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Assessing and Understanding Trail Degradation: Results from Big South Fork National River and Recreational Area

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Assessing and Understanding Trail Degradation: Results from Big South Fork National River and Recreational Area

by:

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Abstract

This report describes results from a comprehensive assessment of resource conditions on a large (24%) sample of the trail system within Big South Fork National River and Recreational Area (BSF). Components include research to develop state-of-knowledge trail impact assessment and monitoring methods, application of survey methods to BSF trails, analysis and summary of results, and recommendations for trail management decision making and future monitoring. Findings reveal a trail system with some substantial degradation, particularly soil erosion, which additionally threatens water quality in areas adjacent to streams and rivers. Factors that contribute to or influence these problems are analyzed and described. Principal among these are trail design factors (trail topographic position, soil texture, grade and slope alignment angle), use-related factors (type and amount of use), and maintenance factors (water drainage). Recommendations are offered to assist managers in improving the sustainability of the trails system to accommodate visitation while enhancing natural resource protection.

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Introduction

This report describes results from a comprehensive assessment of resource conditions on a large sample of the trail system within Big South Fork National River and Recreational Area (BSF). This assessment was initiated in response to concerns by park staff and the public regarding the possible environmental impacts associated with BSF trail uses. Concentrated traffic on trails and primitive roads can remove protective vegetative and organic litter cover and increase water runoff and erosion rates. Impacts to trail treads include excessive tread widening, muddiness, and proliferation of visitor-created paths. While some of these environmental impacts are unavoidable, excessive impacts threaten natural resource values, visitor safety, and the quality of recreational experiences.

This research also supports park and trail system planning and management decision-making, particularly as they relate to the professional management of a trail system able to sustain a variety of recreational uses while protecting the park's natural and cultural resources. Responding to these concerns and needs, this research was sponsored by the National Park Service (NPS) to provide objective data describing the current trail conditions, to identify and describe the most important factors that influence trail degradation, and to suggest effective management options for achieving park management objectives.

NPS managers operate under legislative and administrative mandates directing them to balance the provision of appropriate park recreational opportunities with their associated resource changes or impacts. Specifically, the NPS Organic Act of 1916 (16 *United States Code* (USC) 1) which established the Service, directed it to "promote and regulate the use ... [of parks] ... in such manner and by such means as will leave them unimpaired for the enjoyment of future generations." What constitutes an impaired resource is ultimately a management determination, although public input is routinely sought and considered in management decision-making. Other legislation, such as the National Environmental Policy Act of 1969 (42 USC 4321 *et seq*) and the park's enabling legislation, provide further guidance.

Authority to implement congressional legislation is delegated to agencies, which identify and interpret all relevant laws and formulate administrative policies to guide their implementation. The NPS *Management Policies* describes these policies to provide more specific direction to management decision-making (NPS 2001). For example, relative to the need for balancing visitor use and resource impacts, the NPS *Management Policies* state that:

> "Congress, recognizing that the enjoyment by future generations of the national parks can be ensured only if the superb quality of park resources and values is left unimpaired, has provided that when there is a conflict between conserving resources and values and providing for enjoyment of them, conservation is to be predominant. This is how courts have consistently interpreted the Organic Act, in decisions that variously describe it as making "resource protection the primary goal"…
>
> The impairment that is prohibited by the Organic Act and the General Authorities Act is an impact that, in the professional judgment of the responsible NPS manager, would harm the integrity of park resources or values, including the opportunities that otherwise would be present for the enjoyment of those resources or values. Whether an impact meets this definition depends on the particular resources and values that would be affected; the severity, duration, and timing of the impact; the direct and indirect effects of the impact; and the cumulative effects of the impact in question and other impacts.

> The fact that a park use may have an impact does not necessarily mean it will impair park resources or values for the enjoyment of future generations. Impacts may affect park resources or values and still be within the limits of the discretionary authority conferred by the Organic Act. However, negative or adverse environmental impacts are never welcome in national parks, even when they fall far short of causing impairment. For this reason, the Service will not knowingly authorize a park use that would cause negative or adverse impacts unless it has been fully evaluated, appropriate public involvement has been obtained, and a compelling management need is present. In those situations, the Service will ensure that any negative or adverse impacts are the minimum necessary, unavoidable, cannot be further mitigated, and do not constitute impairment of park resources and values."

Thus, relative to visitor use, park managers must evaluate the types and extents of resource impacts associated with recreational activities, and determine to what extent they are unacceptable and constitute impairment. Further, managers must seek to avoid or limit any form of resource impact, including those judged to fall short of impairment. Scientific studies such as this one can assist managers in making objective evaluations of impairment and managing recreation impacts by providing quantitative documentation of the types and extent of recreation-related impacts to natural resources. This study has two research objectives:

Objective 1: Develop, pilot test, and refine a set of cost effective and scientifically defensible trail condition assessment procedures.

Objective 2: Apply trail condition assessment procedures to a large sample of BSF trails and prepare a technical report that compiles, analyzes and presents results and management recommendations.

The data collected from assessing trail conditions within the park are summarized in this report by individual trails and for groupings of trails. Managers may find this information to be useful for carrying capacity planning and decision-making using the NPS Visitor Experience and Resource Protection framework (National Park Service, 1997). Data may also be used to prepare and justify trail management actions or trail maintenance budget and staffing requests. Data on individual trails may be used to direct trail maintenance activities or to set priorities for needed work. The data are also analyzed to evaluate the relative influence of various causal or non-causal factors, which may suggest potentially effective actions to avoid or minimize future impacts. Managers may find this information useful in evaluating the resistance of new, existing or alternative trail routings or managing certain types of uses. Finally, trail condition information can be compared to data from future assessments using the same procedures as part of a monitoring program to identify trends in trail condition or evaluate the effectiveness of management actions.

This report contains a review of the relevant scientific literature describing trail impacts and the influence of various use-related, environmental and managerial factors, a review of the study area and methods used to assess the park's trail conditions, results from the trail survey, and discussion of findings and their implications for managers and the public.

Literature Review

This section reviews recreation impacts associated with the use of trails and describes the influence of both casual factors (e.g., type and amount of trail use) and non-causal, yet influential factors, (e.g., environmental and managerial attributes like soil type and trail grade). It is drawn from updated but previously published literature reviews, particularly Marion and Leung (2001), Leung and Marion (1996), Hammitt and Cole (1998) and Widner and Marion (1993).

Trail Resource Impacts

Trails are generally regarded as an essential facility in parks and recreation areas, providing access to unroaded areas, offering recreational opportunities, and protecting resources by concentrating visitor use impacts on resistant tread surfaces. Much ecological change assessed on trails is associated with their construction and is considered unavoidable (Birchard & Proudman, 2000). The principal challenge for trail providers is therefore to prevent post-construction degradation from both recreational use and natural processes such as rainfall and water runoff.

Unsurfaced trail treads are susceptible to a variety of trail impacts. Common impacts include vegetation loss and compositional changes, soil compaction, erosion, muddiness, exposure of tree roots, trail widening, and the proliferation of visitor-created side trails (Table 1) (Hammitt & Cole, 1998; Leung & Marion, 1996; Tyser & Worley, 1992). Soil erosion exposes rocks and plant roots, creating a rutted, and uneven tread surface. Erosion can also be self-perpetuating when treads erode below the surrounding soil level, preventing the diversion of water from the tread. Eroded soils may find their way into water bodies, increasing water turbidity and sedimentation impacts to aquatic organisms (Fritz, 1993). Similarly, excessive muddiness renders trails less usable and aggravates tread widening and associated vegetation loss as visitors seek to circumvent mud-holes and wet soils (Marion, 1994). Trail widening and the creation of parallel treads and side-trails unnecessarily increases the area of land disturbed by trails (Liddle & Greig-Smith, 1975).

Trails, and the presence of visitors, can also impact wildlife, fragment wildlife habitat and cause avoidance behavior in some animals and attraction behavior in others seeking to obtain human food (Hellmund, 1998; Knight & Cole, 1991). While most impacts are limited to a linear disturbance corridor, some impacts, such as alterations in surface water flow, introduction of invasive plants, and disturbance of wildlife, can extend considerably further into natural landscapes (Kasworm & Monley, 1990; Tyser & Worley, 1992). Even localized disturbance can harm rare or endangered species or damage sensitive resources, particularly in environments with slow recovery rates.

Impacts such as severe soil erosion and exposed roots are visually offensive and can degrade the aesthetics of recreational settings. Recent studies have found that resource impacts are noticed by visitors and that they can degrade the quality of recreation experiences (Roggenbuck, Williams, & Watson, 1993; Vaske, Donnelly, & Shelby, 1993). Impacts such as deep ruts and excessive muddiness increase the difficulty of travel and threaten visitor safety. From a managerial perspective, excessive trail-related impacts to vegetation, soil, wildlife or water quality can represent an unacceptable departure from natural conditions and processes. Impacts also result in substantial costs for the maintenance and rehabilitation of trails and operation of visitor management programs.

Table 1. Different forms of trail resource impact and their ecological and social effects.

Form of Impact	Ecological Effects	Social Effects
Soil Erosion	Soil and nutrient loss, water turbidity/sedimentation, alteration of water runoff, most permanent impact	Increased travel difficulty, degraded aesthetics, safety Increased restoration costs
Exposed Roots	Root damage, reduced tree health, intolerance to drought	Degraded aesthetics, safety
Secondary Treads	Vegetation loss, exposed soil	Degraded aesthetics
Wet Soil	Prone to soil puddling, increased water runoff	Increased travel difficulty, degraded aesthetics
Running Water	Accelerated erosion rates	Increased travel difficulty
Widening	Vegetation loss, soil exposure	Degraded aesthetics
Visitor-Created Trails	Vegetation loss, wildlife habitat fragmentation	Evidence of human, disturbance, degraded aesthetics

Factors Affecting Trail Resource Impacts

The type and extent of trail impacts are influenced by use-related and environmental factors, both of which may be modified through management actions. Use-related factors include type of use, amount of use, and user behavior; environmental factors include attributes such as vegetation and soil type, topography and climate. Recent comprehensive reviews of the role of these factors are provided by Leung and Marion (1996), Hammitt and Cole (1998), and Marion (1998).

Use-Related Factors

For well-designed and constructed trails, post-construction trail impacts would be minimal in the absence of use. Rainfall might erode some soil following construction but in most environments organic litter and vegetative colonization would increasingly minimize such impacts on unused trails. Numerous studies have documented a curvilinear relationship between amount of use and most forms of trail impact (Cole, 1983; Sun & Liddle, 1993; Weaver, Dale, & Hartley, 1979). Initial or low levels of use generate the majority of use-related impact, with per-capita impacts diminishing as use increases. For example, vegetation and organic litter are either removed during trail construction or are quickly lost from trails receiving even light traffic. Further traffic when soils are dry causes relatively little additional impact, provided the trails receive adequate maintenance to control water runoff , muddiness, and tread widening. An important implication is that substantial use reductions, or closure, must occur on heavily used trails to achieve any significant reduction in impact.

Some specific impacts, such as trail widening and creation of parallel treads (trail braiding) or side trails, are strongly influenced by user behavior (Hammitt & Cole, 1998). Visitors seeking to avoid severe rutting or rockiness caused by soil erosion or muddiness often cause trail widening. Visitors traveling side-by-side rather than single file also contribute to this problem. Type of use has also been shown to be a significant determinant of the type and extent of trail impacts. For example, Wilson and Seney (1994) evaluated tread erosion from horses, hikers, mountain bikes, and motorcycles and found that horses made significantly more sediment available for erosion than the others uses, which did not significantly vary from the control. Thurstan and Reader (2001) found no significant differences between the vegetation and soil impacts from hiking and mountain biking, though they speculated that behavioral differences between the two groups could contribute to the belief that mountain biking has led to trail degradation problems.

The following two sections provide a more thorough review of the literature on horse and off-road vehicle impacts due to their heavy use on primitive roads and trails at BSF. National Park Service staff view both uses as acceptable activities on appropriately designated roads and trails. However, scientific studies and management experience have shown these uses to have a higher potential for resource and social impact in comparison to other forms of human-powered recreation. A more thorough understanding of their impact potential and mechanisms of impact can assist managers in developing the most effective resource and visitor management strategies and tactics for sustaining these uses while protecting natural resource qualities.

Trail-Related Horse Impacts

Impacts from horse use can be ecological: impacts to the resource, or social: impacts to the experiences of other visitors. Both types of impact serve to bring horse use concerns to the attention of managers. For example, many studies have revealed conflicts between hikers and horseback riders. Watson et al. (1993) found that 36% of wilderness hikers did not like encounters with horses on trails but only 4% of horse riders disapproved of meeting hikers. In another wilderness study, 75% of managers reported they received complaints about horses, including excessive trail impacts, manure on trails, and damage to meadows and riparian areas (Shew et al. 1986). There is not space for a complete review of the social impacts of horse use here; additional pertinent references include Hammitt and Cole (1998), Jacob and Schreyer (1980), McClaran (1989), Newsome et al. (2002), and Watson et al. (1993).

The severity of resource impacts depends on the characteristics and behavior of the user, environmental attributes, and how visitors and trails are managed. In order to understand horse impacts and to arrive at viable solutions regarding their management, it is important to examine and understand the impacts and factors that influence them.

The major ecological impacts to horse trails are vegetation loss, trail widening, erosion, muddiness, and informal trail development. Erosion is considered to be the most severe form of impact because its effects are long lasting, if not permanent (Hammitt and Cole 1998). Trampling and erosional impacts caused by horses have been found to be significantly higher than hikers, llamas, mountain bikes and even off-road motorcycles (Cole & Spildie, 1998; DeLuca et al., 1998; Wilson & Seney, 1994). Many studies demonstrate that trampling by a horse is more destructive to vegetation than trampling by foot (Nagy and Scotter 1974; Weaver and Dale 1978; Whittaker 1978). Whittaker (1978) found vegetation on horse trails to be churned up and often cut off at the roots, instead of flattened, as on hiking trails. An experimental trampling study by Nagy and Scotter (1974) found vegetation loss to be four to eight times greater from horse trampling than hiker trampling. The greater vegetation loss from horse use tends to widen horse trails, which are often two to three times the width of hiker trails (Weaver and Dale 1978). The greater width of exposed soil and inherent characteristics of horses also contribute to the greater erosion potential of horse trails.

Erosion occurs once vegetation is lost, exposing soil that is removed by hooves or by wind and water. Horse use can be a significant precursor for increased erosion potential (Hammitt and Cole 1998). Soil erosion resulting from horse use is a product of the trampling and eventual loss of vegetative cover, subsurface soil compaction leading to lowered water infiltration rates, and the increased roughness and detachment of surface soil particles. A horse carries a heavy weight on a small, usually shod, hoof. This weight exerts approximately 18 lbs/in^2 ground pressure for unshod horses to 62 lbs/in^2 for shod horses, compared to 2.9 lbs/in^2 for a hiker in boots (Liddle 1997). Thus, horse traffic causes significant compaction to the underlying soil layers, reducing water infiltration and increasing surface runoff. In addition, the action of a horse hoof tends to puncture and dig up the soil surface (McQuaid Cook 1978). Loose, unconsolidated soil is more prone to erosion than compacted soil and as a result, the potential for erosion increases on horse trails as compared to hiker trails. An evaluation by Deluca et al. (1998) of the mechanisms by which trail traffic leads to accelerated erosion suggested that soil loosening and detachment of soil particles by horses contributed to the higher erosion rates. Soil compaction and decreased infiltration were not considered as important, a finding supported by the work of Wilson and Seney (1994).

Heavy horse traffic in areas with wet soils can result in the formation of muddy quagmires and excessive trail widening. Whittaker (1978) found loosening of the soil to be a precursor to muddy trail sections. Loose soil is more apt to form mud than compacted soil and the highly compacted subsurface soils prohibit water infiltration. The resulting impermeable basins retain water and mud long after rainfall. Marion (1994) noted that deep hoof prints collect and retain water, providing greater surface contact between water and soil and accelerating the formation of mud. Trail muddiness can be a temporary or seasonal problem, making travel difficult and often resulting in significant trail widening when trail users seek to circumvent muddy sections.

Other trail problems attributed to horse use include the proliferation of informal trails, manure on trails, tree damage, and the introduction and spread of exotic vegetation. Trail braiding is especially troublesome in meadows, where stock users tend to spread out rather than ride in single file (Hammitt & Cole 1998). The creation of side trails to access water, features of interest, or short cuts to other trails are also considered a significant form of trail impact. User-created trails are often poorly routed and not maintained, resulting in an increased potential for degradation. Manure on trails is both an ecological and social problem. Manure can contain the seeds of exotic plants, although seeds may also be introduced from horse feed, equipment, and mud stuck to horse hooves. Large numbers of weed seeds can pass through the gut of horses and germinate in their manure (St John-Sweeting & Morris 1991). However, Whinam et al. (1994) found that weed seeds were limited to the manure, and Whinam and Comfort (1996) revealed no indication of introduced weeds from monitoring. Excessive amounts of manure may also pose a threat to water quality (Hammitt & Cole 1998).

Finally, horses tied to trees can result in damage to bark and roots. Ropes or chewing can damage tree bark and may completely girdle and kill trees (Cole 1983). Bark damage weakens trees and opens their inner wood to invasion by insects and diseases. Pawing and digging by confined horses erodes soils and exposes tree roots. In the Bob Marshall wilderness of Montana, campsites used by horse groups had eleven times as many damaged trees and twenty-five times more trees with exposed roots than backpacker sites (Cole 1983).

It is important to note that while horse use is often a more impacting type of use, other factors may be more influential determinants of resource degradation. For example, McQuaid Cook (1978) found trail impact to be more a function of slope and trail location than a result of user type. Nagy and Scotter (1974) concluded that although horse use generally causes more damage than hikers, the degree of difference depends on the soil, vegetation, topographic and climate characteristics. Summer (1980) identified the most influential landscape factors governing trail deterioration as parent material, grade of trail and side-slope, soil texture and organic content, rockiness, vegetation, and drainage. Measurements of physical changes along trails receiving a constant amount of horse use resulted in a wide spectrum of erosion impacts as influenced by one or more of the landscape factors listed above. Summer (1980, 1986) concluded that horse traffic was not the most important agent contributing to trail degradation.

