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Environmentally Sustainable Trail Management

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Introduction

A trail system that facilitates access to remote ecotourism destinations, provides safe, high quality recreational experiences, and concentrates traffic on durable treads maintained to minimize resource degradation can only result from professional planning and management. This chapter outlines and reviews the essential ingredients of trail management programmes from a resource protection perspective. This begins with planning considerations for selecting and developing a sustainable system of trails, decision frameworks for balancing resource protection and recreation provision objectives, trail construction and maintenance, and visitor management. All aspects are considered important to avoid common trail impact problems, including unacceptable impacts from poorly located trails, deficient construction or trail maintenance, and lack of trail condition standards and monitoring.

In the absence of effective trail management, resource degradation along trails often occurs, ranging in both type and severity. Vegetation loss along the primary tread is generally expected but, in response to other trail impacts (e.g. muddiness or erosion), can extend to adjacent areas through trail widening and braiding. Compositional changes in trailside vegetation may also occur, including the introduction and spread of invasive exotic species. Similarly, loss of organic litter and soil, and compaction of mineral soil, is generally expected on designated trails, but can extend to trailside areas or to alternative visitor-created paths when the main tread becomes degraded. Common problems include soil erosion that may expose rocks and roots or create deep rutting, and muddiness, including muddy treads and mud-holes with standing water. Trail widening and braiding generally follow – avoidable resource impacts that can substantially expand the cumulative spatial extent of disturbance. Other impacts include sedimentation of water resources (Fig. 13.1) and disturbance of wildlife. More extensive reviews of these impacts and the trail degradation literature are provided by Cole (1987), Leung and Marion (1996, 2000), Liddle (1997), Hammitt and Cole (1998) and Newsome *et al.* (2002).

Trail Planning

The management of environmentally sustainable trails begins with preparation of a trail system plan that provides direction and guidance to all trail management decision-making. An exceptional trail plan should address four general topics: (i) management guidance, including goals, objectives and desired resource and social condition statements; (ii) identification of a decision-making framework, including

Fig. 13.1. Erosion of soil into a stream, Big South Fork National River and Recreation Area, USA.

indicators, standards, monitoring methods and alternative management actions; (iii) evaluation of existing trail resources in light of administrative and recreational needs intended for the trail system; and (iv) description of the actions and resources necessary to develop and manage the trail system (see Table 13.1). Developed for a World Heritage area, Tasmania Parks and Wildlife Service (1998) provides a good example of what a comprehensive trail management plan might include.

General planning guidance can be found by contacting major land management agencies, guidance specific to trails is provided by Flink and Olka (2000) for urban/suburban multiple-use trails, by Birchard and Proudman (2000) and Demrow and Salisbury (1998) for backcountry trails, and by Vogel (1982) for equestrian trails. An important step omitted in many trail plans is the specification of prescriptive management objectives and desired resource and social conditions for the trail system, generally by management zone (NPS, 1998). Application of zoning allows different classifications of guidance for social, physical and managerial settings and spatial segregation of conflicting uses (Forest Service, 1982). For example, zone 'x' will provide for low-intensity human-powered activities on primitive trails with few facilities and pristine resource conditions, while zone 'y' will provide for high use, including equestrians, on designated routes with crushed stone (aggregate) surfacing, bridges for stream crossings, and allowance for greater levels of resource degradation. Comprehensive and specific desired condition statements provide improved management guidance, particularly for identifying the type and extent of trail development, justifying requests for additional resources, or need for controversial management actions.

Desired resource and social conditions can be sustained by employing planning and decision frameworks such as the Limits of Acceptable Change (LAC) (Stankey *et al.*, 1985; NPS, 1997a,b; Farrell and Marion, 2002). These permit inclusion of indicators and standards of quality, and monitoring to gauge management success in achieving prescriptive objectives. Conditions that exceed management standards prompt an evaluation of the impact problem and selection and implementation of corrective actions (Anderson *et al.*, 1998). Omitting this step and these frameworks greatly increases the subjectivity of management decisions and can permit a spiralling decline in social and resource conditions beyond acceptable levels.

Table 13.1. Elements of a potential trail plan.

