America. Ed. by N.G. Bayfield & G.C. Barrow. Recreation Ecology Research Group, Wye, 53-62.

RANWELL, D.S. & BOAR, R. (1986). *Coastal dune management guide.* Institute of Terrestrial Ecology, Norwich. 105 pp.

REES, S.L. (1990). The effects of trampling on a grassland area, Brathens, Scotland: an assessment of the relative impact of plimsols, walking boots and a mountain bike, and a comparison of two different soil moisture levels. MSc Dissertation, University of Leicester.

ROBERTS, E.H. (1972). *Dormancy: a factor affecting seed survival in the soil.* In: Viability of seeds. Ed. E.H. Roberts. Chapman & Hall, London. 321-359.

SALISBURY, E. (1964). *Weeds and aliens.* Collins, London.

SCANDRETT, E. (1990). *Regenerating heather moorland. A study of methods to encourage regeneration of heather (Calluna vulgaris from seed.* Macaulay Land Use Research Institute, Roslin. 52 pp.

SLATER, F.M. & AGNEW, A.D.Q. (1977). Observations on a peat bogs ability to withstand public pressure. *Biological Conservation.* 11, 21-27.

SPEIGHT, M.C.D. (1973) Outdoor recreation and its ecological effects. *Discussion papers in conservation;* 4. University College, London.

STANKEY, G.H. & SCHREYER, R. (1985). *Wilderness use and user characteristics: a state-of-knowledge review.* In: Proceedings - National Wilderness Research Conference: Issues, state-of-knowledge, future directions. Ed. R.C. Lucas. USDA Forest Service General Technical Report INT-220.

STANKEY, G.H., COLE, D.N., LUCAS, R.C., PETERSEN, M.E. & FRISSELL, S.S. (1985). *The limits of acceptable change (LAC) system for wilderness planning.* USDA Forest Service General Technical Report INT-176 Intermountain Forest and Range Experimental Station, Ogden. 37 pp.

STANKEY, G.H. & BADEN, J. (1977). *Rationing wilderness use: methods, problems and guidelines.* USDA Forest Service, Research Paper INT-192. 20 pp.

TALLIS, J.H. & YALDEN, D.W. (1983). *Peak District Moorland restoration project.* Phase 2 Report: Revegetation Trials. Peak Park Joint Planning Board, Bakewell.

TOURISM AND RECREATION RESEARCH UNIT (1983). *Recreation site survey manual. Methods and techniques for conducting visitor surveys.* E. & F.N. Spon, London.

USDA (1984). *National Forest Landscape Management Ski areas.* Volume 2, Chapter 7. USDA Forest Service, Agriculture Handbook No. 617.

USDA (1977). *National Forest Landscape Management.* Volume 2. Chapter 6 Roads. Forest Service. US Department of Agriculture. Agricultural Handbook No. 483, Washington. 62 pp.

USDA Forest Service (1985). *Trails management handbook.* FSH 2309-18 USDA, Washington. 144 pp.

VAN der PLOEG, S.W.F. (1990). *Outdoor recreation and the multiple use management of natural resources.* PhD Thesis, Vrije Universiteit te Amsterdam.

WATSON, A. (1984). A survey of vehicular hill tracks in North- east Scotland for land use planning. *Journal of Environmental Management;* 18, 345-353.

WATSON, A. (1991). Increase of people on Cairn Gorm plateau following easier access. Scottish Geographical Magazine; 107, 99-105.

WEAVER, T., DALE, D. & HARTLEY, E. (1979). *The relationship of trail condition to use, vegetation, user, slope, season and time.* In: Recreation impact on wildlands. Forest Service USDA. National Park Service Report R-6-001-1979. 94-100.

WEAVER. T. & DALE, D. (1978). *Trampling effects of hikers, motor cycles and horses in meadows and fields.* Journal of Applied Ecology, 15: 451-457.

WEBB, N.R. & ROSE, R.J. (1987). *The effect of temporary roadways on the recovery of heathland vegetation.* ITE report to British Gas. Institute of Terrestrial Ecology, Wareham.

WELLS, T.C.E., BAYFIELD, N.G., COX, R. & McGOWAN, G.M. (1990). *Wild flower swards for trunk road and motorway landscaping. A handbook.* Report to Department of Transport. Institute of Terrestrial Ecology, Monks Wood. 114 pp.

WELLS, T.C.E., COX, R. & FROST, A. (1989). *Diversifying grasslands by introducing seed and transplants into existing vegetation.* In: Biological habitat reconstruction. Ed. G.P. Buckley. Belhaven Press, London. 283-298.

WELLS, T.C.E., BAYFIELD, N.G., COX. R. & McGOWAN, G.M. (1992). Wildflowers for trunk road and motorway landscaping. A handbook. Department of Transport (in press).

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