Trail-Related ORV/ATV Impacts

Motorized uses, including 2- and 4-wheel drive vehicles, all-terrain vehicles and motorcycles (hereafter referred to as ORVs), have a greater potential for impact than non-motorized uses due to a number of factors (Gersper & Challinor 1975; Hill & Kirby 1948; Sheridan 1979; Webb et al. 1978). Tires that spin at higher rates of speed cause more substantial abrasion damage to vegetation, roots and soils (Meyer, 2002). The greater weight and ground pressure of vehicles also cause greater soil compaction, shearing, and displacement – actions that cause soil rutting through the compaction or displacement of soil. Direct impacts include the abrasion of vegetation, surface litter, and plant roots; compaction of soil and breakdown of soil structure from shear forces; and the formation of ruts from displacement of soil away from tires or detachment of soil particles stuck to or flung from tire treads (Meyer 2002). Indirect impacts include an increase in the occurrence, intensity, or channeling of runoff due to rutting, increased erosion and sediment load, and increased wind erosion and dust (Kockelman 1983). Deposition of soils in water bodies are a secondary impact.

Dry soils more easily resist compaction and rutting from ORVs while soils that are wet, loose, or on steep slopes are particularly vulnerable to damage (Reisinger et al. 1990). In wet soils, water fills soil pores and resists compaction but water also weakens soil strength and shear resistance, resulting in more severe rutting. Higher vehicle weights and narrower tires exacerbate such problems. The type and intensity of soil erosion is strongly influenced by soil composition and structure. Snyder et al. (1976) compared the relative vulnerability of soil types to ORV affects. Soils composed of sand and gravel were easily removed by ORV riding while soils rich in clay endured less mechanical disturbance but experienced greater erosion rates.

Although not as widely represented in the literature, ground and surface water amount and quality are also affected by ORV use. According to Kockelman (1983), increased runoff, linked to a diminished ability of the ground to absorb water, is frequently evident in ORV riding areas. In areas subject to flooding, overland flow is channeled through ORV trails and downstream areas may experience increased sediment loading and siltation problems (Hinckley et al. 1983; Geological Society of America 1977). In addition to water pollution, Kockelman (1983) links air pollution to ORV use. Dust and gas emissions are the principal effects. Fires sparked by exhaust systems are other potential hazards.

Wildlife impacts due to noise are also an impact associated with ORV use. Rennison and Wallace (1976) found that the vehicles produced high decibels of noise could be heard from two to four kilometers away. Auditory disturbance is linked to disruption of feeding, resting, caring for their young and exposure to predators. Direct contact may kill or injure animals. Off-road ORV traffic may also endanger isolated species, remnant populations, and other rare, threatened or endangered species (Berry 1980). Habitat is fragmented by roads and trails, disrupting the balance of different ecosystem components (Bury 1980).

Environmental Factors

A substantial number of studies have demonstrated the influential role that environmental factors play in influencing trail degradation (Leung & Marion, 1996). These include vegetation type, topography, and soil and surface characteristics.

Vegetation Type

In general, dense understory vegetation that is resistant to trampling will inhibit trail widening, though these attributes are less important in reducing soil loss. Dense trailside vegetation confines the lateral spread of trail users while segments crossing open meadows often widen or split to form multiple treads. At low use levels, vegetation types with high trampling resistance and/or resilience (ability to recover) can sustain use with little degradation. The influence of these attributes diminish with increasing use and are relatively unimportant at high use levels (Cole 1988).

Topography

Characteristics of topography have been the most intensively investigated influences on trail degradation. Numerous studies have documented strong positive relationship between trail slopes and soil loss (Weaver and Dale 1978; Bratton et al. 1979; Teschner et al. 1979). The greater velocity and erosivity of surface runoff on steep slopes is the predominant cause but other influences, such as the slippage of feet and hooves, are also likely contributors.

The orientation of the trail to the prevailing slope, termed the trail angle by Bratton et al. (1979), and slope alignment angle by Marion and Leung (2001), is an important factor often overlooked by trail designers and researchers. Trails that more directly ascend the fall line of a slope, irrespective of its steepness, have a low slope alignment angle. Side-slopes, the terrain adjacent to either side of the trail, are relatively flat with low slope alignment angles, relative to the plane of the trail tread (Figure 1). Trails with a low slope alignment angle are susceptible to degradation because their flatter sides-lopes offer little resistance to trail widening, and hinder or block the drainage of water from incised trail treads. The slope alignment angle is important regardless of topographic position (valley bottom, mid-slope, ridge- or mountaintop), though the greater rainfall at higher elevations can increase erosion rates. The importance of slope alignment angle increases in significance as trail slope increases. Water trapped within low slope alignment trails with lower grades create muddiness and are highly susceptible to widening. This can occur in both valley bottom and ridge-top settings.

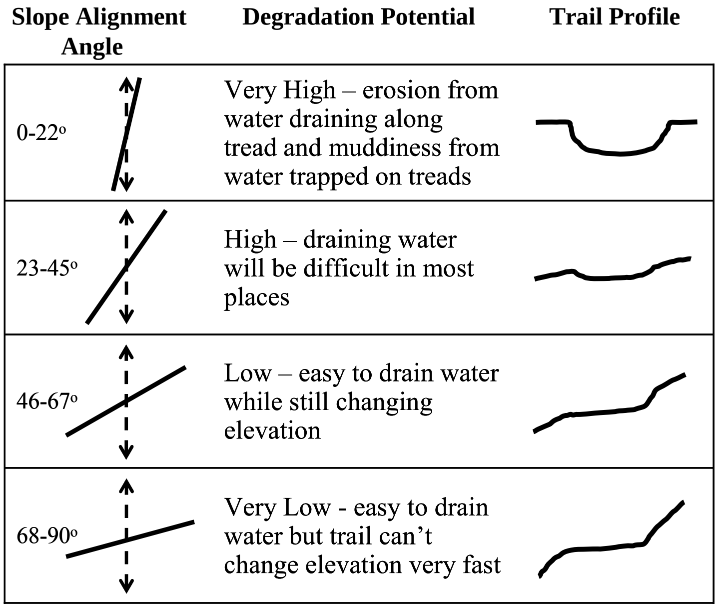


Figure 1. Trail erosion potential and probable profile for trails with different slope alignment angles (landform slope is dotted line/trail is solid line).

Trails that more closely follow the contour have a high slope alignment angle: they are more perpendicular to the slope (Figure 1). Known as "side-hill" trails, their steeper side-slopes confine use to the constructed tread and facilitate tread drainage. Though side-hill trails often develop a berm of soil along their lower edge, these can be cut through during water bar or drainage dip construction to allow water to drain off trail treads (Birchard and Proudman 2000; Hesselbarth and Vachowski 2000). The easy removal of water from side-hill trails and the ease of angling them to avoid steep trail grades makes high slope alignment angle trails far more sustainable and less expensive to maintain over time.

Proximity to groundwater discharge areas or streams can also increase the susceptibility of trails due to excessive wetness and periodic flooding of trail treads (Root and Knapik 1972). Such problems are most prevalent in valley bottom settings adjacent to streams and rivers. Unless adequate drainage and hardening features are provided in these areas, trails with eroded and muddy tread surfaces are unavoidable. In summary, degradation can be minimized by mid-slope topographic positions with low trail grades, and higher slope alignment angles with moderate side-slopes.

<u>Soil and Surface Characteristics</u>

Researchers have investigated a number of physical soil properties to evaluate their influence on trail degradation. Trails on soils with fine and homogeneous textures are more erodible and often have greater tread incision (Bryan 1977; Welch and Churchill 1986). Trails that traverse poorly drained soils are susceptible to excessive trail widening as users seek to avoid muddy areas. Wet muddy soils are also more susceptible to erosion, especially when trail grades are steeper. Highly organic soils retain water long after rains and with traffic become mucky (Bryan 1977). Wet soils often present seasonal limitations, as during times of the year when rainfall or snowmelt are particularly high. However, these problems are exacerbated if trails are located near streams and groundwater discharge areas.

Surface characteristics generally refer to the roughness of trail treads, such as stoniness and the presence of exposed tree roots. Trails on soils with a high rock or gravel content are less susceptible to soil erosion (Bryan 1977; Weaver and Dale 1978). Rocks and gravels are less easily eroded by water or wind, and these materials can act as filters, retaining and binding finer soil particles. In general, small rocks and stones should not be removed from trail treads as their presence tends to slow the velocity of water runoff and protect underlying soils (Summer 1980; Summer 1986).

Managerial Factors

Few studies have directly examined the influence of managerial actions, though they have considerable potential for modifying the roles of use-related and environmental factors (Leung & Marion, 1996). Knowledge of relationships between environmental factors and trail impacts can be applied to route trails in the most resistant and sustainable locations. Muddiness can be limited by avoiding wet organic soils and flatter terrain, erosion can be limited by avoiding steep trail grades and low trail alignment angles, and parallel treads and tread widening can be limited by locating trails in sloping terrain where steeper side-slopes direct visitors to stay on the provided tread (Birchard & Proudman, 2000). Through educational and regulatory actions, managers can influence or control all use-related factors. For example, the impacts of horses or vehicles may be limited by restricting their use to resistant trails, prohibiting their use on non-graveled trails during wet seasons, or limiting their numbers. Trail construction and maintenance actions, including installation and upkeep of tread drainage features, rock steps, and bridging, are also vital to limiting soil erosion and tread muddiness, which in turn, influence user behavior and the extent of impacts such as tread widening and secondary tread development (Birchard & Proudman, 2000). Unfortunately, trail management functions, because of their expense, are often neglected and may be traded for use-related restrictions and regulations.

Methods

Study Site

The Big South Fork National River and Recreational Area is located in northeastern Tennessee and southeastern Kentucky within the Cumberland Plateau. BSF was established in 1974 and encompasses 125,000 acres managed to "conserve and interpret an area containing unique cultural, historic, geologic, fish and wildlife, archeological, scenic, and recreational values, [while] preserving as a natural, free-flowing stream the Big South Fork of the Cumberland River...". Approximately one-half of BSF is a river gorge featuring an upland plateau flanked by sheer bluffs and narrow drainages that feed the Big South Fork River. Designated as Outstanding National Resource Waters, the river provides critical habitat for six federally listed endangered mussel species. Mixed-oak with mixed-mesophytic pockets constitute the general forest type. Gorge soils are in the Ramsey-Hartells-Grimsely-Gilpin group complex, and plateau soils are in the Hartsells-Lonewood-Ramsey-Gilpin group complex. While richer in the floodplains, they are generally, thin, and sandy.

The Recreation Area receives between 800,000 and 900,000 visitors annually, with trail-related activities accounting for a large portion of total visitor use. The current trail system contains approximately 227 miles of single and multi-use primitive roads and trails used primarily by horseback riders, though ATV use, hiking, and mountain biking are also common recreational activities. The area is well-known as a horseback riding area, attracting many local riders but also riders from outside the region. The origins of these trails are quite varied, some follow old logging roads and access roads to mining and oil/gas sites, very few were formally designed and constructed as recreational trails.

The trail system plays a significant role in shaping visitor access and distribution patterns within the Recreation Area, sustaining substantial traffic from both day and overnight visitors. Primitive roads and trails provide a transportation network facilitating visitor access to most of the park's attractions. The trail system also permits NPS staff access to backcountry areas to perform essential administrative functions, including facility maintenance, visitor rescues, fire fighting, and natural and cultural resource management. Congressional legislation prohibits motorized recreational use within the Recreation Area's gorge (approximately 50% of the park).

Primitive roads and trails were identified as a major resource protection issue in a BSF Water Resources Management Plan (BSF 1997). As described in this plan, the trail system includes many primitive roads that were poorly designed and receive little or no maintenance. Road and trail impacts are further aggravated by: 1) highly erosive soils and steep terrain, 2) poor design, construction, and maintenance, 3) poorly designed or unmaintained stream crossings, and 4) high use by ORVs and horseback riders when soils are wet. The trail system's development and management may be considered quite "young" in comparison to older and established NPS units. Some trails have been developed for use with parking lots, directional signs, bridges, and routine tread and vegetation maintenance, but many trails lacking these features receive substantial visitor use. Further, past and present NPS capabilities for trail management staffing and funding are very limited.

Existing road and trail system information includes basic trail mapping and documentation of trail uses. More accurate mapping using GPS equipment is underway. Assessment of the existing road and trail system uses, needs, maintenance requirements, and relationship to proposed developments and adjacent public lands have been completed. Though quite dated, recreation demand studies (1975, 1978) and a trail use study (1985) have also been completed. The only study that has examined impacts was conducted in 1983 and provided only a general examination of impacts at 13 access sites. According to a preliminary draft of the Road and Trail Management Plan, "Present information on trail impact is sparse and based only on superficial personal observations by rangers, maintenance personnel, and a few visitors."

Sample Selection

A random sample, taken from the BSF Geographic Information System trails and roads database, was produced using the SPSS Random Sample procedure. The population of trails upon which the sample was extracted included 327 miles of primitive roads and trails (Table 2). The population excluded all hard-surfaced roads and improved graded 2-wheel drive graveled roads. Long trails were subdivided into 6-mile segments to avoid under-sampling. Of the resulting trail population (327 miles, 171 trail segments) a large (24%) sample was taken (78.5 miles, 47 trail segments). This was to ensure an adequate quantitative representation of diverse environmental, managerial, and use-related factors for an accurate assessment and characterization of baseline conditions for the entire trail system (Cole, 1983). Estimates of amount of use (low, intermediate, high) were assigned to each surveyed segment by a long-time knowledgeable park trail manager. Given the multi-use character of many of the trails, use percentages were also assigned for each segment. Segments receiving 75% or more of any one use type were categorized as representative of that type for use type analyses; remaining segments were categorized as "mixed use" (Table 2). Amount of use estimates were also assigned by this staff member using broad high, moderate, and low use categories.

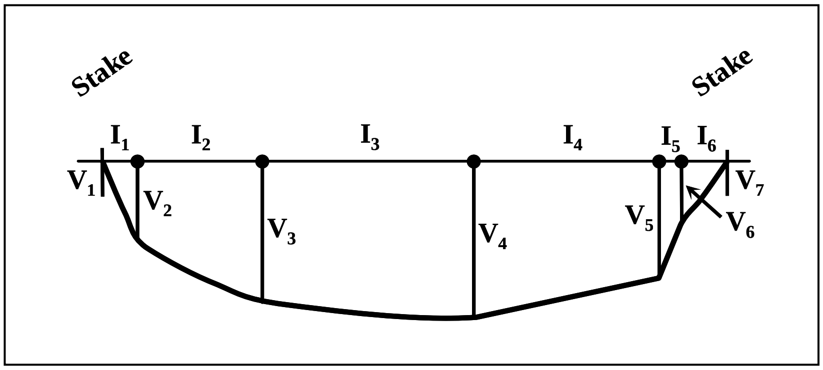
Table 2. Trail system miles and segments for the study sample by predominant type of use. Use type categories are approximate; most trails are multi-use and fall into more than one category.

Primary Trail Use Type	Study Sample	
	Miles	**Segments**
Horse	27.45	12
Hiking	26.01	15
Mixed Use	20.29	17
ATV	2.84	2
Mtn. Bike	1.91	1
Totals:	78.50	47

Field Procedures

Field work was conducted during the early summer of 2002. A detailed description of all trail condition assessment procedures is presented in Appendix 1 and summarized here. Elements of two trail condition assessment methodologies were integrated in developing the procedures applied to assess selected impact indicators for the sampled trail segments. A *point measurement method* with a systematic sampling interval at 500 ft intervals, following a randomized start, was the primary method (Leung and Marion 1999a; Marion and Leung, 2001). A trail measuring wheel was used to identify sample point locations. At each sample point, a transect was established perpendicular to the trail tread with endpoints defined by visually pronounced changes in non-woody vegetation height (trampled vs. untrampled), cover, composition, or, when vegetation cover is minimal or absent, by disturbance to organic litter. Representative photos promoted consistent judgment. The objective was to select visually obvious boundaries caused by trampling disturbance that contained the majority (>95%) of traffic. Temporary stakes were placed at these boundaries and the distance between was measured as tread width; maximum depth from a taut string tied to the base of these stakes to the trail surface was measured as maximum incision (MIC), an indicator of soil erosion (Farrell and Marion, 2002). Refer to Appendix 1, Figure 2 for diagrams showing how MIC measures were taken on trails in flat and sloping terrain (where side-hill construction complicates such measures).

The cross sectional area (CSA) of soil loss, from the taut string to the tread surface, was also measured using a variable interval method. CSA provides a more accurate measure of trail soil erosion that can be extrapolated to provide an estimate of total soil loss from each trail segment. The variable method is an adaptation of the traditional fixed interval method described by Cole (1983), designed to reduce measurement time to allow application at every sample point. Instead of taking vertical measurements along the horizontal transect at fixed intervals, vertical measurements are taken only at points directly above tread surface locations where changes in tread micro-topography occur (Figure 2). This variable interval method was applied by positioning beads along the transect string over tread locations that, when connected with straight lines, would most accurately represent the cross sectional shape or profile of the tread surface. The number of beads employed varied with tread surface complexity. The distance from each bead to the left boundary stake was recorded, along with the vertical measure of incision under each bead (Figure 2, table). A computer program was developed and used to calculate CSA from data collected at each sample point. These procedures were applied to derive CSA estimates only at sample points where maximum trail incision along the transect exceeded one inch, a decision rule included to further conserve assessment time at locations where soil loss was minimal.



Vertical (in)	Interval (in)	Area (in^2)
T_1: 0	I_1: 5.0	21.3
T_2: 8.5	I_2: 12.5	146.9
T_3: 15.0	I_3: 20.0	360.0
T_4: 21.0	I_4: 16.5	272.3
T_5: 12.0	I_5: 2.5	21.9
T_6: 5.5	I_6: 5.0	13.8
T_7: 0	CSA:	836.0

Figure 2. Illustration of the variable interval CSA method for assessing soil loss at each transect. Table shows data for use in the computational formula: Area = $(T_i + T_{i+1}) \times I_i \times .5$ for each row and summed to compute CSA.