Goals, prescriptive objectives, and specific desired resource and social condition statements for the trail system and zones related to recreational opportunities and resource conditions
Evaluation and specification of appropriate recreational opportunities
Incorporation/description of a decision-making framework to guide and justify management actions
Identification of indicators, standards and monitoring protocols needed to sustain high-quality resource conditions and recreational experiences. Description of alternative management actions that may be applied to achieve desired conditions
Inventory of existing trails and roads for their suitability to sustain intended types and amounts of uses. Consider management zoning; environmental sensitivity; recreational and administrative needs; distribution, design and condition of existing trails; and facility/ maintenance features
Evaluation of proposed uses in relation to the existing network, to identify deficiencies. Description of the actions and resources necessary to address deficiencies (e.g. new trail construction, reconstruction, relocations) and to manage the proposed trail system (e.g. support trail maintenance and visitor management)
Trail standards specifying the general level of trail development, including tread widths, substrates, grades, difficulty, maintenance features, and corridor width and height

An exceptional trail is almost always the result of good planning, one designed to meet the specific requirements of its intended types and amounts of recreational uses, level of difficulty, and physical characteristics of the land (Hesselbarth and Vachowski, 2000). Unfortunately, most protected area managers inherit a trail system opportunistically patched together from a network of old roads and trails with varied origins and purposes. Many trails were visitor-created, others were constructed for logging, fire fighting, or to provide vehicular access to remote locations. Few were designed as recreational trails, and most were probably not carefully planned and constructed to sustain high use, limit resource degradation, or fulfil recreation objectives (Leung and Marion, 1996). Furthermore, managers often find they have more trails than are truly needed or that can be maintained in acceptable condition.

These issues are best addressed through a trail system assessment process, conducted to evaluate existing trails for suitability and retention in a formal trail system. We suggest a three-tiered approach, beginning with a fatal flaw analysis to omit trail segments that are inherently harmful to natural or cultural resource protection. This evaluation is designed to identify trails that could threaten sensitive flora, fauna, cultural/historic sites, contain significant degradation requiring expensive re-routes or reconstruction work, or include significant public safety hazards. Next, trail suitability can be evaluated from an array of perspectives, including needs for administrative and public access to backcountry features and locations, and recreational objectives for different zones and visitor activities. Finally, ground-based technical assessments of trail suitability based on existing trail locations, construction methods, maintenance and resource conditions can identify those trails most able to sustain heavy recreational traffic with limited maintenance.

Trails found to be unsuitable from such reviews may be unnecessary, while others will require re-routeing, reconstruction, or maintenance to be included in a formal trail system. In spite of the controversial nature of such decisions, we emphasize that closing trails that threaten resource protection objectives, are unnecessary, highly degraded, unsafe, or unsuitable is more professionally responsible than leaving them open to continued use and degradation. Trails intended for inclusion within the system should not be reopened until needed re-routeing or reconstruction work is completed. A negative public response may even be useful in garnering additional funding to construct and maintain an improved trail system.

Trail Location and Design

Many trail impact problems are the result of poor planning and location rather than higher impacting types or amounts of use (Cole, 1987; Leung and Marion, 1996, 2000). Many trails have sections ranging from good to poor condition, yet each trail likely receives the same types and amounts of use. Thus, problems like muddy soils or eroded treads are primarily a function of trail routeings through wet soils or up steep slopes. Applying tread reconstruction and maintenance solutions to such problems can be expensive, effective for only a short time, and give the trail a more 'developed' appearance that can alter the nature of recreational experiences. Short trail re-routes or larger relocations are a more effective long-term solution for sustaining traffic while minimizing resource impacts and maintenance. The following topics highlight some important trail location and design considerations to promote sustainable trail development.

Trail grade

An important goal of trail layout and design is to minimize the number of tread structures (e.g. drainage features, steps, tread armouring) and tread maintenance (Birchard and Proudman, 2000). The most important design specification for limiting soil erosion is keeping trail grades below 10% (Hooper, 1988) or 12% (Agate, 1996; Hesselbarth and Vachowski, 2000). A design grade of less than 9% is recommended for equestrian trails (Vogel, 1982). Crushed stone (aggregate) will migrate downslope at unacceptable rates when applied to trail grades over 8% (The Footpath Trust, 1999). Trail segments with steeper grades should be re-routed wherever possible, particularly those receiving moderate to heavy use. When topographic features prohibit relocation, more extensive tread work, involving steps, drainage and armouring with rock (stone pitching), will be essential to prevent excessive erosion.

Slope alignment angle

The orientation of the trail to the prevailing slope, termed slope alignment angle, determines the ease with which water can be removed from a trail (Leung and Marion, 1996). Trails that directly ascend a slope have a low slope alignment angle (irrespective of trail grade) and will be difficult or impossible to drain water from if they become incised (Fig. 13.2). Re-routeing these sections is generally the most effective long-term solution. Sidehill trails on the contour or at oblique orientations (45–90°) are easily drained to minimize muddiness and erosion, and their steeper sideslopes confine use to a narrow tread.

Fig. 13.2. It is impossible to drain water out of this entrenched trail in Zion National Park, USA, due to its low slope alignment angle. Re-routeing is recommended to avoid the need for extensive tread work involving erosion control measures and steps on the existing alignment.

Stream crossings

A good trail design will minimize the number of stream crossings and carefully plan the locations where crossings are necessary. Trails approaching stream crossings often directly descend steep slopes and are prone to erosion, the sediments from which can drain into streams (Fig. 13.1). The employment of a sidehill design across slopes permits control of trail grades and drainage. Adequate tread drainage in the vicinity of streams prevents the buildup of larger, more erosive volumes of water. Tread outsloping is a recommended tread drainage method near streams, because runoff is slowed and evenly distributed, allowing adjacent organic litter and vegetation to filter out soil particles before reaching streams. Bridges are also critical resource protection facilities on horse and motorized trails, uses that are more apt to loosen tread soils, making them more susceptible to erosion.

Soil type/limitations

Soil properties, including soil wetness, texture, structure and depth, influence the ability of soil to withstand a given type and amount of traffic (Demrow and Salisbury, 1998; Scottish Natural Heritage, 2000). Avoid soils that are seasonally wet and poorly drained, or be prepared to employ trail construction techniques such as boardwalks, turnpikes, causeways, puncheon or geosynthetics to sustain traffic and avoid muddiness (Hesselbarth and Vachowski, 2000). Loam and sandy-loam soils, because of their even mixture of silt, clay and sand, provide the fewest limitations for trails (Demrow and Salisbury, 1998; Hammitt and Cole, 1998). Removal of organic litter and soils during trail construction to expose underlying mineral soil creates a more durable tread, less prone to muddiness. Rock and gravel in the mineral soil further strengthens them to support heavy traffic while resisting erosion and muddiness. Where possible, avoid soils high in silt and clay, which become muddy when wet, or cracked and dusty when dry.

Soil depth to bedrock of greater than 1 m is preferred – shallower soils may become saturated and subject to muddiness. Extremely thin soils in alpine terrain are easily eroded, so contain traffic on clearly marked treads (Demrow and Salisbury, 1998). Repeated traffic will alter soil structure, compressing the arrangement of soil aggregates and decreasing air and water infiltration (Pritchett, 1979). However, compacted treads provide a more stable and resistant surface, which sheds water to resist muddiness and minimizes the potential for soil erosion.

Sensitive resource considerations

The critical habitats of rare, threatened and endangered plants and animals, or sensitive resources, such as fragile vegetation, important wildlife habitat or irreplaceable archaeological or cultural sites, are best protected through their avoidance. Routeing trails away from such areas is preferable, unless they are an appropriate destination for visitors. In such cases, employing boardwalks and railings can protect resources while permitting visitor access.

Design for special uses

Special uses, particularly more impacting motorized or horse traffic, require special design considerations. These include, for example, tread surfacing with crushed stone (Fig. 13.3), wider trails and cleared trail corridors, a wider radius at turns, hitching posts, and staging areas for loading/unloading animals or equipment and parking trailers. Parking capacity can be limited to the capacity of the trail to sustain the planned types of uses. Refer to the following, more specialized references for further guidance (Vogel, 1982; Keller, 1991; McCoy and Stoner, 1991; Wernex, 1993).

Trail Construction

Sidehill trails

Trails with a high slope alignment angle (sidehill trails) are always the most preferred design (Birchard and Proudman, 2000) (Fig. 13.3b). A properly constructed sidehill trail design allows the greatest control over trail grades and effectively minimizes the most common and significant trail degradation problems: tread erosion, muddiness, widening, and secondary treads (Agate, 1996; Demrow and Salisbury, 1998; Birchard and Proudman, 2000; Hesselbarth and Vachowski, 2000). However, sidehill construction is more difficult, particularly on steep slopes. The amount of excavation on slopes greater than 50% is considerable and treads will slump or erode unless shored up with retaining walls (Birchard and Proudman, 2000). Regardless, the benefits of avoiding or minimizing future

(a)

(b)

Fig. 13.3. (a) Extensive rockwork and application of gravel are employed to sustain traffic in reconstructing this highly used trail at Acadia National Park, USA. (b) While gravel can be visually obtrusive when initially applied, over time it sinks in and combines with soil to produce the highly resistant tread shown on this trail in Shenandoah National Park, USA.

resource degradation and the cumulative costs of repetitive short-term maintenance clearly make sidehill trails the preferred design for resource protection and sustainable use.

Sidehill trail construction requires excavating the trailbed into the slope to create a gently outsloped bench. A trail crossing slopes up to 10% may require only the removal of organic litter and soils to expose mineral soil, which will remain drier and is more resistant to traffic than organic materials. Sideslopes of 10–30% can employ a half-bench design, where half the tread rests on original mineral soil exposed by excavation and half is on compacted mineral soil dug from upslope (Hesselbarth and Vachowski, 2000). A three-quarter or full-bench construction will be more sustainable and is preferred, particularly on slopes above 30%.