We note that use of a visitor trampling disturbance definition for establishing trail boundaries, from which MIC and CSA soil loss is assessed, will underestimate soil erosion from the time of trail creation. For example, a trail that is entrenched a several feet deep has sides that are not traveled upon so tread boundaries would be placed only as high as trampling disturbance was evident. This was viewed as valid as our intent was to assess erosion associated with relatively recent recreational use rather than "historic" erosion from earlier pre-park uses (see Appendix 1, Figure 2) , or from soil excavation during trail construction. Trails with such historic erosion often followed old woods roads and nearly always had shrubs and trees rooted in the eroded embankments, indicating that the erosion had occurred more than 10-15 years ago. Finally, soil loss on minimally eroded treads with less than 1 in. incision was not assessed to conserve field assessment time. As a consequence, CSA measures were completed for 375 of the 821 transects in the sample population. While these procedures clearly underestimate soil erosion measures, we believe this to be necessary for two reasons: 1) underestimating recreation-related erosion is better than including soil loss caused by older pre-park trail or woods road uses or by trail construction work, and 2) focusing soil loss measures on more recent erosion is more managerially relevant for monitoring and decision making purposes.

Trail tread condition characteristics, including vegetation cover, organic litter, exposed soil, muddy soil, water, rock, gravel, and roots, were defined as mutually exclusive categories and assessed across each transect. These indicators were evaluated as a proportion of tread width in 10% categories (5% where necessary). A count of additional secondary trails that paralleled the survey trail at each sample point provided a measure of the extent of trail braiding.

A *problem assessment method* integrated into the monitoring procedures provided census information on three specific trail impact problems: excessive erosion, excessive muddiness, and number of informal trails branching from the formal trail since the last sample point (Leung & Marion 1999a). Excessive erosion was defined as sections of tread (≥10 ft in length) with tread incision exceeding 5 in. Excessive muddiness was defined as sections of tread (≥10 ft in length) with seasonal or permanently wet, muddy soils that show imbedded foot or hoof prints ≥0.5 in deep.

Informal trails are trails that visitors have created to access features such as streams, scenic attraction features, and camping areas, or to cut switchbacks, go around mud-holes or downed trees, or that simply parallel the main trail (see Appendix 1 for further details). As they hiked, field staff looked for and recorded the beginning and ending distances from the starting point for all occurrences of these problems. A trail measuring wheel was used to measure distances. In contrast to the point sampling, this method provides census data on the extent and location of specific pre-defined problems, facilitating management efforts to rectify such impacts.

Several inventory indicators were also assessed at sample points. These included:

Tread grade – percent slope of the trail at the sample point

Trail slope alignment angle – orientation of the trail (0-90^{o}) to the prevailing grade of the landform. A low slope alignment angle trail is oriented up- and down-slope, a high slope alignment angle trail is oriented along the contour.

Tread drainage feature – distance in 25-foot increments up to 75 feet, to any reasonably effective human-constructed tread drainage feature (water bar or drainage dip) located in an up-slope trail direction from the sample point.

Water drainage – an estimate of the amount of water (25% categories) that would flow off the tread within 10 feet upslope of the sample point during a rainstorm.

Trail position – categorized as valley bottom, ridge top, or mid-slope.

Soil texture – assessed using a field assay method described by Foth (1990) to determine soil texture in the vicinity of the sample point.

Data Analysis

Data were input into an Excel spreadsheet and imported to the SPSS Statistical package for analyses. Basic frequencies and descriptive statistics were run for all indicators. Relational analyses, including Analysis of Variance and Multiple Regression Analysis, were conducted to evaluate the influence of various use-related, environmental, and managerial factors.

Results

Results are reported for the entire sample and for individual trails and trail segments. Presentation of data for the survey trails as a whole is relevant because the sample is representative of the park's trail system and trail use types. Results are first presented for inventory variables that describe various physical attributes (e.g., trail grade and topographic position) of the trail system. This is followed by presentation of impact indicators that describe trail conditions (e.g., trail width and depth). The influence of use-related factors (e.g., type and amount of use), environmental factors (e.g., soil texture), and managerial factors (e.g., trail grade and drainage features) are then investigated through statistical analyses and testing. These are included to provide additional insight into the trail degradation process and to identify factors that managers might manipulate to encourage sustainable trail use while minimizing associated trail impacts.

Inventory Indicators

Trail grade ranged from 0 to 48% with a mean of 7.9. An examination of the frequency distribution (Table 3) reveals that one-fifth of the trails are nearly flat (0-2% grade), which are susceptible to muddiness if in valley bottom or ridge top settings. More importantly, one-quarter of the trails have grades in excess of 10%, which is generally considered to be at high risk for soil erosion. Grades in excess of 30% were recorded at 15 sample points. Trail alignments that more directly ascend slopes are also a noted problem on 16% of the trails with slope alignment angles of less than 23 degrees. When such trails become incised water cannot be drained from their treads making them particularly vulnerable to erosion when trail grades are steep, or muddiness, when grades are mild (see Figure 1). Another 18% of trails have poor slope alignment angles ($23\text{-}45^{o}$) that are also often difficult to drain.

Field staff also assessed the distance from each sample point, in an up-slope direction, to any reasonable effective human-constructed tread drainage features. This provides an indication of the extent of effective tread drainage maintenance work. Data for this indicator reveals the existence of very few such features: Only 59 sample points (7.1%) had drainage features within 75 feet of sample points (Table 3). Similarly, when asked to assess the percentage of water from a rainstorm that would tend to flow off the trail within 10 feet upslope from the sample point, staff estimated 0% for 51% of the sample points compared to only 15% for 75% or more water removal (Table 3).

The trail system appears to be well-distributed across topographic positions, with 28% in valley bottom positions, 25% at midslope and 47% at ridge positions. The effects of these positions are explored in later analyses. Soil texture, recorded at each sample point, were predominately loams (39%), sandy loams (31%), and clay loams (14%) (Table 3). While the wider range in particle sizes of loamy soils make them more susceptible to soil compaction, compacted soils on trails can make them more resistant to erosion from water and wind. However, decreased water infiltration on compacted soils can also exacerbate problems with tread muddiness, particularly when it’s the underlying soils that become compacted.

Table 3. Number and percent of sample points by inventory indicator category.

Inventory Indicator	Sample Points	Percent
Grade		
0-2%	178	21.5
3-6%	272	32.9
7-10%	166	20.1
11-15%	122	14.8
16-20%	39	4.7
21-30%	35	4.2
>31%	15	1.8
Mean: 7.9		
Slope Alignment Angle		
0-22^o	129	15.6
23-45^o	154	18.6
46-68^o	217	26.2
69-90^o	323	39.0
Mean: 54.6		
Tread Drainage Features		
Within 25 ft	30	3.6
Within 26-50 ft	17	2.1
Within 51-75 ft	12	1.4
Within >75 ft	768	92.9
Water Drainage		
0%	419	50.7
25%	186	22.5
50%	98	11.9
75%	60	7.3
100%	64	7.7
Topographic Position		
Valley	234	28.2
Midslope	203	24.5
Ridge	390	47.0
Soil Texture		
Sandy Clay Loam	8	1.0
Clay Loam	114	13.8
Silty Clay	19	2.3
Sandy Loam	257	31.1
Loam	325	39.3
Silt Loam	38	4.6
Organic	63	7.6

Table 4 reveals the proportion of sample points stratified by type and amount of use. Estimated use levels for surveyed trails indicate that most receive heavy traffic. Horse and hiker uses are predominant, along with the mixed use category. Trails receiving 75% or more use from any single type were categorized as that type with remaining segments assigned as mixed use.

Table 4. Number and percent of sample points by type of use and use level.

Type of Use	Use Level		
	Low	Medium	High
Hiker	12, 1.4%	31, 3.7	233, 28.1%
Horse	0	18, 2.2%	273, 32.9%
Mtn. Bike	20, 2.4%	0	0
ATV	3, 0.4%	26, 3.1%	0
Mixed	0	49, 5.9%	164, 19.8%

Impact Indicators

The number of informal visitor-created trails counted between sample points (at fixed 500 ft intervals) ranged from 0 to 10 with a mean of 0.33 (about 3.5/mile)(Table 5). While most segments had no informal trails (653, 79%), 20 segments had 3 or more. This indicator is intended to gauge the extent of unofficial, visitor-created trails and to monitor their proliferation over time. Such trails are created by visitors for a variety of reasons: to access attraction features such as viewpoints, water, campsites, other trails, and avoid muddy or rutted trails, or to cut switchbacks. The number of secondary trails, a measure of trail braiding, reveals that this form of trail impact is not currently prevalent at BSF, likely due to topographic constraints (Table 5). All but six sample points had no secondary trails and those six only had one each.

Trail width ranged from 11 to 249 inches (20.8 ft) with a mean of 60 inches (5 feet) (Table 5). Forty sample points (4.8%) were wider than 10 feet, which is approximately the widest of any constructed trail. Trail width is generally a function of constructed or maintained width as affected by use. Most trails need not be wider than 24 inches, though motorized use trails are wider and horse trails that follow old road alignments or that have been hardened with gravel are wider. Muddiness on trails is the leading factor contributing to trail widening. Trails that have low trail slope alignment angles generally are also wider, as topography does not act to inhibit the lateral spread of traffic.

Two measures of erosion were included in the survey. A traditional rapid assessment method has been to measure the maximum incision or depth of the trail at each sample point from a taut string attached to stakes placed at trail borders. Incision ranged from 0 to 19.8 inches with a mean of 2.3. The majority of sample points had incision values of less than 2 inches (452 sample points, 54.7%). However, 108 points (13%) had incision values of more than 5 inches and 18 points were 10 inches or higher (Table 5). The cross sectional area (CSA) between the string and the tread surface was also measured and computed, providing a more accurate measure of trail erosion. When maximum incision was 1 inch or less the CSA procedure was not done and a zero was recorded. CSA ranged

Table 5. Number and percent of sample points by impact indicator category.

Impact Indicator	Sample Points	Percent
Informal Trails (#)		
0	653	79.1
1	113	13.7
2	40	4.8
3	12	1.5
4	3	0.4
>4	5	.6
Mean: .33		
Secondary Trails (#)		
0	821	99.3
1	6	0.7
Mean: .01		
Tread Width (in.)		
<= 24	190	23.0
25 - 41	142	17.2
42 - 71	167	20.2
72 - 89	166	20.1
90+	162	19.6
Mean: 60		
Maximum Incision (in)		
<= .5	232	28.1
0.6 - 1.0	220	26.6
1.1 - 3.0	165	20.0
3.1 - 5.0	101	12.2
5.1+	108	13.1
Mean: 2.3		
Cross Sectional Area (in^2)		
0	452	54.7
1 - 100	121	14.6
101 - 200	115	13.9
201 - 400	80	9.7
401+	59	7.1
Mean: 104		
Mud/Water (%)		
0	711	86.1
1 - 33	51	6.2
34 - 66	22	2.7
67+	42	5.1
Mean: 7		

from 0 to 2195 in^2 with a mean of 104 in^2. Fifty-four percent of the sample points had a CSA of 0; 139 points (16.8%) exceeded 200 in^2 and 59 points exceeded 400 in^2 (Table 5). To provide perspective, a CSA of 400 on at trail with the mean width of 60 inches would have an incision of 6.7 in. across its entire width. Photos illustrating trail erosion are included in Appendix 3.

CSA values were also extrapolated to estimate total soil loss for surveyed trail segments. These estimates are based on the assumption that each sample point is representative of a trail distance of 250 ft on either side (with special procedures for the beginning and final trail segments). CSA extrapolated values ranged from 0 to 7620 ft^3 with a mean of 440 ft^3.

Ten categories of tread substrates (e.g., soil, vegetation, rock) were assessed as a proportion of tread width at each sample point. As an impact indicator, trail muddiness was evaluated by summing the measures for mud and water. Eighty-six percent of the sample points were not muddy by this measure, 73 points (8.9%) had mud or water across 1-66% of their width and 42 points (5.1%) had more than this amount. Photos illustrating trail muddiness are included in Appendix 3.

Trail condition summaries for individual trails are provided in Appendix 2 for designated and/or "managed" trail segments surveyed by field staff. Some of these results and management implications are highlighted here to illustrate common trail degradation problems and solutions. As previously noted, trail conditions are a function of the environmental resistance of the native soils and vegetation, trail design and maintenance, and type and amount of use. The trail summaries reveal a wide diversity in each of these factors. For example, the Lee Hollow Look (Laurel Branch) horse trail is well-designed in most areas, though steep trail grades are evident (mean trail grade = 10.6%). Maintenance features to drain water from the tread were also present and sufficiently maintained in most areas to effectively limit tread muddiness and erosion. However, some stream crossings were problematic, with direct descents to the stream and ineffective water drainage features such that stream deposition and water turbidity are occurring. Erosion was limited (mean CSA = 112 in^2), in part due to applications of gravel (mean = 35% of tread width). In contrast, conditions along the River Trail West were more degraded due to poor design and maintenance. The River Trail West (90% horse, 10% hiker) follows flat riverbank terrain with wet soils. Lack of tread drainage or use of gravel has led to 42 occurrences of wet soil (mean = 41% of tread width), excessive widening (mean = 94 in, max. = 135 in), and substantial soil erosion caused largely by river flooding that removes soil from non-vegetated substrates (mean CSA = 197 in^2).

The No Business and Miller Branch trails were similar in their poor layout through riparian areas and lack of effective maintenance (i.e., no gravel and sparse/ineffective tread drainage features). Stream crossings were a significant resource protection issue along the No Business trail along with extensive muddiness and erosion for the eastern portion nearest the river. Thirteen informal trails have been formed to circumvent muddy areas. The Miller Branch trail has muddiness along 18% of its length but this problem extends to portions of the trail that rise to side-hill mid-slope positions. Here the trail frequently intercepts seeps and small streams, which run along and erode the trail tread creating deep ruts and gullies.

Hiking and biking trails were generally in good condition, with narrow treads and limited erosion and muddiness. For example, the Grand Gap Grand Gap Loop hiking trail has an excellent design, lacks tread drainage features, but has a narrow width (mean = 26 in), and little erosion (mean CSA =

4 in^2) or muddiness (mean = 0%). However, the creation of informal trails along hiking trails to access campsites often directly descended steep slopes. Severe erosion was noted for a number of these trails (e.g., see Honey Creek). Trails with heavy ATV use, such as those in the Grassy Knob Area, are the most highly impacted. This trail rarely follows the contour and had no signs of maintenance. Mean trail width is 104 in., with a mean CSA of 222 in^2 (highest of any surveyed trail) and 18% of the segment was found to have excessive erosion.

The Influence of Use-Related Factors

This section examines the influence of amount and type of use on trail conditions. Estimated use in three categories (low, moderate, and high) was used to evaluate amount of use differences. Statistical testing and plotting of results revealed no relationship between use level and trail muddiness, a weak relationship with erosion (CSA) and a significant relationship with tread width. Mean CSA is 59 in^2 for low use trails, 136 in^2 for moderate use trails, and 100 in^2 for high use trails, though differences are not statistically significant (Analysis of Variance, *p-value* = .093). Tread width does vary significantly by use level, however, with tread widths of 36, 66 and 59 inches for low, moderate and high use trails (ANOVA, *p-value* = .000). Means testing revealed differences between each of the use level categories. These findings, particularly that moderate use segments have greater erosion and width than high use segments, suggest the influence of other factors.

Recall that trails receiving estimated use of 75% or more by a specific type of use were categorized as that use type. Remaining trails were combined into a mixed use category. Mean use estimates for these mixed use trails are as follows: horse (33%), hiker (30%), bike (18%), ATV (12%), wagon (5%), and vehicle (2%). Thus, mixed use trails are mostly used by horses and hikers, though bike and ATV use also occurs on some.

Findings reported here related to type of use differences agree with those from other research studies. The lower weight and ground pressure of hikers and bikers creates less disturbance to vegetation and soils along trails, which have fewer problems with widening, erosion, and muddiness. Point sampling data reveals that bike trails are quite narrow at BSF with a mean width of 24 in, followed by hiking trails at 32 in. Horse trails are more than two times as wide (81 in) but ATV trails were widest at 104 in (Table 6). These differences in trail width were statistically significant.

Significant differences were also found in the extent of soil erosion associated with different types of use. Again, bike trails have the lowest CSA values (mean = 6 in^2) followed by hiking trails with a mean CSA of 19 in^2. However, a very substantial increase in erosion occurs on horse trails, with an average CSA of 150 in^2, followed by another large and significant increase for ATV trails (mean CSA = 246) (Table 6). Mixed use trails (mean CSA = 144 in^2) were similar in erosion levels to horse trails.

Results for tread muddiness were somewhat different (Table 6), though bike and hiking trails were again lowest (mean = 0). Muddiness across horse trail transects had a mean of 12%, with 3% for ATV trails, though these differences were also statistically significant (Table 6).

Table 6. One-way Analysis of Variance (ANOVA) for impact indicators stratified by type of use.

Indicator & Use Type	Mean ± 95% Confidence Interval[1]
Trail Width (in)	
Bike (n=20)	23.8 ± 2.4[a]
Hiking (n=276)	32.1 ± 2.1[a]
Horse (n=289)	81.3 ± 3.0[b]
ATV (n=29)	104.3 ± 12.9[c]
Mixed Use (n=213)	63.1 ± 5.2[d]
Total (n=827)	59.6 ± 2.4
	Anova: F=142.8, sig. = .000
Cross Sectional Area (in^2)	
Bike (n=20)	5.7 ± 6.2[a]
Hiking (n=276)	18.8 ± 6.9[a]
Horse (n=289)	149.6 ± 22.6[b]
ATV (n=29)	245.6 ± 115.2[c]
Mixed Use (n=213)	143.9 ± 39.3[b]
Total (n=827)	104.4 ± 14.2
	Anova: F=23.8, sig. = .000
Muddy Soil (%)	
Bike (n=20)	0 ± 0[a]
Hiking (n=276)	0 ± 0[a]
Horse (n=289)	12.1 ± 3.1[b]
ATV (n=29)	3.3 ± 5.2[ac]
Mixed Use (n=213)	8.7 ± 3.2[c]
Total (n=827)	6.6 ± 1.4
	Anova: F=14.8, sig. = .000

1 - Superscripts refer to results from the LSD multiple comparison test for differences between means. Mean values with the same letters are not significantly different (p<.05).