Outsloping treads 5% (2.5 cm drop for every 46 cm of width) during construction allows water to drain across and off the tread, rather than accumulate and run down the trail to erode soil (Hooper, 1988; Birchard and Proudman, 2000). However, natural processes and trail use eventually compromise tread outsloping, so additional measures are needed to remove water from treads. The most effective and sustainable method for removing water from trails is the Coweeta or grade dip, also known as terrain dips or rolling grade dips (Birchard and Proudman, 2000; Hesselbarth and Vachowski, 2000). These are constructed by reversing the trail's grade periodically to force all water off the tread. These must be planned during initial construction so that a descending trail's grade levels off and ascends for 3–5 m before resuming its descent. A sufficient frequency of grade dips, particularly on steeper trail grades and in mid-slope positions, is necessary to prevent the accumulation of sufficient water to erode tread surfaces. Additional methods for removing water on previously constructed trails are described under Trail Maintenance.

Techniques for wet soils

Areas with wet soils require more expensive initial construction and continuing maintenance and should be avoided whenever possible. When wet soils do need to be traversed, large stepping stones are a preferred method for short stretches, including small stream crossings. Constructing parallel drainage ditches can also be effective by draining water away from tread soils. More expensive options include turnpike and puncheon construction, which elevate the trail above wet ground. A turnpike is constructed by placing mineral soil excavated from two parallel trailside ditches between rows of rot-resistant logs or rocks (Steinholtz and Vachowski, 2001). Geosynthetics (described in a following section) can be used under the fill material or to encapsulate gravel or rock to improve drainage and trafficability (Monlux and Vachowski, 2000). Puncheons are elevated wooden walkways ranging from primitive bog bridging (Demrow and Salisbury, 1998) to more elaborate structures with wooden stringers and decking (Steinholtz and Vachowski, 2001). Puncheon has much higher initial and recurring costs, so it is generally used only in locations where suitable mineral soil or gravel is unavailable for turnpike construction (Birchard and Proudman, 2000). Puncheon must also be well-anchored in areas prone to flooding and may burn during dry season forest fires. More elaborate elevated boardwalks and bridges are required when deeper water or ravines must be traversed (Steinholtz and Vachowski, 2001).

Tread hardening

A number of tread-hardening techniques may also be employed during original trail construction or during subsequent reconstruction and maintenance. Wet soils can be capped with crushed stone or excavated and replaced with crushed stone or other suitable fill material (Meyer, 2002). Large stones are often used to form a stable base in wet soils, often capped with crushed stone and 'crusher fines' or 'whin dust' (screened material less than 6 mm) to provide a smoother tread surface that can be periodically hand or machine graded (Scottish Natural Heritage, 2000). In Scotland, aggregate placed on top of geosynthetics has been used to effectively 'float' trails over deep peat substrates (Bayfield and Aitken, 1992; The Footpath Trust, 1999). Even soils that are not seasonally wet may require capping with crushed stone to create a tread surface capable of sustaining heavy horse or motorized traffic.

Special measures are required when trails must be constructed with grades over 10%. Wood or rock staircases (Fig. 13.4) and features for removing water from trail treads are critical. Regardless of construction materials, steps must be stout, well-anchored and immobile to sustain heavy traffic. Broken rock makes the most suitable fill material above steps, as angular edges interlock yet allow drainage, providing a stable base for soil or crushed stone tread substrates. Water must be removed from treads quickly to prevent its buildup and erosive force. Outsloped treads, or alternating steps with water bars, are two common methods. Trails with low slope alignment angles must have extensive rockwork armouring with little exposed soil, or severe erosion is inevitable.

Other options for steep slopes include aggregate with rock anchors positioned flush with the path surface to prevent the downward migration of gravel (The Footpath Trust, 1999). Rounded (natural) gravel has little cohesion, requiring closely spaced anchors and limiting its application on steeper grades. Angular crushed stone with crusher fines included contains a mix of particle sizes that pack tightly to form a hard, durable surface when dry (Fig. 13.3a). With a sufficient number of stone anchors and adequate drainage, crushed stone can be applied to slopes up to 16% (Bayfield and Aitken, 1992; The Footpath Trust, 1999). Stone-pitched paths, consisting of well-anchored rockwork across the entire tread surface, are another alternative for steep slopes (The Footpath Trust, 1999). Additional options for exceptionally steep pitches include crib ladders, pinned rock or wooden steps, log ladders, and even wooden staircases constructed from dimensional lumber (Demrow and Salisbury, 1998).

(a)

(b)

Fig. 13.4. (a) A rock staircase was constructed to replace several damaging and eroded visitor-created trails on these Mayan ruins at Altun Ha, Belize. (b) A wooden staircase prevents erosion while permitting access to a waterfall at the Monteverde Cloud Forest Reserve, Costa Rica.

Geosynthetics

Monlux and Vachowski (2000) and Bayfield and Aitken (1992) describe a diverse array of geosynthetics that are available to enhance the effectiveness of construction methods and reduce the amount of fill material needed:

- Geotextiles – construction fabrics made from long-lasting synthetic fibres, primarily used for separation and reinforcement. They support loads through tensile strength and allow water, but not soil, to pass through.
- Geonets – composite materials with a thin polyethylene drainage core sandwiched between geotextile layers. These can provide separation, reinforcement and drainage.
- Sheet drains – similar to geonets but more rigid and with a wider egg-crate shape to enhance drainage. Less fill is needed due to their greater rigidity.

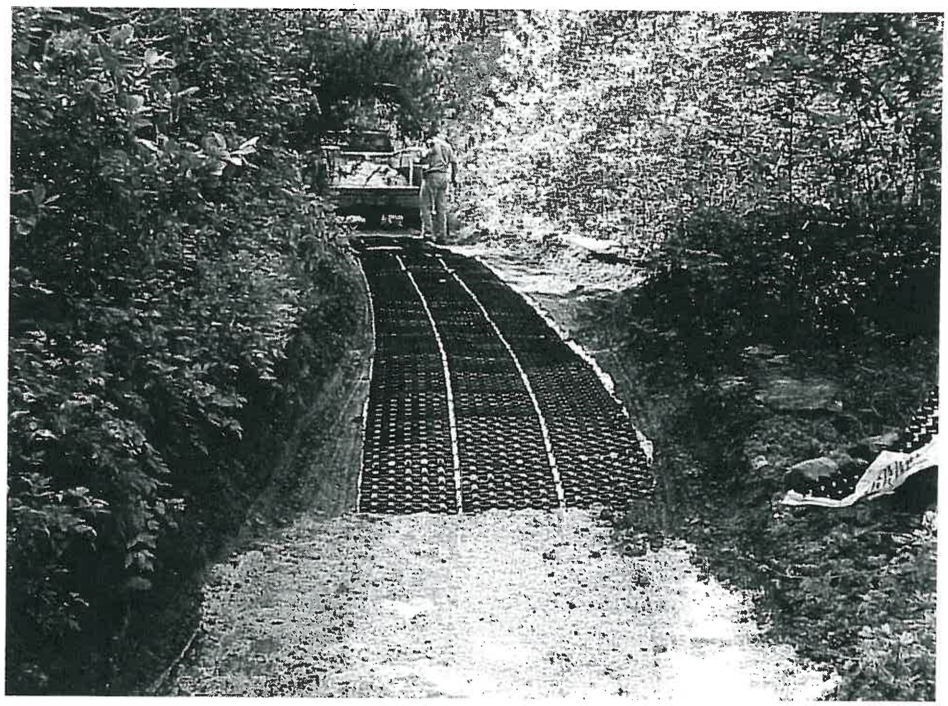

Fig. 13.5. Geosynthetics are applied on this trail in the Daniel Boone National Forest, USA, to improve trafficability for all-terrain vehicles and horses.

- Geogrids – polyethylene sheeting configured into an open grid with high tensile strength. They are used for reinforcement and often placed on top of a layer of geotextile to provide separation.
- Geocells – polyethylene strips bonded together to make a three-dimensional honeycomb structure. Fill material placed within the cells stabilizes and reinforces soil by confining substrates in cells to prevent lateral movement.
- Turf reinforcement – semi-rigid three-dimensional products designed for installation at or near the soil surface to reinforce vegetation mats and increase resistance to shear stress. These 'wear-and-carry' surfaces can be used in porous pavement systems.

Geosynthetics are particularly effective in increasing the trafficability of treads in wet soils (Fig. 13.5) (Meyer, 2002). Due to their tensile strength and/or rigidity, these materials increase the substrate's load bearing capacity by distributing loads over a larger area (Meyer, 2002). Geosynthetics are also available for limiting erosion on steep slopes, though none were found that are specifically designed or recommended for supporting trail traffic. Two-dimensional natural fibre and synthetic mats can be applied over soil to retard erosion and enhance vegetative growth. Three-dimensional geosynthetics can be filled with soil to stabilize and reinforce steep slopes and protect vegetative growth. Experimentation and research is needed to evaluate the efficacy of alternative geosynthetics employed to stabilize recreational trail surfaces with grades in excess of 8%. Regardless, the high cost of geosynthetics will generally restrict their use to problem areas where other practices have been ineffective.