As noted previously, estimated total soil loss for each surveyed trail segment was calculated by extrapolating CSA measures from point samples 250 feet to either side and summing for each trail. Data in Table 7 reveal a total of 293,448 ft^3 of soil loss for the surveyed trails, with an estimated 1,255,988 ft^3 for the entire trail system (327 miles). Horse trails in the sample account for the majority of soil loss (148,099 ft^3, 50%) from 27.45 miles of trail. ATV use has the second highest measure of soil loss of 23,388 ft^3 on only 2.84 miles of trail. The ft^3/mi measure provides a standardized means for directly comparing soil loss by use type. ATV trails had an estimated 8,235 ft^3/mi of soil loss, the highest of any category. Soil loss on horse trails was estimated at 5,395 ft^3/mi, approximately eight times more than occurs on hiker trails (669 ft^3/mi). In contrast, mountain biking, at 202 ft^3/mi, has the lowest estimated level of soil loss, about 30% as much as on hiking trails. This finding reflects a limited mileage of trails where mountain biking was the predominant use (1.91 mi), and these trails received low to moderate levels of use. As a percentage of aggregate erosion, erosion from horse trails (50.5%) accounts for the majority of soil loss. Mixed use trails, for which the predominant use is horse riding, account

Table 7. Estimated soil loss on trails classified by type of use; based on extrapolations of CSA soil erosion measures from sample points to each survey trail segment.

CSA Soil Loss	Horse	Hiking	Bike	ATV	Mixed	Total
ft^3/mi	5,395	669	202	8,235	5,134	3,738
Sum (ft^3)	148,099	17,391	386	23,388	104,174	293,448
Total Sum (%)	50.5	5.9	0.1	8.0	35.5	100

for 35.5% of aggregate soil loss, followed by ATV's (8.0%), hikers (5.9%) and mountain bikes (0.1%). These data are not presented to apportion blame to specific use types, rather to emphasize that managers seeking to accommodate horse and ATV uses should acknowledge their higher potential for eroding soil and incorporate improved trail design, construction, maintenance and visitor use management practices to ensure that such uses are sustainable.

Data from the continuous problem assessment survey provides a more comprehensive picture of conditions for the three indicators assessed. These data reveal bike trails to be in the best condition, with only two occurrences of severe (>5 inches deep) soil erosion and muddiness (Table 8). Hiking trails are also in good condition with respect to muddiness and running water on the tread. For example, only 0.6% of the sampled hiking trails have substantial muddiness with an average of 30 ft/mi. However, survey staff recorded 54 sections with eroded treads (>5 inches deep) along hiking trails, affecting 1.4% of the hiking trail mileage with an average of 73 ft/mi (Table 8).

Data from the problem assessment method also reveal horse and ATV trails to be substantially more impacted than the hiking and bike trails. Staff assessed 226 occurrences of excessive erosion, affecting 9.0% of the horse trail mileage with an average of 473 ft/mi. Note that the standardized measures (#/mi, %, and ft/mi) should be used for use type comparisons, other measures are affected by differences in the number of miles sampled. Muddiness and running water were also common forms of impact, affecting 9.9% (522 ft/mi) and 4.3% (226 ft/mi), respectively, of the assessed horse trail mileage (Table 8). Comparing percentage data, ATV trails are approximately 17 times more eroded than hiking trails and 2.6 times more eroded than horse trails (Table 8). Excessive erosion affects 24.1% of ATV trails with an average of 1263 ft/mi. Muddiness is also common on ATV trails, affecting 7.9% of their mileage at a rate of 419 ft/mi.

Table 8. BSF trail condition assessment data from the problem assessment method.

Indicator	Occurrences		Lineal Distance			
	(#)	(#/mi)	(ft)	(mi)	(%)	(ft/mi)
Soil Erosion						
Bike	2	1.1	26	.01	0.6	14
Hiking	54	2.1	1,851	0.35	1.4	73
Horse	226	8.4	12,771	2.42	9.0	473
ATV	30	11.1	3,410	0.65	24.1	1263
Mixed	147	7.5	12,260	2.32	11.9	629
Total	459	6.0	30,318	5.74	7.5	397
Muddiness						
Bike	2	1.1	58	.01	0.6	32
Hiking	15	0.6	769	0.15	0.6	30
Horse	219	8.1	14,081	2.67	9.9	522
ATV	29	10.7	1,131	0.21	7.9	419
Mixed	107	5.5	6,134	1.16	5.9	315
Total	372	4.9	22,173	4.20	5.5	290
Running Water						
Bike	0	0	0	0	0	0
Hiking	6	0.2	470	0.09	0.4	19
Horse	52	1.9	6,112	1.16	4.3	226
ATV	0	0	0	0	0	0
Mixed	26	1.3	3,171	0.60	3.2	163
Total	84	1.1	9,753	1.85	2.4	128

The Influence of Environmental and Managerial Factors

As previously noted, trail degradation can be minimized through proper trail design (alignment), construction and maintenance. The influence of some of these factors is investigated in this section. An important aspect of trail design is the grade or slope of trails. Steeper trail grades are associated with greater susceptibility to soil erosion, particularly when, in the case of BSF, the substrates have little rock content and are readily eroded. Another previously described factor affecting trail degradation is trail slope alignment angle. Trails that directly ascend slopes are difficult or impossible to drain water from so they are highly susceptible to erosion. The influence of both these factors was statistically tested with ANOVA (General Linear Model) and found to be highly significant (F/*p-value*: model = 10.2, .000; grade = 8.1, .000; alignment = 18.7, .000). Marginal means, corrected for the influence of the other factor, are graphed in Figure 3. These findings are dramatic, illustrating the strong influence of both trail design-related factors. The least eroded trails are those that are aligned with the contour. The influence of trail grade increases as trail slope alignment angles decrease from 90 (contour) to 0 (direct-ascent). In particular, substantial increases in CSA values are shown to occur for trails in the 0-22^{o} category and for trails with grades in excess of 15% (Figure 3).

Trail width is also strongly influenced by trail slope alignment (ANOVA F/*p-value*: model = 11.7, .000). The sloping terrain above and below contour aligned trails inherently inhibits trail widening, forcing trail users to center their traffic. Trail width increased from 52 inches for contour trails to 72 inches for trails that more directly ascended slopes. The relationship between trail slope alignment angle and tread muddiness was not significant, though trails with low slope alignments are substantially muddier.

Trail topographic (landscape) position significantly influences tread width (ANOVA F/*p-value*: model = 11.3, .000), erosion (ANOVA F/*p-value*: model = 12.0, .000) and muddiness (ANOVA F/*p-value*: model = 16.9, .000). Ridge trails are least degraded (width = 53 in, CSA = 67.4, muddiness = 3.5%) while valley trails are in the poorest condition for width (67 in) and muddiness (12.9%). Erosion is greatest on midslope trails (140 in^2) and valley trails (135 in^2). Field staff reported that the high erosion rates on valley trails are associated with river flooding, which scours and removes soils from non-vegetated treads.

Soil texture also appears to influence trail degradation. Tread substrates classified as sandy have the highest mean values for tread width and erosion (73 in and 128 in^2, respectively). Organic soils have the lowest mean values (32 in and 27 in^2), with loamy and silty soils intermediate. Differences for these two indicators were significant (ANOVA for tread width, F/*p-value*: model = 31.2, .000; ANOVA for CSA, F/*p-value*: model = 4.6, .003). Results for muddiness were not significant (ANOVA F/*p-value*: model = 2.5, .058), though organic substrates were substantially lower than

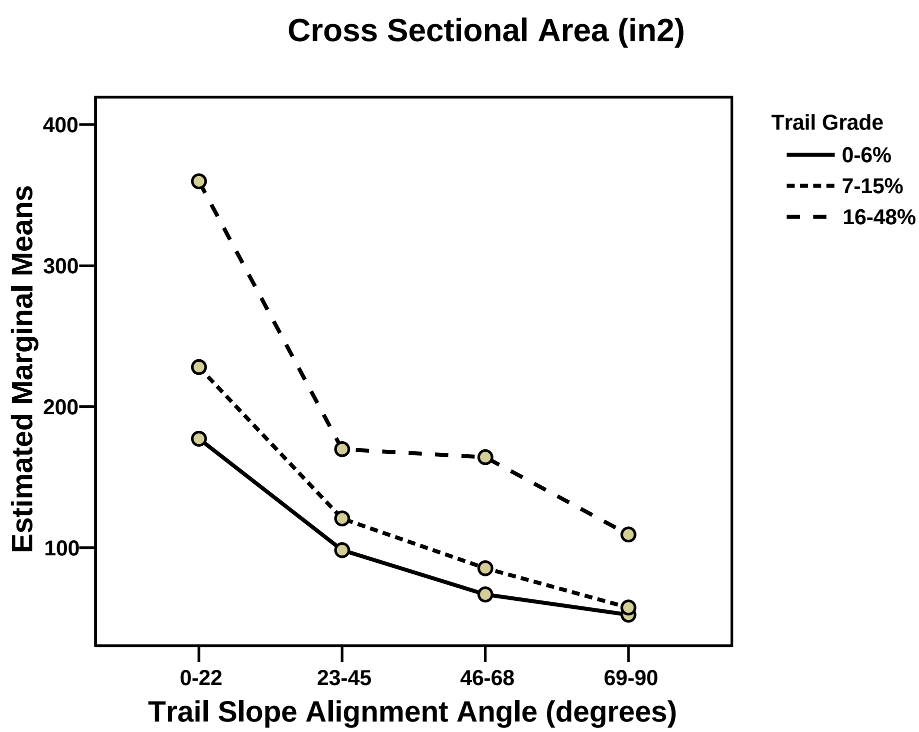


Figure 3. The influence of trail slope alignment angles and trail grade on soil erosion, as measured by cross-sectional area.

the other soil textures (0% compared to 6.6-8.1%). Further evaluations revealed that the sample points classified with organic substrates are nearly all on hiker and mixed use trails, though a substantial majority of these receive heavy use.

Current trail uses occur on both designated trails that are maintained by park staff and on undesignated trails that are unmanaged. In the sample, 39 trail segments (69.9 miles) are designated and 7 segments (8.2 miles) are undesignated. Because there are only two categories of trail designation the influence of this variable was evaluated with t-tests. For soil erosion, designated trails (mean = 81 in^2) are significantly less eroded than undesignated trails (mean = 255 in^2) (t = -4.7, *p-value* = .000). Similarly, designated trails are significantly narrower than undesignated trails (mean values 56 in and 89 in, respectively) (t = -9.1, *p-value* = .000). Differences in muddiness are small and non-significant.

The influence of trail maintenance was evaluated though three indicators: the proximity of tread drainage features, the percentage of water that would flow off a trail in the vicinity of the sample point, and the proportion of tread covered in gravel. Very few tread drainage features are present on the BSF trail system. Field staff found only 59 reasonably effective drainage features (e.g., water bars, drainage dips) within 75 feet of the sample points in an uphill direction (30 within 25 ft, 17 within 26-50 ft and 12 within 51-75 ft). No drainage features were apparent within 75 feet of 768 sample points (93%), indicating that most portions of the trail system are not receiving adequate maintenance to drain water from treads.

An analysis of soil erosion (CSA) by proximity to drainage features was statistically significant (ANOVA F/*p-value*: 4.2, .020) with mean CSA of 56 in^2 for sample points with a drainage feature within 25 ft in an uphill direction, 157 in^2 for points with a feature within 26-50 ft, and 252 in^2 for points with a feature within 51-75 ft. An analysis of muddiness by proximity to tread drainage features was not statistically significant (ANOVA F/*p-value*: 2.2, .120) though mean percent muddiness values suggested a relationship: 1.3% for sample points with a drainage feature within 25 ft in an uphill direction, 10% for points with a feature within 26-50 ft, and 16% for points with a feature within 51-75 ft.

Trails can be maintained to shed water without construction of tread drainage features by outsloping the tread so that water runs across and off the trail rather than down it. Natural features such as roots and rocks can also remove water. Field staff estimated the amount of water that would flow off the tread within 10 feet in an uphill direction by selecting the most representative value: 0%, 25%, 50%, 75%, and 100%. At 419 sample points staff estimated that 0% of the tread water would flow off, with 186 points at 25%, 98 points at 50%, 60 points at 75% and 64 points at 100%. Statistical testing revealed that both CSA and muddiness were significantly correlated with water drainage (ANOVA for CSA, F/*p-value*: 38.4, .000, ANOVA for muddiness, F/*p-value*: 14.7, .000). CSA values ranged from 185 in^2 for sample points with 0% water drainage estimates to 1.8 in^2 for sample points with 100% estimates. Similarly, muddiness values ranged from 11.7% for sample points with 0% water drainage estimates to 0% for sample points with 100% estimates.

Finally, trails can be hardened through rockwork or by the addition of gravel to lessen muddiness and tread erosion. Gravel has been applied to a number of horse trails at BSF in an effort to make them more sustainable to heavy traffic. The effectiveness of applying gravel is of substantial interest by park managers challenged with reducing the resource impacts associated with horseback riding in the park. The efficacy of gravel application was investigated by classifying the percentage of gravel seen in trail transects into 3 categories: 1-30% (64 sample points), 31-60% (60 sample points), 61-100% (30 sample points). We note that trails assessed as <61% gravel may be fully graveled but that vegetation or litter cover could have reduced the gravel estimates. Alternately, over time gravel sinks into the soils so older graveled trails may also have been assessed as only partially graveled. No measurements of gravel depth were taken.

Most of the gravel has been applied to horse trails; no gravel was present on ATV or bike trails and only a small number of hiking and mixed use trails have substantial amounts of gravel. Trail grade in four categories (0-5%, 6-11%, 12-17%, 18-48%) was also included in the analysis to examine the extent to which gravel is effective as grades increase.

The influence of graveling trails and grade on trail erosion was statistically tested with ANOVA (General Linear Model); the model and both indicators were found to be highly significant (F/*p-value*: model = 6.2, .000; gravel = 9.9, .000; grade = 13.3, .000) with an insignificant interaction term. Marginal means, corrected for the influence of the other factor, are graphed in Figure 4. Trails with little or no gravel have significantly greater erosion, particularly at grades above 11%. Graveling is most effective on trails with grades of less than 6%, particularly for trails with 61-100% gravel coverage. Gravel continues to provide protection from soil erosion on higher graded trails, however, erosion accelerates on graveled trails above grades of 17% (Figure 4).

A similar analysis for trail muddiness found that grade was not significant so a one-way ANOVA was conducted with just levels of gravel, which was significant (F/*p-value*: model = 4.6, .011). Mean muddiness for the three levels of gravel application are shown in Figure 5.

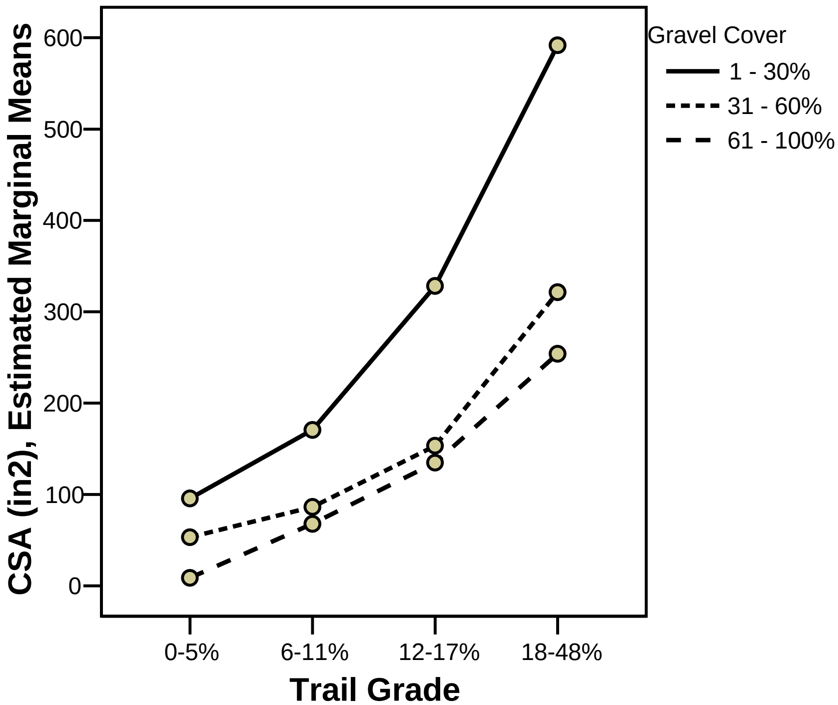


Figure 4. The influence of gravel application and trail grade on soil erosion, as measured by cross-sectional area.

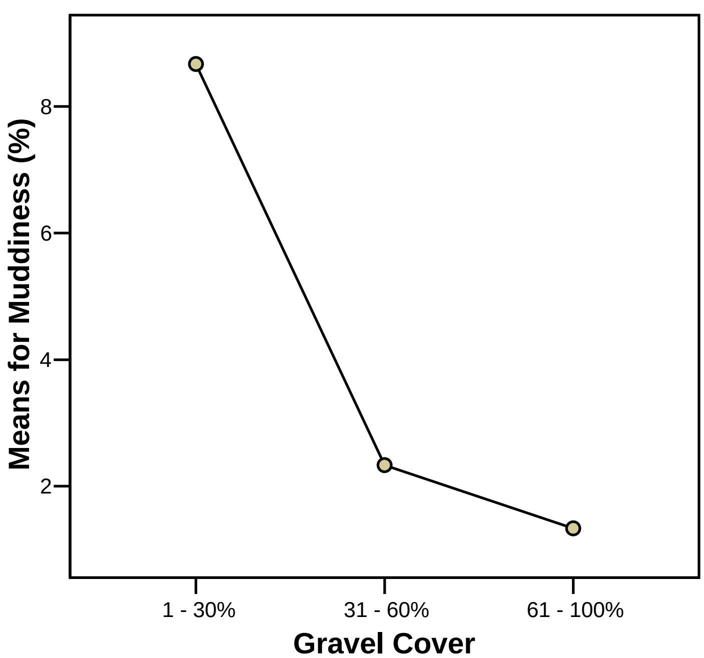


Figure 5. The influence of gravel application on trail muddiness.