Reinforcing/augmenting soil structure

Materials can also be added to existing tread substrates to improve their engineering characteristics (Bayfield and Aitken, 1992; Meyer, 2002). Chemical binders are commercial liquid concentrates formulated to increase the density, cementation, moisture resistance, bearing and shear strength, and stability of compacted earth materials. These include organic products (e.g. Road Oyl, Stabilizer), and latex polymer products (e.g. PolyPavement, Soil Sement) (Bergmann, 1995; Meyer, 2002). Physical binders are fine-textured native soils that can be mixed with coarsely textured aggregate to fill voids and help 'bed' the larger material. Examples include Bentonite, a natural clay material, and class C Flyash, a powdery by-product from coal combustion, containing quicklime, that reacts chemically to cement soil or crushed stone particles.

Trail Maintenance

Trail maintenance work addresses post-construction trail management needs – from routine maintenance to the resolution of severely degraded treads. First, analyse and understand the root cause of existing problems, such as perennially wet soils, low slope alignment angles, steep grades, lack of tread drainage features, or heavy traffic (Bayfield and Aitken, 1992). Take a long-term perspective and consider whether the trail should be relocated to avoid future degradation and repetitive high maintenance, or if tread reconstruction, drainage work or hardening will suffice. Options such as seasonal or type-of-use restrictions and controlled (restricted) use should also be considered (Meyer, 2002). Also recognize that resolving problems with wet soils, deeply incised treads, or uneven tread surfaces will likely also reduce associated problems with trail widening and braiding.

Tread shaping

Over time, trails will often lose their constructed cross-sectional 'shape' or 'profile'. Most trail treads are constructed with outsloped treads, but soil, rock and organic material generally accumulate along both sides of trails, causing water to run down the trail and erode tread substrates. Slough material on the upslope side of the trail should be removed and the original outsloped tread surface should be re-established (Birchard and Proudman, 2000). Berm material on the downslope side should also be cleared when present, allowing water to more quickly move across and off the tread. Non-organic slough and berm material may be used to fill in eroded ruts, or over exposed roots and rocks. Some trails are insloped to a ditch and others, particularly in flat terrain, are crowned – re-establishing and maintaining these profiles are critical to removing the erosive effects of water from trails.

Treads may also creep downhill from their original alignments. Trail creep is caused by a natural tendency for trail users to travel the downslope edges of side-hill trails (Hesselbarth and Vachowski, 2000). Trails should be returned to their original alignments through side-hill tread reconstruction work and by the strategic placement of embedded anchor rocks on the downhill edges of trails. Trail users will seek to avoid the rocks, centring their use along the tread. Crib walls to support treads may be necessary for sections that traverse particularly steep slopes.

Tread shaping can also address problems with trail widening and development of multiple treads. Both problems generally occur in flatter terrain in places where woody trailside vegetation provides insufficient deterrence. Reshape treads to improve their trafficability while piling rocks and woody debris along braided treads to discourage further use and prevent erosion. Strategic, yet naturally appearing, guide rocks can also be embedded along trail edges, particularly adjacent to drainage features, to confine traffic to the designed tread width. Lining the tread with rock scree in alpine areas may appear artificial but will be more effective in containing traffic to a single narrow tread than a trail marked with cairns (Demrow and Salisbury, 1998). If such measures are ineffective, consider relocating the segment out of flat terrain where possible.

Surface water control

Two of the very worst trail problems, soil erosion and muddiness, are caused by water accumulating on trail treads. Water removal should be a top trail maintenance priority, one that cannot be deferred without the potential for suffering significant long-term and, possibly irreversible, trail degradation. Grade dips and tread outsloping are the best and most sustainable methods for water removal – both should be original design features and may be difficult to add during routine trail maintenance work (Hesselbarth and Vachowski, 2000). Subsequent trail maintenance seeks to enhance the ability of natural features, or to construct and maintain artificial features that divert water from tread surfaces. Natural features may be roots, rocks, or low points where water can be drained from the trail. Minor ditching at these sites can increase their ability to remove water. Some authors refer to these as 'bleeders' (Birchard and Proudman, 2000). Artificial tread drainage features include water bars and drainage dips, which are designed to intercept and drain water to the lower sides of trails.

Numerous authors provide guidance on the installation and maintenance of water bars and drainage dips (Agate, 1996; Demrow and Salisbury, 1998; Birchard and Proudman, 2000; Hesselbarth and Vachowski, 2000). The US Forest Service (1984, 1991) provides specifications for these installations and other trail construction techniques. Key considerations include their frequency, trail angle, size and stability. Water bars may be constructed of rock or wood, including a wheel-friendly design with a protruding flexible rubber strip bolted between buried treated lumber (Birkby, 1996). Drainage dips are shallow angled channels dug into the tread to drain water with an adjacent downslope berm of soil to increase their effectiveness and longevity. US Forest Service guidance specifies tread drainage frequencies based on trail grade and soil type; for example, every 30m for loam soil at 6% grade, every 15m for loam soil at 10% grade, and every 45 m for clay soil at 10% grade (Forest Service, 1991).

The angle at which water bars and drainage dips are installed relative to the trail alignment is also critical. An angle of 45–60° ensures that water will run off the trail with sufficient speed to carry its sediment load (Hesselbarth and Vachowski, 2000). Larger angles will cause water to pool first, dropping sediment loads and filling in drainage channels. Cleaning and reconstruction of tread drainage features must be done one to three times/year to maintain their effectiveness. Effective water bars must be of sufficient length to extend across the trail and be anchored beyond tread boundaries. This will discourage trail users and surface water from seeking to circumvent the drainage feature. For log water bars, a diameter of >6 inches (15.2 cm) allows 2–3 inches (5.1–7.6 cm) to be embedded, with sufficient above-ground material left to divert water from larger storm events. Stability is also critical, rock and wood water bars must be sufficiently anchored to sustain heavy traffic from hikers or horses.

Publications from England and Scotland (Agate, 1996; The Footpath Trust, 1999) place an emphasis on designing an integrated trail drainage system that includes off-path drainage with ditching, culverts and stone cross-drains or culverts, and on-path drainage with stone cross-drains, stone water bars, and Letts drains (bleeders). Though used less frequently, drainage ditches, check dams and culverts can be important elements of a water drainage and erosion control system. Their use is described best by Birkby (1996) Hesselbarth and Vachowski (2000), and Birchard and Proudman (2000).

Vegetation management

Sustained vegetation management efforts are essential to the utility, safety and natural condition of trail corridors. Annual vegetation clearing maintains an open and passable trail corridor. Hazard trees and tree falls can be hazardous to the safety of trail users and when not cleared, also promote trail widening and braiding. Proper vegetation clearing to design dimensions can centre and constrain traffic to a specified tread width. Management of exotic plant populations along trail corridors is also an increasing activity and concern in the USA.

Visitor Management

While natural processes can degrade trails that receive no use, visitor traffic breaks down protective vegetative and organic cover, exacerbates muddiness and increases tread susceptibility to soil erosion. Trail management therefore necessarily includes managing the type, amount, behaviour and timing of visitor use, to ensure resource protection. We provide a limited summary of this topic here and direct readers to more comprehensive treatments in

Table 13.2. Description and purpose for four trail survey methods.

Survey type	Description and purpose	Citations
Trail inventory	Document general physical attributes (e.g. location, lengths, trail features) and/or trail conditions	Cole (1983), Williams and Marion (1992)
Prescriptive work log	Identify tread deficiencies and prescribe engineering solutions to direct work crews and provide cost and staffing estimates	Williams and Marion (1992), Demrow and Salisbury (1998)
Trail condition monitoring	Systematic procedures for assessing trail conditions to monitor trends, understand trail degradation and assess efficacy of management actions	Cole (1983), Leung and Marion (1999), Marion and Leung (2001)
Use assessment	Assesses types and amounts of trail uses	Hollenhorst *et al.* (1992), Watson *et al.* (2000)

the literature: Manning (Chapter 16, this book), Cole *et al.* (1987), Anderson *et al.* (1998), Leung and Marion (2000), and Hendee and Dawson (2002).

Trampling research has shown that the majority of resource impact on trails, excepting construction, occurs with relatively low use levels (Cole, 1987; Leung and Marion, 2000). Above moderate-use levels, the per capita impact associated with increasing visitation diminishes substantially, so dispersing or restricting use to control trail impacts may be an ineffective management strategy. Some exceptions include higher impact types of use (e.g. horses or motorized uses) and trail use during wet seasons. For example, the substantially greater susceptibility of trails to muddiness and erosion during wet seasons has led some managers to issue wet-weather restrictions on all or certain types of trail uses.

Trail impact research has revealed the importance of numerous other factors that are as, or more, important than use level in determining trail conditions (Cole *et al.*, 1987; Leung and Marion, 1996). These include trail grade, slope alignment angle and construction and maintenance work, that are reviewed in this chapter, and rainfall, infiltration rates and vegetation type, that are not (see Leung and Marion, 1996).