Multivariate Analyses

Interpreting results from the preceding analyses can be complicated by the influence of other important variables. Further, the relative influence and importance of different variables is unknown. For example, which is more influential, trail grade or trail slope alignment angle? What is the relative importance of type of use, vs. amount of use, vs. various trail maintenance actions? These questions can only be answered through multivariate analyses, which simultaneously examine the influence of numerous variables. This section employs multiple regression analyses to model trail erosion, using CSA as the dependent variable. The focus of these analyses is on soil erosion because park staff and study findings revealed this form of trail degradation to be the most significant long-term problem affecting park resources.

Indicators with categories rather than numeric data (like type of use) were analyzed by creating related sets of "dummy" variables, a standard procedure in regression analysis. However, since these procedures do not allow dummy variables to be included in complete sets, literature findings and managerial relevance were considered in producing two conceptual groupings of variables: 1) a baseline model of control variables, and 2) a set of main variables with a high degree of managerial relevancy and statistically significant effects on soil erosion. Insignificant variables detracting from the relational model were excluded to avoid specification error.

Control Variables

Baseline variables for the relational model take into consideration less influential variables that make significant contributions to CSA. Included variables are soil texture, water drainage percentage, use level, and gravel percentage. Similar soil textures were aggregated to create the dummy variable categories loam, sandy loam, organic soil, and the reference category clay. Use levels are categorized as low, medium, and the reference category high.

Main Variables

Four main independent variables were chosen on the basis of statistical significance, findings present in the literature, and managerial relevancy: trail position, trail alignment, use type, and trail grade. Trail position was categorized as ridge, mid-slope, and the reference category valley. Use type was categorized into hike, bike, ATV, mixed, and the reference category horse.

Analysis Methodology

Note to readers, skip this section unless you are familiar with multiple regression procedures. Weighted least squares regression analyses were used to examine the relationships and interactions of influential variables on soil erosion (CSA). One-way analysis of variance (ANOVA) tests were used within regression procedures to test for significant differences in effects on CSA. Dummy variable categories were tested with ANOVA relative to reference (omitted) categories. Finally, product terms were computed and tested using ANOVA for interactions between trail grade and alignment, and alignment and use type. Means for these variables were centered in the process to avoid multicollinearity.

Preliminary analyses revealed severe skew in the dependent variable, caused by a large number of zero values, where CSA was assumed to be zero because maximum incision was less than one inch. Also, a fanned pattern in distribution of standardized residuals revealed heteroskedasticity, which was found to be a function of extreme outliers and the distance of sample points to trailheads: as points increased in distance from trailheads, a pattern of irregularity in errors was observed.

To address these issues CSA was recoded as a binary response, where only values greater than zero ($N = 375$) were included in relational analyses. This was appropriate because the zero values did not undergo the CSA measurement procedure, and the distribution of CSA error values are assumed in OLS regression to be normally distributed. A weighted least-squares procedure was included in analyses to control the effects of distance, and six extreme high-end outliers were excluded ($N = 369$) to meet the assumption of homoskedasticity and provide an unbiased regression line fit. In addition, Tobit top and bottom end censuring regression using the statistical program Stata 8.3 was applied for comparison to the full sample base ($N = 821$) to address concerns that binary results would be biased due to the exclusion of zero measure "success" cases. By using the binary sample, interactions between main variables were studied from the computation of relevant product terms. The variance inflation factor (VIF) and a correlations matrix was examined for each variable in regression modeling to detect any unacceptable levels of multicollinearity. Neither cut-off points of 4 (VIF) and
.75 (correlations) were violated, indicating that multicollinearity was not a problem.

<u>Results</u>

Table 9 presents the effects of Main variables on values of CSA. Isolation of these variables without the influence of Control variables facilitates understanding of individual main effects and detection of potential interaction effects between Main variables. Each Main variable is ordered across models in descending value based on their contribution to the coefficient of multiple determination (R^2), which represents the proportion of "explained" variation in CSA by the included independent variable(s).

Models 1 through 4 include each predictor entered separately. Note that the category selected as the "reference" for categorical variables (Valley for Trail Position) has no coefficient. The value is 0, by definition, and is used as a reference for comparisons with the other categories for that variable. For example, in Model 1, the coefficients reveal that mid-slope trails have 111 in^2 less erosion as measured by the CSA method, than valley points. This difference is statistically significant (*p-value* = .000). Examination of the R^2 values for models 1-4 also reveal that trail position is the highest explanatory predictor for CSA ($R^2 = .14$). Model 2 shows that as alignment values move toward perpendicularity from the prevailing slope, CSA values drop 2 in^2 per degree of increase. Model 3 presents differences in effects based on use type, revealing that hiking trails have significantly lower erosion than horse trails (-117 in^2, *p-value* = .000). Model 4 shows that as trail grade increases, CSA increases 3 in^2 (*p-value* = .013), but that it explains the least amount of variance (R = .014).

Model 5 presents their joint contribution and is a more appropriate model depicting the *relative* contributions of each factor. Trail position effects became more pronounced, particularly for the mid-slope position (-111 to -164 in^2, *p-value*=.000) in comparison to valley position trails. The use type dummy variable reveals that ATV use has significantly higher CSA values (113 in^2, *p-value* =.005) compared to horse use, though the small sample size for this factor (14 sample points) should be considered. Mixed use (-41 in^2, *p-value*=.048) and hiker use (-140, in^2, *p-value*=.000) have significantly lower CSA values than horse and ATV use types when topographical variables are considered. Trail grade effects also increased, to 4 in^2 (*p* =.000) per degree of increase. Together, more variance is explained by the sequential model (R^2 =.31), but these results suggest more complex relationships under linearly additive assumptions.

Table 9. Effects of Main variables across models on soil erosion (CSA).

Variables	Regression Models				
	(1)	(2)	(3)	(4)	(5)
Trail Position					
Valley[a]					
Mid-slope	-111 (.000)[b]				-164 (.000)
Ridge	-170 (.000)				-181 (.000)
Trail Alignment		-2 (.000)			-2 (.000)
Use type					
Horse[a]					
ATV			45 (.324)		113 (.005)
Hike			-117 (.000)		-140 (.000)
Bike			-177 (.089)		-121 (.177)
Mixed			-40 (.081)		-41 (.048)
Trail grade				3 (.013)	4 (.000)
Constant	285	184	209	183	329
Adjusted R^2	.14	.07	.05	.01	.31
N of cases	369				

All table values are unstandardized coefficients, values are CSA in^2.
[a] Reference category for dummy variables.
[b] *p-values* in parentheses (two-tailed t-test).

The introduction of the control variable set (Table 10) to each main variable model changes some significant effects of main variables and clearly improves the explanatory power of the regression model. This is particularly evident in Model 2, where the R^2 term increases from .10 to .21. ATV and mixed use effects are significantly altered by the addition of control variables. Post Hoc investigations revealed that use level suppressed the effects of ATV impact, as there were no low use ATV trails in the sample. Other Post Hoc testing revealed that water drainage and soil texture altered the effect of trail grade, which are no longer significant. These results indicate that trail position, alignment, and horse and hiker use types are robust predictors of CSA when entered into the equation with control variables, but that trail grade and mixed and ATV use type effects (which all fell from significance) are largely dependent on the relationship with other variables. Continuing with the exploration, it was necessary to consider the additive or possibly multiplicative effects of main effects in the equation.

Table 10. Effects of Main and Control variables across models on soil erosion (CSA).

Variables	Regression Models (1)	(2)	(3)	(4)	(5)
Control Variables					
Soil texture					
Clay [a]					
Sandy loam	-51 (.047)[b]	-61 (.012)	-47 (.063)	-60 (.020)	-40 (.126)
Loam, silt loam	-19 (.445)	-50 (.049)	-9 (.744)	-15 (.586)	-14 (.602)
Organic soil	-133 (.021)	-124 (.024)	-129 (.024)	-90 (.110)	-129 (.028)
Use level					
High [a]					
Medium	63 (.024)	50 (.050)	62 (.021)	95 (.008)	67 (.015)
Low	-46 (.538)	-9 (.904)	-70 (.348)	34 (.787)	-52 (.498)
Water drainage	-2 (.000)	-2 (.000)	-2 (.001)	-2 (.000)	-2 (.060)
Gravel	-.1 (.816)	.4 (.362)	-.1 (.781)	-.7 (.130)	-.2 (.670)
Main Variables					
Trail position					
Valley [a]					
Mid-slope		-117 (.000)			
Ridge		-160 (.000)			
Trail Alignment			-1 (.000)		
Use type					
Horse [a]					
ATV				-75 (.184)	
Hike				-108 (.000)	
Bike				-146 (.333)	
Mixed				-92 (.000)	
Trail grade					2 (.060)
Constant	232	340	220	270	223
Adjusted R^2	.10	.21	.14	.14	.10
N of cases	369				

All table values are unstandardized coefficients, values are CSA in^2.
[a] Reference category for dummy variables.
[b] *p-values* in parentheses (two-tailed t-test).

The addition of control variables and theoretically-driven sequential entry of main effects provides a comparison of differences between models of CSA prediction (Table 11). Models 1 through 4 reveal the complex effect differences between models, and model 5 presents important interaction effects. Models 1 and 2 are consistent with traditional theoretical assumptions that topographic variables heavily influence CSA rates. But while past research has documented that grade and trail position are two of the primary factors under management control, trail alignment has often been overlooked in trail erosion analyses. Model 1 includes only trail position and grade as main effects, which have highly significant (*p-value* <.002) effects on CSA. But in Model 2, trail alignment is added, revealing a significant effect (-1.3 in^2, *p-value*=.000) and trail grade simultaneously falls from significance – while accounting for a slightly higher explanation of CSA variance (R^2 =.27). These findings suggest a possible interaction or mediating effect between alignment and trail grade, to be expected as they both account for a conceptual relationship between trail position and local slope.

Models 3 and 4 build on the main variable topographic effects accounting for use type, based on research acknowledging use type as an influential factor, but that environmental considerations are also important predictors of trail erosion. Model 3 excludes trail alignment, and the significant effect of trail grade (*p-value* =.000) remains from the similar model 1, increasing slightly.

Model 4 received full specification and serves as the most explanatory model for variables contributing to soil erosion (R^2 =.32). Unlike model 2, trail grade remains significant (*p-value*=.001) and decreases slightly in effect (4 in^2). This suggests that trail grade effects are significantly dependent on use type, as well as other variables previously discussed, and that interaction effects between topography and use type are probable. Interestingly, the difference in this final model and the main variable model 5 in Table 9 varies little in regression fit and main effect significant relationships with CSA. In fact, only ATV use effects have fallen from significance. Post hoc analyses showed that by dropping use level out of the model, ATV regained its significant difference from horse impacts (*p-value* < .05). This might have been a function of uneven distribution given the small number of low use sample points.

Finally, the more specialized Tobit regression procedures were applied to the full sample base (*N* = 829) to address concerns that model 4 results were biased due the exclusion of zero measure “success” cases. Tobit regression results showed clearly that model 4 results are robust across the two sample groupings, with only slight differences in the magnitude of effects. The only notable differences in significant relationships were mid-slope positions, which fell out of significance, as did sandy loam, and water drainage became significant (-6.7 in^2, *p-value* <.01).

Table 11. Relational effects of Control and Main variables on soil erosion (CSA).

Variables	**Regression Models**			
	(1)	(2)	(3)	(4)
Control Variables				
Soil texture				
Clay [a]				
Sandy loam	-47 (.054)[b]	-50 (.034)	-46 (.058)	-50 (.034)
Loam, silt loam	-45 (.079)	-38 (.134)	-22 (.396)	-14 (.573)
Organic soil	-117 (.031)	-116 (.030)	-97 (.069)	-91 (.080)
Use level				
High [a]				
Medium	58 (.024)	54 (.029)	30 (.361)	33 (.024)
Low	-14 (.864)	-32 (.639)	68 (.505)	50 (.538)
Water drainage	-2 (.000)	-1 (.004)	-1 (.009)	-.7 (.000)
Gravel	.3 (.542)	.3 (.465)	-.4 (.372)	-.4 (.816)
Main variables				
Trail position				
Valley [a]				
Mid-slope	-136 (.000)	-134 (.000)	-159 (.000)	-158 (.000)
Ridge	-166 (.000)	-163 (.000)	-160 (.000)	-156 (.000)
Trail Alignment		-1 (.000)		-1 (.000)
Use type				
Horse [a]				
ATV			67 (.218)	57 (.279)
Hike			-140 (.000)	-142 (.000)
Bike			-144 (.303)	-153 (.262)
Mixed			-55 (.033)	-67 (.008)
Trail grade	3 (.002)	2 (.084)	5 (.000)	4 (.001)
Constant	341	331	365	361
Adjusted R^2	.23	.27	.29	.32
N of Cases	369			

All table values are unstandardized coefficients, values are CSA in^2.

[a] Reference category for dummy variables.

[b] *p-values* in parentheses (two-tailed t-test).

Discussion and Management Recommendations

This section of the report will review and summarize the principal research findings and management implications. Recommendations for improving management of a trail system that can accommodate and sustain a variety of trail uses while protecting the park's natural resources are also offered.

Review and Summary of Findings

This research developed state-of-the-art trail condition assessment and monitoring procedures and applied them to a large randomly selected sample of the BSF trail system. The sample included 47 trail segments, including 78.5 miles of designated (69.9 miles) and undesignated (8.2 miles) trails. The sample was also adequately representative of the park's various types and amounts of uses, topographic positions, soil types, and levels of trail design and maintenance.

Trails were surveyed with a point measurement method with transects located at 500 foot intervals and with a problem assessment method providing census data for selected trail problems. Assessments were made of trail conditions and of various trail design and maintenance attributes. Findings reveal a trail system with some substantial degradation, particularly soil erosion, which additionally threatens water quality in areas adjacent to streams and rivers. The survey documented 459 occurrences of severe erosion (>5 inches deep) affecting 7.5% of the surveyed trails (Table 8). Mean soil loss at sample points is 104 in^2 with 7.1% of the surveyed trails in excess of 400 in^2 (Table 5). More significantly, estimated soil loss from the surveyed trails totaled 293,448 ft^3 (10,868 cubic yards) or about 1,086 single-axel dump trucks of soil. Assuming a representative sample, this equates to 46,518 yd^3 or 4,651 dump trucks of soil for the entire trail system. Readers should also recall from the Methods section that the soil erosion measures employed sought to exclude erosion from historic trail/road uses, trail construction, and minimally eroded sections and therefore represents conservative estimates of soil loss.

Trail muddiness was also a notable form of trail degradation (372 occurrences) affecting 5.5% of the surveyed trails (Table 8). Trails that intercepted streams or seeps and had running water along their treads (84 occurrences) were particularly prone to muddiness and erosion. Tread width ranged from 11 to 249 inches with a mean of 60 inches (Table 5). Twenty percent of sample points were ≥90 inches in width. Survey trails were wide due to the heavy horse use many receive, and to trail users seeking to circumvent muddy sections. Visitor-created informal trails, often to access campsites or circumvent muddiness and tree falls, were numerous only in some areas (79% of the surveyed trails had none). Secondary or parallel trail treads (e.g., trail braiding) were extremely rare.

Analyses to investigate the influence of use-related, trail design, and maintenance factors were conducted. Type of use was found to be a substantially greater determinant of trail degradation than amount of use. Horse and ATV trails are significantly more degraded than hiking and biking trails (Tables 6-8). For example, mean soil loss measured at sample points are 246 in^2 for ATV trails, 150 in^2 for horse trails, 19 in^2 for hiking trails and 6 in^2 for bike trails (Table 6). Similarly, the proportion of trails with severe erosion (> 5 inches deep) is 24% for ATV trails, 9% for horse trails, 1.4 % for hiking trails and 0.6% for bike trails. Muddiness is a common problem on horse trails, 219 occurrences affecting 10% of the horse trail mileage. Muddiness affected 8% of ATV trails and 0.6% of hiking and biking trails. Finally, ATV trails are the widest (mean = 104 inches), followed by horse, hiking and biking (81, 32, and 24 inches), respectively (Table 6).

Several trail design-related factors were found to have substantial influence on levels of trail degradation. One-fifth of the trails are nearly flat (0-2% grade) making them susceptible to problems with tread muddiness, while one-quarter of the trails have grades in excess of 10%, which increase their susceptibility to erosion and the difficulty of travel (Table 3). Another important design issue is the prevalence of trails that directly ascend slopes. These trails have low slope alignment angles and are difficult or impossible to drain water from once their treads become eroded. Sixteen percent of the sample points were located along such "direct ascent" trails (with slope alignment angles of less than 23^{o}) (Table 3). When trail grades are low, muddiness is often an unavoidable problem; when trail grades are high, soil erosion cannot be controlled. The influence of trail grade and alignment angle on soil erosion are graphically illustrated in Figure 3. Erosion is significantly higher on trails with grades in excess of 15% and on all trails having slope alignment angles of less than 23^{o}.

Trail topographic position was also found to significantly influence levels of trail degradation. BSF's ridge trails are significantly less eroded, muddy, and wide. Valley trails are muddiest and widest while erosion is greatest on midslope, with valley trails a close second. Soil textures were variable and also influenced tread width and erosion. Tread width and erosion were greatest on soils with a sandy texture.

A principle maintenance-related factor affecting trail degradation is whether a trail is designated and receives maintenance (39 segments, 60.9 miles) or is undesignated and not maintained (7 segments, 8.2 miles). Undesignated trails are significantly more eroded than designated trails (mean = 255 vs. 81 in^2) and wider (mean = 89 vs. 56 in). Maintenance features such as water bars, designed to remove water and lessen erosion on trails, were found to be uncommon. Only 59 of 827 sample points (7%) had drainage features along the trail within 75 feet in an uphill direction. The influence of these features are highly significant as analyses revealed that erosion at sample points where drainage features were located within 25 feet averaged 56 in^2, while erosion at sample points where drainage features were found within 51-75 feet averaged 252 in^2.

Application of gravel was shown to be an effective maintenance action on horse trails. Trails with gravel have significantly less soil erosion, particularly at trail grades of less than 16% (Figure 4). The influence of graveling on trail muddiness is even more pronounced, with mean values for muddiness less than 3% regardless of grade (Figure 5). Subsequent research by the author and others at the Hoosier National Forest (Aust et al. 2005) concluded that graveling was an important management action for minimizing soil loss and muddiness on horse trails. Even well-designed trails could sustain only low levels of horse use without gravel. While many visitors find gravel to be aesthetically displeasing when first applied, experience there revealed that within several years the gravel mixes with soil, retaining a resistant tread that is less objectionable to visitors. Shenandoah NP has had success with pre-mixing gravel and soil for application on trails.

Finally, multiple regression analyses were used to explore the interrelationships between different variables and their relative influence on trail erosion. These analyses seek to model and increase understanding of the overall trail degradation process. Trail position, trail alignment, grade, water drainage, and type of use are all significantly influential variables in the best trail degradation model. According to this model, trail erosion can be most effectively minimized by avoiding use on steep trails with direct ascent alignments, valley trails, by installing tread drainage features, and by reducing horse and ATV use or restricting them to well-designed and maintained alignments. As previously noted, the curvilinear use/impact relationships suggests that reducing use is often an ineffective management practice. Thus an emphasis on proper trail design, construction and maintenance should be emphasized, though high levels of use when trail surfaces are wet should be avoided.

Recommendations

Managing Visitor Use

Big South Fork National River and Recreation Area was established in 1974 to provide recreational opportunities and to preserve and protect its resources. While a variety of recreational uses, including trail-related activities, are clearly appropriate, park managers must also ensure that they avoid significant impairment of natural and cultural resources. As described in the Introduction section, park managers are charged with applying their professional judgment in evaluating the type and extent of recreation-related impacts when judging what constitutes impairment. This report provides useful information for rendering such determinations and provides a basis for decisions to enhance management of visitors and resources to avoid or minimize recreation impacts.

Survey results reveal that trail impacts related to horse and ATV use are substantially greater than other forms of human-powered trail activities. Park managers should carefully consider the trails upon which such uses are currently occurring, seeking to limit high impact uses to trails that are designed, constructed and maintained to sustain those uses with minimal impact. Survey findings reveal that this is not currently the case. The recently completed General Management Plan (GMP) and Environmental Impact Statement indicates that public use will be restricted to a designated primitive road and trail system (excepting foot traffic). Study findings indicate that this provision is critical to the protection of park resources from current trail uses on undesignated trails, which are often poorly located and not designed, constructed or maintained to sustain such use. These routes will continue to receive use and unacceptable levels of impact to park resources in the absence of actions to block access, along with education to inform visitors of appropriate designated trail alternatives, and an effective program of enforcement where necessary.

It is also recommended that managers consider the appropriateness of recreational ATV use within the park. ATV's used solely for removing large game during the hunting season are a potential exception to the following discussion. This recreational pursuit is the most impacting type of use and has a higher potential for experiential conflicts with non-motorized forms of trail use. Loud high-powered engines, knobby tires, high rates of speed, and some riders who desire to challenge their machines combine to make this a "high-impact" recreational activity. Because of their speed, recreational ATV riders require substantial miles of trail which this survey reveals will become highly impacted, particularly related to soil erosion, with potentially significant impacts to water quality. ATV tracks found by survey staff revealed that riders commonly ignore trail closures or use designations (including within the Gorge), ride in creeks, and pioneer networks of informal trails. Further, most of these visitor-created routes in sloping terrain follow considerably higher-impacting "direct ascent" alignments. This is because riders traveling at an angle to the slope are susceptible to being overturned when uphill wheels encounter rocks, stumps or uneven terrain.

Visitor use regulations and educational programs can also assist in reducing resource impacts associated with trail use. Regulations restricting horse and ATV uses to designated trails are recommended. Study results show that trails accommodating higher impact uses must be more carefully designed, constructed and maintained to sustain use while protecting natural resources. Unacceptable levels of impact will likely occur if such uses occur on poorly designed or unmaintained trails. Restricting higher impact uses to graveled trails during wet seasons is also recommended. Trail use when soils are wet is considerably more damaging than when soils are dry. Educational programs, such as the national Leave No Trace program, provide excellent low impact trail use practices that can help trail users to avoid or reduce both resource and social impacts. The park should consider hosting Leave No Trace Master's and Trainer's courses to train an adequate cadre of park staff, outfitters and guides, and stakeholders from area recreation organizations. Courses specific to horse use, backpacking/camping and river use are available. A comprehensive array of educational materials has already been developed by this organization and can be adapted to address local needs. The 2004 online park newspaper includes a brief article covering numerous low impact horse riding practices. Field survey staff identified two topics as critical for special focus in educational programs. They cited off-trail horse traffic as a common problem responsible for substantial resource damage not reflected by this report. They also observed that there was evidence of horse use on every surveyed trail except the Honey Creek Loop.

Evaluate, Relocate, and Reconstruct Trails

The GMP identifies a proposed trail system with 396 miles of recreational trails, mostly comprised of existing woods roads and trails of varied origins and purposes. Some 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 not carefully planned and constructed to sustain high use, limit resource degradation, or fulfill recreation objectives. As shown by this survey, many of these proposed trails will require substantial relocations, reconstruction and maintenance work to bring them into standard so that they can support their intended uses while adequately protecting the park's natural resources.

In order to provide adequate resource protection, it is recommended that the park consider a two-tiered approach to the "opening" of the proposed trail system. An assessment could be made to open those proposed trails that are in substantial compliance with trail standards immediately upon acceptance of the GMP. Adequate resource protection can only be assured by temporarily closing those trails judged to be out of compliance with trail standards until reconstruction and maintenance work are completed to bring them into substantial compliance. Some of the proposed trails are highly degraded, may be unsafe, and their further use could result in long-term, possibly irreversible, impacts. A phased opening process is particularly a concern relative to the higher impacting types of uses, including the proposed 182 miles of horse trails. This is a substantial amount of mileage for the park's small maintenance staff to adequately develop and maintain. Permitting continued heavy traffic on these trails while waiting to complete such work will result in their continued degradation, particularly as additional traffic is added from the closure on non-designated trails. Some forms of trail impact, such as soil erosion from trails, are irreversible, and sedimentation of streams is possible.

Finally, in Chapter 5 of the GMP on Environmental Consequences, there is recognition that many trails do not presently meet accepted standards for facility design and location, especially those that traverse steep slopes from plateau to gorge bottom. Survey results support this conclusion (see below). Trails that can be rerouted to avoid steep trail grades and direct ascent alignments should be given a high priority for relocation. Addressing these problems through increased construction and maintenance on existing alignments are a less effective means for achieving sustainable low impact use on such trails. The number of these types of trails that cannot be rerouted due to descents through cliffs should be restricted to those that are absolutely essential, as these will require substantial initial and sustained investments to support heavy horse or motorized traffic while protecting natural resources.

Survey results identified several trail design factors that significantly influence trail degradation. These factors can help park managers in evaluating the relative resistance of individual trails, particularly for higher impacting uses. In particular, steeper grades and low trail slope alignment angles (e.g., less than 23^{o}) should be avoided, especially for trails receiving higher impact uses. Study results reveal these trails to be highly susceptible to both soil erosion and trail widening. Trails with low slope alignment angles and low slopes are also highly susceptible to muddiness. These types of trails located in valley bottom settings next to streams or rivers were also found to be highly eroded from river flooding. Each of these trail design alignment problems should be assessed and corrected through relocations as soon as is practical. Continued heavy use on such trails will continue to cause increasing amounts of resource degradation.

GMP trail standards specify a target grade for trails of 3-10%, with maximum grades of 18% for hiking trails for up to 25 ft, and maximum grades of 25% for up to 50 ft for horse trails. Our review of the literature suggests maximum grades of 10-12% for hiking trails and 9% for horse trails, and 8% for trails to which gravel is applied. Short maximum grade “exceptions” to these grades are acceptable for locations where no other alternatives are feasible but rockwork or other expensive forms of trail construction and greater maintenance and monitoring attention will be needed. Survey results indicate that approximately 25% of the trail system likely exceeds these recommended grades and are therefore highly susceptible to soil erosion. Trail sections that exceed recommended grades require rerouting (preferable) to achieve an acceptable grade or special tread reconstruction and maintenance treatments to harden and drain water from tread surfaces.

Current standards lack reference to trail slope alignments that employ “side-hill” design and construction. Figure 3 reveals the importance of this trail design attribute and regression analyses revealed trail slope alignment angle to be a more important predictor of soil loss than trail grade. Side-hill trails can always be easily drained while “direct-ascent” or “fall-line” trails cannot be drained (regardless of their grade) and flat-terrain trails are also problematic as they are susceptible to muddiness, tread widening, and trail braiding. Trail managers should give strong consideration to rerouting fall-line trails, particularly those with steeper grades. The design of new trails and relocations should employ side-hill alignments when possible.

Outsloping treads 5% (1 in. drop for every 18 in. of width) during construction allows water to drain across and off the tread, rather than accumulate and run down the trail to erode soil (Birchard & Proudman 2000, Hooper 1988, IMBA 2004). 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 a grade reversal, also known as Coweeta dips or rolling grade dips (Birchard & Proudman 2000, Hesselbarth & Vachowski 2000). These are constructed by reversing the trail's grade periodically to force all water off the tread (IMBA 2004). A principal advantage of this feature is that no future maintenance is required to ensure their continued effectiveness (in contrast to water bars). However, these must be planned during initial design and construction so that a descending trail's grade levels off and ascends briefly before resuming its descent. These features can be added to existing trails, particularly those with grades below 10-15%. 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. The spacing of these features depends on the trail's grade; recommended spacing is included in the adjacent text box.

Trail Grade	Spacing
3-5%	500 ft
7-10%	300 ft
11-15%	100 ft
>15%	<50 ft

Maintain Trails

Survey results revealed very few trail maintenance features along the park's trails. For example, only 59 of 827 sample points had a tread drainage feature within 75 feet in an uphill direction along the trail. The application of gravel to harden treads was also uncommon. However, analyses suggest that both these actions are effective measures for minimizing trail degradation. While some trails within the park are being actively managed and maintained the survey reveals that heavy use, particularly by horses, is occurring on many miles of trail that receives inadequate maintenance attention.

Building the necessary infrastructure required for the development and management of the proposed trail system will be a significant management challenge given federal budgeting constraints. Current funding and staffing levels appear to be inadequate to develop and manage the proposed trail system. A formal assessment of what resources are needed to complete the trail development and Annual Trail Management actions for the proposed trail system are underway. It is advisable to create a linkage between trail system management capabilities and trail system size; otherwise trail uses could continue to create substantial impacts to park resources.

Our research supports the GMP standards that specify the use of "hardened" surfaces for all horse trails except those receiving light use. Other protected areas have found that equestrian visitors have been accepting of graveled trails when limited in size to 73's (1 inch "crush-and-run" gravel), particularly after several years of compaction and mixing with existing soils and leaf litter. Gravel thicknesses range from 4 to 12 inches, with greater amounts applied to wetter soils. Use of geotextiles to separate and/or contain the gravel can reduce gravel thicknesses. Refer to Marion and Leung (2004) for additional guidance on maintenance options, including a comprehensive review of the best available trail maintenance references, including: Birchard & Proudman 2000, Hesselbarth & Vachowski 2000, and IMBA 2004.

The numerous stream crossings throughout BSF are a particular management challenge. Wooden bridges have been constructed for stream crossings on some trails but others are badly eroded, particularly those receiving heavy horse traffic. Trail erosion into streams is a substantial and continuing problem within the park, which has inadequate funding to bridge every stream crossing. Most horse trail bridges have planking along the edges to contain a bed of soil that covers the bridge deck. This is done to allow use by horses that shy away from travel across wood planking. Unfortunately water often drains to the bridges, contributing to tread muddiness and overflowing directly into streams during storms. All stream crossings by horse trails need to be carefully evaluated to identify the most effective method to minimize soil erosion from entering streams. These may include bridges, trail reroutes, tread hardening with rock, gravel, and/or geotextiles, enhanced drainage by tread outsloping or water bars, or other measures. This is an important issue that requires considerable management attention.

Trail Planning and Decision Making

In the past, NPS planning documents have embraced a carrying capacity approach with restrictions on visitation to control recreation-related resource impacts. However, management experience with numerically defined carrying capacities have met with mixed success (Hammitt and Cole 1998). Research has often shown that the amount of visitor use, while an influential determinant of change, can be less important than other factors, including environmental attributes (e.g., trampling resistance of vegetation or soils), use-related attributes (e.g., type of use and behavior of visitors), and managerial attributes (e.g., trail system design and maintenance) (Cole & Spildie 1998; Leung & Marion 2001). The findings of this research supports this statement. In response, new planning and management frameworks were developed and have largely replaced management approaches based on numerical carrying capacities (Marion, Cole, & Reynolds 1985). Two of the leading frameworks are *Limits of Acceptable Change* (LAC) (Stankey et al. 1985), adopted most widely by the U.S. Forest Service for Wilderness management, and *Visitor Experience and Resource Protection* (VERP), adopted by the National Park Service (NPS 1997). Figure 6 provides an illustration of these planning and decision-making frameworks.

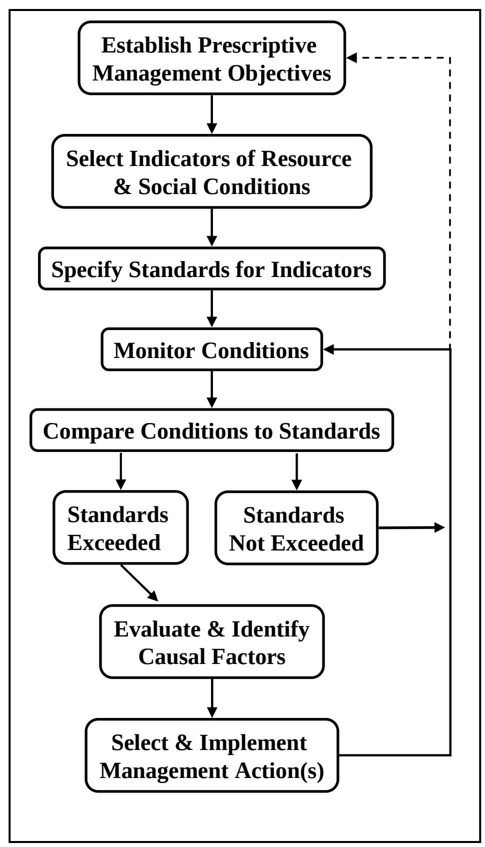


Figure 6. Schematic illustrating LAC and VERP planning and decision-making frameworks. Adapted from Marion 1991.

Under the LAC, VIM, and VERP frameworks, numerical standards can be set for various indicators in accordance with statements defining desired resource and social conditions, which may vary by management zone. These limits define the critical boundary line between acceptable and unacceptable conditions, establishing a measurable reference point to which future conditions can be compared. Visitor impact monitoring programs provide a critical element to these frameworks, furnishing information necessary to formulate realistic standards and to periodically evaluate resource or social conditions in relation to these standards. The NPS *Management Policies* requires management approaches that identify and monitor acceptable limits of change in backcountry settings. The new management-by-objectives approaches meet this requirement and establish a more defensible decision-making process for defining desired conditions, setting and evaluating standards of quality, and justifying appropriate and effective management actions. Implementation of a VERP framework for managing trail uses and conditions at BSF is strongly recommended. In the absence of such frameworks, management decisions are often more subjective and can permit a spiraling decline in resource and social conditions beyond acceptable levels.

Conclusion

A trail system that facilitates access to remote 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 research and report evaluated trail conditions at Big South Fork National River and Recreation Area, and documented many serious trail degradation problems. Hiking and mountain biking trails are currently in excellent condition, due in part to the low use most receive. However, horse and ATV trails were found to be highly degraded in many places. Of particular note are problems with trail erosion, including numerous locations where soils are finding their way into the parks streams and rivers.

Analyses of data point to several potential solutions to trail degradation. Some of the more effective means for sustaining use and reducing impact include closure of unmanaged and impact-susceptible trails, relocation and/or reconstruction of designated trails, increased tread hardening and maintenance work on designated trails, and where necessary, reduction or elimination of higher impacting forms of trail use on impact-susceptible alignments or during wet seasons. Most of these actions would require substantially enhanced funding and staffing for effective implementation.

Adoption of a VERP planning and decision-making framework to define and manage acceptable trails conditions is recommended. The products of this research provide the necessary baseline information for completing several of the VERP framework steps, including the selection of resource indicators and efficient and accurate methods for monitoring them, and insights into the selection of effective trail management actions.

References

Aust, Michael W., Jeffrey L. Marion and Kevin Kyle. 2005. Research for the Development of Best Management Practices for Minimizing Horse Trail Impacts on the Hoosier National Forest. Management Report. U.S. Department of Agriculture, U.S. Forest Service, Final Report, Bedford, IN 77 p.

Berry, K.H. 1980. The effects of four-wheel vehicles on biological resources. In: Andrews, R.N.L. and P. Nowak. 1980. Off-road Vehicle Use: A Management Challenge. USDA, Office of Environmental Quality, Washington, D.C.231-33.

Big South Fork National River and Recreation Area. 1997. Water Resources Management Plan. USDI National Park Service.

Birchard, W. and Proudman, R.D. 2000. Appalachian Trail Design, Construction, and Maintenance. (2nd Ed.). Harpers Ferry, WV: Appalachian Trail Conference.

Bratton, S.P., Hickler, M.G., and Graves, J.H. 1979. Trail erosion patterns in Great Smoky Mountains National Park. *Environmental Management* 3, 431-445.

Bryan, R.B. 1977. The influence of soil properties on degradation of mountain hiking trails at Grovelsjon. *Geografiska Annaler* 59A(1-2), 49-65.

Bury, R.B. 1980. What we know and do not know about off-road vehicle impacts on wildlife. In: Andrews, R.N.L. and P. Nowak. 1980. Off-road Vehicle Use: A Management Challenge. USDA Office of Environmental Quality, Washington, D.C. 110-22.

Cole, D.N. 1983. Assessing and monitoring backcountry trail conditions (Research Paper INT-303). Ogden, UT: USDA Forest Service, Intermountain Forest and Range Experiment Station.