Special management of visitor uses that have a greater potential to degrade trails is generally necessary to minimize resource impacts. For example, horse users may be restricted to a subset of trails specially selected, constructed and maintained to sustain that type of use (for further discussion see Chapter 5, this volume). Higher-impacting visitor behaviours may also be modified to minimize impacts, through visitor education or regulation. Examples include Leave No Trace skills and ethics (http://www.LNT.org), educational messages that promote staying on and travelling down the centre of designated trails, or regulations prohibiting livestock grazing or requiring use of weed-free feed (Hendee and Dawson, 2002).

Educational or regulatory actions may also be implemented to avoid or lessen recreational conflicts or crowding (Anderson *et al.*, 1998). Conflicting uses may be separated by travel zone or trail, incompatible uses may be restricted or prohibited (Cole *et al.*, 1987). Similarly, amount of use on trails or within zones may be influenced or regulated to achieve different use levels, providing solitude in some areas and higher density use in others (Manning, 1999).

Trail Surveys: Maintenance Needs, Conditions and Use

Several types of trail surveys can yield information of value to trail managers, including basic trail inventories, prescriptive work logs, trail condition monitoring and use assessments (Table 13.2). The most basic of these is the trail system inventory, generally accomplished with a measuring wheel or global positioning system (GPS) unit to gather basic data about trail location, physical or maintenance attributes, and condition (Fig. 13.6a). A prescriptive work log survey can document the work and materials needed to address trail impacts or facility

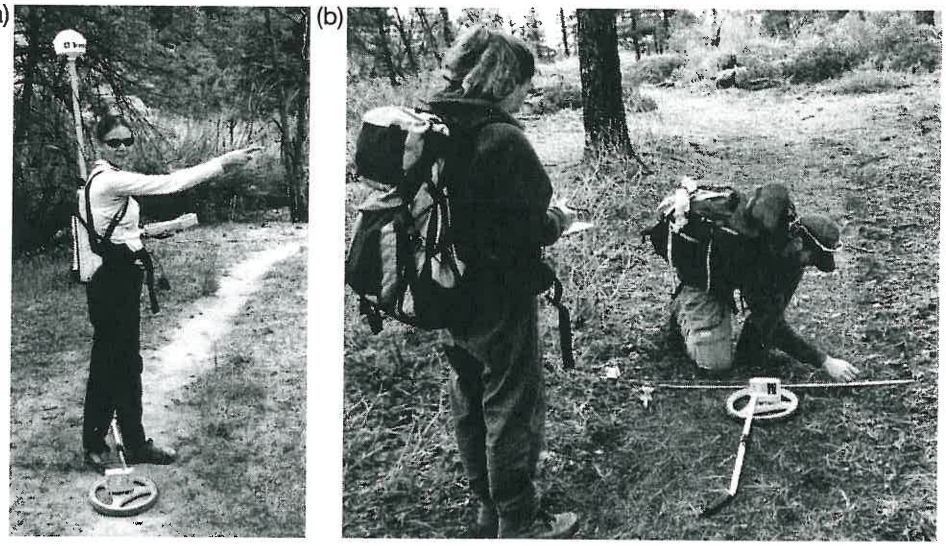

Fig. 13.6. Trail surveyors employ a GPS unit to inventory trails (a), and trail condition assessment methods to document resource conditions (b) in Zion National Park, USA.

needs, but requires the expertise of an experienced trail maintainer. Monitoring surveys periodically apply standardized trail condition assessment procedures to document and track trail degradation (Fig. 13.6b). Carrying capacity decision frameworks require such data to evaluate indicator standards of quality. Use assessment surveys can provide information about visitor use on trails: types, amounts and spatial/temporal distribution. All of these types of information can assist managers in professionalizing their trail planning, management and decision-making.

Conclusion

This chapter has reviewed trail impacts and management practices with an emphasis on professional trail planning and management. Trails able to sustain heavy tourism use will require planning, careful location and construction, visitor management, and an ongoing programme of maintenance. Successful trail management programmes require all of these elements. Trails that are poorly located will either require prohibitive development and maintenance to protect natural resources, or will quickly degrade to a state that is both difficult and unsafe for intended uses. Similar consequences will occur on trails that are properly located and constructed but that lack a sustained programme of maintenance and/or visitor management. And management of trail systems in the absence of decision frameworks with indicator standards and monitoring programmes run the risk of permitting long-term or irreversible degradation, unsafe use and a declining quality of visitor experiences.

Fortunately there is a substantial and growing literature on trail planning and management that can aid ecotourism and protected area managers in professionalizing their trail-management programmes. We sought to highlight the core attributes of an exceptional trail management programme and to introduce readers to available literature in this chapter. With the continued growth of tourism visitation worldwide, improved trail management is becoming critical at most high-use tourism destinations.

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