Cole, D.N. 1988. Disturbance and recovery of trampled montane grassland and forests in Montana. Research Paper INT-389). Ogden, UT: USDA Forest Service, Intermountain Forest and Range Experiment Station.

Cole, D.N. 1991. Changes on trails in the Selway-Bitterroot Wilderness, Montana, 1978-1989 (Research Paper INT-212). Ogden, UT: USDA Forest Service, Intermountain Research Station.

Cole, D.N. and Spildie, D.R. 1998. Hiker, horse, and llama trampling effects on native vegetation in Montana, USA. *Journal of Environmental Management* 53, 61-71.

DeLuca, T.H., Patterson, W.A.I., Freimund, W.A. and Cole, D. 1998. Influence of llamas, horses, and hikers on soil erosion from established recreation trails in western Montana, USA. *Environmental Management* 22, 255-262.

Farrell, Tracy A. and Jeffrey L. Marion. 2002. Trail impacts and trail impact management related to ecotourism visitation at Torres del Paine National Park, Chile. *Leisure/Loisir: Journal of the Canadian Association for Leisure Studies* 26(1/2):31-59.

Fritz, J.D. 1993. Effects of trail-induced sediment loads on Great Smoky Mountains National Park high gradient trout streams. M.S. Thesis. Cookville, TN: Tennessee Technological University.

Geological Society of America. 1977. Impacts and management of off-road vehicles. Report of the Committee on Environmental and Public Policy. Boulder, CO, 8 pp.

Gersper, P.L. and Challinor, J.L.. 1975. Vehicle perturbation effects upon a tundra soil-plant system. In: Effects on Morphological and Physical Environmental Properties of the Soils. *Soil Sciences of the Society of America* 39(4):734-744.

Hammitt, W.E. and Cole, D.N. 1998. Wildland Recreation: Ecology and Management (2nd Ed.). New York: John Wiley and Sons.

Hellmund, P.C. 1998. Planning trails with wildlife in mind: A handbook for trail planners. Denver, CO: Colorado State Parks.

Hesselbarth, Woody and Vachowski, Brian. 2000. Trail Construction and Maintenance Notebook 2000 Edition. 0023 2839P. Missoula, MT: USDA Forest Service, Missoula Technology and Development Center.

Hill, R.R. and Kirby, F.L. 1948. Tread ruts lead to gullies. *Colorado Conservation* 10(7):11-12.

Hinckley, Bern S., Iverson, Richard M. and Hallet, Bernard. 1983. Accelerated water erosion in ORV-use areas. In: Environmental Effects of Off-Road Vehicles, pp. 81-96. Robert H. Webb and Howard G. Wilshire, (Editors). Springer Verlag New York Inc.: New York, NY.

IMBA, 2004. Trail Solutions: IMBA's Guide to Building Sweet Singletrack. The International Mountain Bicycling Association, Boulder, CO.

Jacob, G.R. and Schreyer, R. 1980. Conflict in outdoor recreation: A theoretical perspective. *Journal of Leisure Research* 12:368-380.

Kasworm, W.F. and Monley, T.L. 1990. Road and trail influences on grizzly bears and black bears in northwest Montana. In L. M. Darling, & W. R. Archibald (Eds.), Bears: Their Biology and Management: Proceedings of the 8th International Conference (pp. 79-84). Victoria, BC: International Association for Bear Research and Management.

Knight, Richard L. and Cole, David N. 1995. Wildlife responses to recreationists. In: Knight, Richard L. and Gutzwiller, Kevin J., eds. Wildlife and Recreationists: Coexistence Through Management and Research. Washington, DC: Island Press: 51-70.

Knight, R.L. and Cole, D.N. 1991. Effects of recreational activity on wildlife in wildlands. Transactions of the North American Wildlife and Natural Resource Conference, 56, 238-247.

Kockelman, William J. 1983. Management concepts. In: Environmental Effects of Off-Road Vehicles, pp. 399-446. Robert H. Webb and Howard G. Wilshire, (Editors). Springer Verlag New York Inc.: New York, NY.

Leung, Yu-Fai and Marion, Jeffrey L. 1996. Trail degradation as influenced by environmental factors: A state-of-the-knowledge review. *Journal of Soil & Water Conservation* 51(2):130-136.

Leung, Y.-F. and Marion, J.L. 1999a. Assessing trail conditions in protected areas: An application of a problem-assessment method in Great Smoky Mountains National Park, USA. *Environmental Conservation* 26, 270-279.

Leung, Y.-F. and Marion, J.L. 1999b. The influence of sampling interval on the accuracy of trail impact assessment. *Landscape and Urban Planning* 43, 167-179.

Leung, Yu-Fai and Marion, Jeffrey L. 2000. Recreation impacts and management in wilderness: A state-of-knowledge review. In: Cole, D.N. and others (eds.), Proceedings: Wilderness Science in a Time of Change; Vol 5: Wilderness ecosystems, threats, and management, pp. 23-48; May 23-27, 1999, Missoula, MT. Proceedings RMRS-P-15-Vol-5. Ogden, UT: USDA Forest Service, Rocky Mountain Research Station. (http://www.wilderness.net/pubs/science1999/volume5.htm)

Liddle, Michael J. 1997. Recreation ecology: The ecological impact of outdoor recreation and ecotourism. Chapman & Hall, London. 639 pp.

Liddle, M.J. and Greig-Smith, P. 1975. A survey of tracks and paths in a sand dune ecosystem, I. Soils. *Journal of Applied Ecology* 12, 893-908.

Marion, J.L. 1994. An assessment of trail conditions in Great Smoky Mountains National Park (Research/Resources Management Report). Atlanta, GA: USDI National Park Service, Southeast Region.

Marion, J.L. 1998. Recreation ecology research findings: Implications for wilderness and park managers. In H. Kirchner (Ed.), Proceedings of the National Outdoor Ethics Conference (pp. 188-196). Gaithersburg, MD: Izaak Walton League of America.

Marion, Jeffrey L. and Leung, Yu-Fai. 2001. Trail resource impacts and an examination of alternative assessment techniques. *Journal of Park and Recreation Administration* 19(1):17-37.

Marion, Jeffrey L. and Leung, Yu-Fai. 2004. Environmentally sustainable trail management. Book Chapter in Environmental Impact of Tourism, CABI Publishing, Inc.

Marion, Jeffrey L., Cole, David N. and Reynolds, David. 1985. Limits of acceptable change: A framework for assessing carrying capacity. *Park Science* 6(1):9-11.

Marion, Jeffrey L., Roggenbuck, Joseph W. and Manning, Robert E. 1993. Problems and Practices in Backcountry Recreation Management: A Survey of National Park Service Managers. Natural Resources Report NPS/NRVT/NRR-93/12. Denver, CO: USDI National Park Service, Natural Resources Publication Office. 64p.

McClaran, Mitchel P. 1989. Recreation pack stock management in Sequoia and Kings Canyon National Parks. *Rangelands* 11(1):3-8.

McQuaid-Cook, J. 1878. Effects of hikers and horses on mountain lakes. *Journal of Environmental*

Management 6:209-212.

Monti, P. and Mackintosh, E.E. 1979. Effect of camping on surface soil properties in the boreal forest region of northwestern Ontario, Canada. *Soil Science Society of America Journal* 43: 1024-1029.

Nagy, J.A. and Scotter, G.W.. 1974. A qualitative assessment of the effects of human and horse trampling on natural areas, Waterton Lakes National Park. Canadian Wildlife Service, Edmonton, AB. 145 pp.

National Park Service. 1997. The Visitor Experience and Resource Protection (VERP) framework: A handbook for planners and managers (Publication No. NPS D-1215). Denver, CO:USDI National Park Service, Denver Service Center.

National Park Service. 2001. Management Policies. USDI National Park Service, Washington, D.C.

Newsome, D., Phillips, N., Milewskii, A. and Annear, R. 2002. Effects of horse riding on National Parks and other natural ecosystems in Australia: Implications for management. *Journal of Ecotourism* 1(1): 52-74.

Reisinger, Thomas W. and Aust, Michael. 1990. Specialized equipment and techniques for logging wetlands. In: Presentation at the 1990 International Winter Meeting Sponsored by the American Society of Agricultural Engineers. Chicago, Illinois. American Society of Agricultural Engineers. Hyatt Regency Chicago. ASAE Paper 90-7570.

Rennison, D.C. and Wallace, A. 1976. The extent of acoustic influence of off-road vehicles in wilderness areas. Department of Mechanical Engineering, University of Adelaide, Adelaide, Australia, 19 pp.

Roggenbuck, J.W., Williams, D.R. and Watson, A.E. 1993. Defining acceptable conditions in wilderness. *Environmental Management* 17, 187-197.

Root, J.D. and Knapik, L.J. 1972. Trail Conditions along a portion of the Great Divide Trail Route, Alberta and British Columbia Rocky Mountains. Research Council of Alberta, Report No. 72-5, Edmonton, Canada.

Sheridan, David. 1979. Off-road vehicles on public land. United States Government Printing office. Council on Environmental Quality 041-011-00041-6. Washington, DC.

Shew, R.L., Saunders, P.R. and Ford, J.D. 1986. Wilderness managers' perceptions of recreational horse use in the Northwestern United States. In Proceedings of the National Wilderness Conference, Current Research (General Technical Report, INT-212, pp. 320-325). Fort Collins, CO: USDA Forest Service, Intermountain Research Station.

Snyder, C.T., Frickel, D.G., Hadley, R.F. and Miller, R.F. 1976. Effects of off-road vehicle use on the hydrology and landscape of arid environments in central and southern California. U.S. Geological Survey, Water Resources Investigations 76-99, 45 pp.

Stankey, G.H., Cole, D.N., Lucas, R.C., Petersen, M.E. and Frissell, S.S. 1985. The Limit of Acceptable Change (LAC) system for wilderness planning (General Technical Report INT-176). Ogden, UT: USDA Forest Service, Intermountain Research Station.

St. John-Sweeting, R.S. and Morris K.A. 1991. Seed transmission through the digestive tract of the horse. In: Plant Invasions The Incidence of Environmental Weeds in Australia. pp. 170-172. Kowari 2, Australian National Parks and Wildlife Service, Canberra.

Summer, R.M. 1980. Impact of horse traffic on trails in Rocky Mountain National Park. *Journal of Soil and Water Conservation 35* 85-87.

Summer, R.M. 1986. Geomorphic impacts of horse traffic on montane landforms. *Journal of Soil and Water Conservation* 42 126-128.

Sun, D. and Liddle, M.J. 1993. A survey of trampling effects of vegetation and soil in eight tropical and subtropical sites. *Environmental Management* 17, 497-510.

Teschner, D.P., DeWitt, G.M. and Lindsay, J.J. 1979. Hiking Impact on Boreal Forest Vegetation and Soils in Vermont's Northern Green Mountains. University of Vermont, Recreation Management Program, Research Note SNR-RM 6, Burlington, VT.

Thurston, Eden and Reader, Richard L. 2001. Impacts of experimentally applied mountain biking and hiking on vegetation and soil of a deciduous forest. *Environmental Management* 27(3):397-409.

Tyser, R.W. and Worley, C.A. 1992. Alien flora in grasslands adjacent to road and trail corridors in Glacier National Park, Montana (U.S.A.). *Conservation Biology* 6, 253-262.

Vaske, J.J., Donnelly, M.P. and Shelby, B. 1993. Establishing management standards: Selected examples of the normative approach. *Environmental Management* 17, 629-643.

Watson, Alan E., Niccolucci, Michael J. and Williams, Daniel R. 1993. Hikers and recreational stock users: predicting and managing recreation conflicts in three wilderness. Res. Pap. INT-468. Ogden, UT: USDA For. Serv., Intermountain Research Station 35p.

Weaver, Tad and Dale, Donn. 1978. Trampling effects of hikers, motorcycles and horses in meadows and forests. *Journal of Applied Ecology* 15(2):451-457.

Weaver, T., Dale, D. and Hartley, E. 1979. The relationship of trail condition to use, vegetation, user, slope, season and time. In R. Ittner, D. R. Potter, J. K. Agee, & S., Anschell (Eds.), Recreational Impact on Wildlands: Conference Proceedings (pp. 94-100). Seattle, WA: USDA Forest Service, Pacific Northwest Forest and Range Experiment Station and USDI National Park Service.

Webb, R.H., Ragland, H.C. and Jenkins, D. 1978. Environmental effects of soil property changes with off-road vehicle use. *Environmental Management* 2(3):219-233.

Welch, D.M. and Churchill, J. 1986. Hiking trail conditions in Pangnirtung Pass, 1984, Baffin Island, Canada. Parks Canada Report, Ottawa, Canada.

Whinam, J. and Comfort, M. 1996. The impact of commercial horse riding on sub-alpine environments at Cradle Mountain, Tasmania, Australia. *Journal of Environmental Management* 47, 61-70

Whittaker, P.L., and Bratton, S.P. 1978. Comparison of surface impact by hiking and horseback riding in the Great Smoky Mountains National Park (Research/Resource Management Report No. 24). Gatlinburg, TN: Great Smoky Mountains National Park, Uplands Field Research Laboratory.

Widner, Carolyn and Marion, Jeffrey L. 1993. Horse impacts: Research findings and their implications. Master Network, part 1 - 1993:No. 5 (pp. 5, 14); part 2 - 1994:No. 6 (pp. 5-6).

Wilson, J.P. and Seney, J.P. 1994. Erosional Impact of Hikers, Horses, Motorcycles and Off-road Bicycles on Mountain Trails in Montana. *Mountain Research and Development* 14(1): 77-88.

Appendix 1: Trail Survey Manual

Trail Monitoring Manual

Big South Fork National River & Recreation Area
Description of Procedures

This manual describes standardized procedures for conducting an assessment of resource conditions on recreation trails. The principal objective of these procedures is to document and monitor changes in trail conditions following construction. Their design relies on a sampling approach to characterize trail conditions from measurements taken at transects located every 500 feet (152 meters) along randomly selected trail segments. Distances are measured with a measuring wheel. Measurements are conducted at sample points to document the trail's width, depth, substrate, slope, alignment and other characteristics. These procedures take between 3 to 6 minutes to apply at each sample point. Data is summarized through statistical analyses to characterize resource conditions for each trail segment and for the entire trail system. During future assessments it is not necessary to relocate the same sample points for repeat measures. Survey work should be conducted during the middle or end of the primary use season during the growing season. Subsequent surveys should be conducted at approximately the same time of year.

Materials

This manual on waterproof paper
Field forms (both types) - some on waterproof paper
Clipboard w/compartment for forms
Measuring wheel
Topographic and driving maps
Tape measure (12ft)
Pencils
Tent stakes (2)
Clinometer
Compass
20 ft 1/16th inch braided nylon string with 12 beads (or twist-ties) attached
Random # table

Point Sampling Procedures

Trail Segments: During the description of amount and type of use (indicators 5 & 6 below) be sure that the use characteristics are relatively uniform over the entire trail segment. Most of the study trails have multiple uses, though uses are regulated on some trails. For example, a gate in the middle of a study segment restricting vehicle use beyond it or a sign prohibiting horse use, can substantially affect visitation and impact. Even when use types are not regulated the study trail may intersect with another route that diverts one of the user groups. In such instances where substantial changes in the type and/or amount of use occur, the trail should be split in two segments and assigned separate names and forms, upon which the differences in use can be described. This practice will facilitate subsequent statistical summaries and analyses.

Also collect and record any other information that is known about the trail's history, such as original construction, past uses, type and amount of maintenance, history of use, etc.

1) **Trail Segment Code:** Record a unique trail segment code (can be added later).

2) **Trail Name:** Record the trail segment name(s) and describe the segment begin and end points.

3) **Surveyors:** Record initials for the names of the rail survey crew.

1 - Developed by Dr. Jeff Marion, USDI, U.S. Geological Survey, Patuxent Wildlife Research Center, Virginia Tech/Dept. of Forestry, Blacksburg, VA 24061-0324 (540/231-6603) email: jmarion@vt.edu

4) **Date:** Record the date (mm/dd/yr) the trail was surveyed.

5) **Use Level (UL):** Record an estimate of the amount of use the trail receives, relative to all trails in the park, from the most knowledgeable park staff member: High, Medium, Low. Work with them to quantify these use levels on an annual basis (e.g., low use, < 100 users/wk for the 12 wk use season, < 30 users/wk for the 20 wk shoulder season, < 10 users/wk for the 20 wk off-season = < 2000 users/yr).

6) **Use Type (UT):** Record estimates for the types of use the trail receives (including any illegal uses) using percentages that sum to 100%. These should be provided by the most knowledgeable park staff member. Categories include: Hiking, Horseback, Vehicle, ATV, Bike, Wagon, Other (specify).

Starting/Ending Point: Record a brief description of the starting and ending point of the trail survey. Try to choose identifiable locations like intersections with other trails, roads, or permanent trailhead signs.

Measuring Wheel Procedures: At the trail segment starting point, use a random number table to select a random number from 0 to 500. Record this number on the first row of the form. This will be the first sample point, from which all subsequent sample points will be located in 500 foot intervals. This procedure ensures that all points along the trail segment have an equal opportunity of being selected. Once you get to the first sample point, reset the wheel counter and use it to stop at 500 foot intervals thereafter.

Push the measuring wheel along the middle of the tread so that it does not bounce or skip in rough terrain. Lift the wheel over logs and larger rocks, adding distance manually where necessary to account for horizontal distances. Your objective is to accurately measure the distance of the primary (most heavily used) trail tread. Monitor the wheel counter and stop every 500 feet to conduct the sampling point measures. If you go over this distance, you can back the wheel up to the correct distance. If the wheel doesn't allow you to take distance off the counter then stop immediately and conduct your sampling at that point, recording the actual distance from the wheel, not the "missed" distance.

If an indicator cannot be assessed, e.g., is "Not Applicable" code the data as -9, code missing data as -1.

Rejection of a sample point: Given the survey's objective there will be rare occasions when you may need to reject a sampling point due to the presence of boulders, tree falls, trail intersections, road-crossings, stream-crossings, bridges or other odd "uncharacteristic" situations. The data collected at sample points should be "representative" of the 250 foot sections of trail on either side of the sample point. Do not relocate a point to avoid longer or common sections of bog bridging, turnpiking, or other trail tread improvements. Use your judgment but be conservative when deciding to relocate a sample point. The point should be relocated by moving forward along the trail an additional 30 feet; this removes the bias of subjectively selecting a point. If the new point is still problematic then add another 30 feet, and so on.

7) **Distance:** In the first column record the measuring wheel distance in feet from the beginning of the trail segment to the sample point.

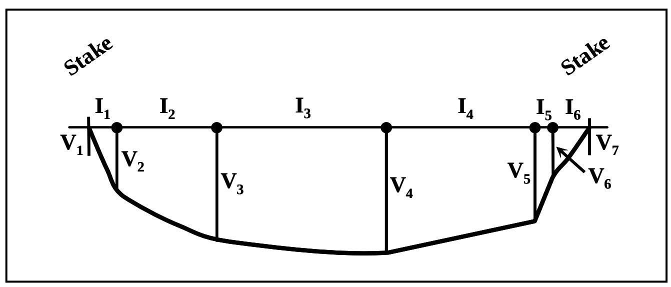
8) **Informal Trails (IT):** Sum and record your tallies of informal or "visitor-created" trails that intersected with the survey trail since the last sample point. Do not count formal trails or roads of any type, or extremely faint trails or trails that have been blocked off by managers. Informal trails are trails that visitors have created to access streams, scenic attraction features, camping areas, or other features, to cut switchbacks, go around mud-holes or downed trees, or that simply parallel the main trail. Count both ends of any informal trails longer than 20 feet that loop out and return to or parallel the survey trail. Include any distinct animal or game trails as these are often indistinguishable from human trails and their true origin is likely unknown. This indicator is intended to provide an approximation of the extensiveness of unofficial, visitor-created trails associated with survey trail.

9) **Secondary Treads (ST):** Count the number of trails that parallel the main tread at the sample point. Count all treads regardless of their length. *Do not count the main tread*.

10) **Tread Width (TW):** From the sample point, extend a line transect in both directions perpendicular to the trail tread. Identify the endpoints of this trail tread transect as the most pronounced outer boundary of visually obvious human disturbance created by trail use (not trail maintenance like vegetation clearing). These boundaries are defined as pronounced changes in ground vegetation height (trampled vs. untrampled), cover, composition, or, when vegetation cover is reduced or absent, as pronounced changes in organic litter (intact vs. pulverized) (see photo illustrations in Figure 1). The objective is to define the trail tread that receives the majority (>95%) of traffic, selecting the most visually obvious outer boundary that can be most consistently identified by you and future trail surveyors. Include any secondary treads (see #9) within the transect unless there are undisturbed areas between treads (as defined by the tread boundary definition). In this latter case, establish the transect and conduct measurements for the primary tread. Temporarily place tent stakes at the boundary points. Note: incision and cross-sectional area measures will be taken from this line so it should be unobstructed. If raised up by soil or litter then push down the obstructing materials. If pushed up substantially by rocks or roots then move the line forward along the trail in one foot increments until you reach a location where the line is unobstructed. Measure and record the length of the transect (the tread width) to the nearest inch (don't record feet and inches).

11) **Maximum Incision, Current Tread (MIC):** Stretch the nylon string tightly between the two tent stake pins that define the tread boundaries - any bowing in the middle will bias your measurements. Position the string so that it can be used as a datum to measure tread incision caused by soil erosion and/or compaction. Measure the maximum incision (nearest 1/4 inch: record .25, .5, .75) from the string to the deepest portion of the trail tread. Measure to the surface of the tread's substrate, not the tops of rocks or the surface of mud puddles. Your objective is to record a measure that reflects the maximum amount of soil loss along the transect within the tread boundaries. See Figure 2, noting differences in MIC measures for side-hill vs. non-side-hill trails.

12) **Cross-Sectional Area:** On the Cross Sectional Area form, record the distance from the measuring wheel. Record a 0 in the Area column and skip this procedure if the maximum incision is ≤1 inch. Otherwise complete the following:



- Starting at the left tread boundary, position beads (or twist ties) along the nylon string so that they are above tread surface locations that, if connected with straight lines, would accurately characterize the tread cross-section (see illustration above).

Vertical (in.)	Interval (in.)	Area (in.^{2})
V_1: 0	I_1: 5.0	21.3
V_2: 8.5	I_2: 12.5	146.9
V_3: 15.0	I_3: 20.0	360.0
V_4: 21.0	I_4: 16.5	272.3
V_5: 12.0	I_5: 2.5	21.9
V_6: 5.5	I_6: 5.0	13.8
V_7: 0	CSA:	836.0

- Measure and record the distance to each bead from the left stake. It's most efficient to record these distances in the field and calculate intervals (I_1 to I_n) with a spreadsheet. (Note: if measuring is done as you position the beads you may be able to place them at whole-inch intervals, otherwise record to the nearest half inch.)

- Measure (nearest 1/4 inch: record .25, .5, .75) each vertical transect from the line down to the tread surface (V1 to Vn) beginning with the left tent stake (V1 = 0) and ending with the other tent stake (Vn = 0).

- Compute and sum cross-sectional area with the following formula (use a spreadsheet): Area = $(V_i + V_{i+1})$ x I_i x .5 for each row and summed to compute CSA.

13-22) **Tread Condition Characteristics:** Along the trail tread width transect, estimate to the nearest 10% (5% where necessary) the aggregate lineal length occupied by any of the mutually exclusive tread surface categories listed below. **Be sure that your estimates sum to 100%**.

S-Soil:	All soil types including sand and organic soils, excluding organic litter unless it is highly pulverized and occurs in a thin layer or smaller patches over bare soil.
L-Litter:	Surface organic matter including intact or partially pulverized leaves, needles, or twigs that mostly or entirely cover the tread substrate.
V-Vegetation:	Live vegetative cover including herbs, grasses, mosses rooted within the tread boundaries. Ignore vegetation hanging in from the sides.
R-Rock:	Naturally-occurring rock (bedrock, boulders, rocks, cobble, or natural gravel). If rock or native gravel is embedded in the tread soil estimate the percentage of each and record separately.
M-Mud:	Seasonal or permanently wet and muddy soils that show imbedded foot or hoof prints from previous or current use (omit temporary mud created by a very recent rain). The objective is to include only transect segments that are frequently muddy enough to divert trail users around problem.
G-Gravel:	Human-placed (imported) gravel.
RT-Roots:	Exposed tree or shrub roots.
W-Water:	Portions of mud-holes with water or water from intercepted seeps or springs.
WO-Wood:	Human-placed wood (water bars, bog bridging, cribbing).
O-Other:	Specify.

23) **Trail Grade (TG):** The two field staff should position themselves at the sample point and 10 feet upslope along the trail. A clinometer is used to determine the grade (% slope) by sighting and aligning the horizontal line inside the clinometer with a spot on the opposite person at the same height as the first person's eyes. Note the percent grade (right-side scale in clinometer viewfinder) and record.

24) **Trail Alignment (TA):** Assess the trail's slope alignment angle to the prevailing land-form in the vicinity of the sample point. Use a compass and sight along the trail in the vicinity of the sample point, record the compass bearing on the left side of the column (it doesn't matter which direction along the trail you sight). Next face directly downslope, take and record another compass bearing (aspect). In the office compute the trail slope alignment angle as follows: 1) from the slope and trail alignment angles, calculate the smallest difference on the compass face and record (must be <180); 2) if less than 90, this is your correct trail alignment angle value. If >90 (and <180), subtract from 180 and record this value.

25) **Side-hill Construction (SH):** Was side-hill construction (cut-and-fill) work used to construct the trail at the sample point? Yes (Y), No (N), Unsure (U).

26) **Tread Drainage Feature (TD):** In 25-foot increments up to 75 feet, estimate the distance to any reasonably effective human-constructed tread drainage feature located in an up-slope trail direction from the sample point. Record a 100 if no features are present within 75 feet. Tread drainage features could include water bars (wood or rock), drainage dips, grade dips, etc. constructed to move water off the trail tread (do not consider tread out-sloping).

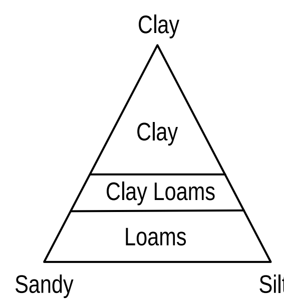
27) **<u>Water Drainage (WD):</u>** During a medium-sized rain storm, about how much of the water on the trail up-slope within 10 feet from the sample point would tend to flow **off** the tread: 1) 0%, 2) 25%, 3) 50%, 3) 75%, or 4) 100%. This could be due to a natural or human-constructed tread drainage feature or to tread out-sloping.

28) **<u>Trail Position (TP):</u>** Use the descriptions below to determine the trail position of the sampling point. Record the corresponding letter code in the TP column.
V - Valley Bottom: The transect is located within a flatter valley bottom setting within 60 vertical feet (three 20ft topo lines) from a stream or river.
R - Ridge Top: The transect is located within a flatter plateau or ridge-top position.
M - Midslope: All other mid-slope positions.

29) **<u>Soil Texture (TX):</u>** Follow the field method described by Foth (1990) to determine the soil texture of the soils in the vicinity of the sample point. Soil texture should not vary substantially along most trails. This assessment should be done at the start of the trail (have some water to use and rinse your hands with). Check the texture without wetting at the sample points and repeat the full method if it appears to have changed.

a) Moisten a sample of soil the size of a golf ball and work it until it's uniformly moist; squeeze it out between the thumb and forefinger to try to form a ribbon.

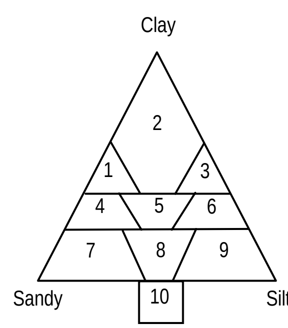
b) First Decision: If the moist soil is:
* Extremely sticky and stiff, it is a clay.
* Sticky and stiff to squeeze, it is a clay loam.
* Soft, easy to squeeze, and only slightly sticky, it is a loam.



c) Second decision: Add an adjective to refine the description.
If the soil feels:
* Very smooth, it is silt or silty (# 3, 6, or 9).
* Somewhat gritty, use no adjective (#2, 5, or 8).
* Very, very gritty, it is sandy (# 1, 4, or 7).

d) Combine your (b) and (c) determinations to identify and record the proper classification on the form:

1 - sandy clay	6 - silty clay loam
2 - clay	7 - sandy loam
3 - silty clay	8 - loam
4 - sandy clay loam	9 - silt loam
5 - clay loam	10 - organic soil



Collect all equipment and move on to the next sample point. **Be sure to count and tally informal trails and record information on indicators 30 - 32 as you proceed to the next sample point.** These indicators are assessed continuously as pre-defined trail tread problems and when found, surveyors record begin and end distances (from the start of the survey) on the Problem Assessment Form. **Note: after data entry and before analysis the data for these indicators need to be corrected to add in the 1st randomly selected interval distance so that location data is accurate. In particular, examine any indicators that may begin before and end after the first sample point.**

30) **Muddy Soil (MS):** Sections of tread (≥10 ft) with seasonal or permanently wet and muddy soils that show imbedded foot or hoof prints (≥½ inch). Omit temporary muddiness created by a recent rain. This should generally include any longer mud-holes or treads with running water. The objective is to include only tread segments that are frequently wet or muddy enough to divert trail users around the problem, often leading to an expansion of trail width.

31) **Soil Erosion (SE):** Sections of tread (≥10 ft) with soil erosion exceeding 5 inches in depth within current tread boundaries.

32) **Running Water (RW):** Section of tread (≥10 ft) with running water flowing on the tread, generally from intercepted springs or seeps.

Point Sampling Form

Trail Segment Code ________ **Trail Name** ____ **Surveyors**
Date __________ **Use Level** _______ **Use Type(s):** Horse% Hiker% Vehicle% ATV% Bike% Wagon%
Starting/Ending Point:

Dist	IT	ST	TW	MIC	Tread Substrate Characteristics	TG	TA	SH	TD	WD	TP	TX
							/					
							/					
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					0 10 20 30 40 50 60 70 80 90 100							

Dist = Wheel Distance
IT=Informal Trails
ST=Secondary Treads
TW=Tread Width
MIC=Max. Incision, Current Tread

S=Soil
L=Litter
V=Vegetation
R=Rock
M=Mud

G=Gravel
RT=Roots
W=Water
WO=Wood, human placed
O=Other (Specify)

TG=Trail Grade
TA=Alignment (Trail° / Landform°)
SH=Side-Hill construction (Y, N, U)
TD=Tread Drainage feature (25, 50, 75, or 100)
WD=Water Drainage (0%, 25%, 50%, 75%, 100%)
TP=Trail Posit. (Valley=V, Mid-slope=M, Ridge-top=R)
TX=Soil Texture (1-10)

Trail Segment Code ________ **Trail Name** ____________________________________

Problem Assessment Form

Cross Sectional Area Form

Muddy Soil		Soil Erosion		Running Water		Cross Sectional Area			Cross Sectional Area		
Begin Dist	End Dist	Begin Dist	End Dist	Begin Dist	End Dist	Vertical (in)	Inter-val (in)	Area	Vertical (in)	Inter-val (in)	Area

Figure 1. Photographs illustrating different types of boundary determinations. Trail tread boundaries are defined as the most pronounced outer boundary of visually obvious human disturbance created by trail use (not trail maintenance like vegetation clearing). These boundaries are defined as pronounced changes in ground vegetation height (trampled vs. untrampled), cover, composition, or, when vegetation cover is reduced or absent, as pronounced changes in organic litter (intact vs. pulverized). The objective is to define the trail tread that receives the majority (>80%) of traffic, selecting the most visually obvious boundary that can be most consistently identified by you and future trail surveyors.

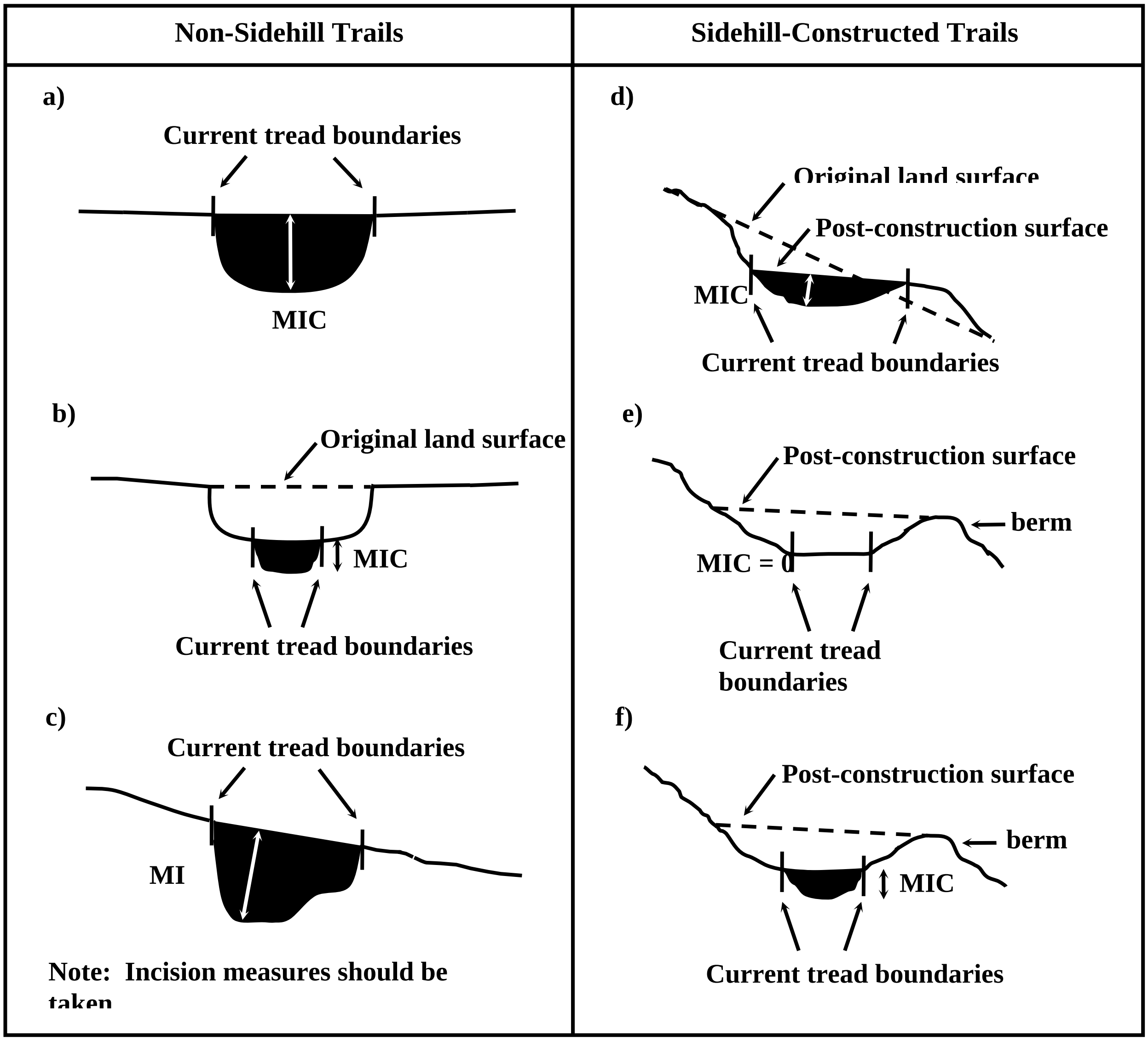

Figure 2. Diagrams illustrating alternative tread incision measurements in terrain where cut and fill work was not performed during tread construction (a-c) and in terrain where sidehill construction involved the excavation of substrate to create a tread surface (d-f).

Appendix 2: Individual Trail Summaries

Trail Name: Big Island Loop
Length: 26,248 ft (4.49 mi) **Use Level:** High
Use Type: Horse (95%), Bike (5%)

This 4.49 mile southern section of the Big Island Loop Trail provides a route from Big Island Road (ridge area) down the gorge walls to reach Station Camp Road as it nears the river. It is used heavily by horses and by bicycles on rare occasion. The trail is generally poorly designed and maintained, in particular, trail grade is often excessive. There is a notable lack of functional tread drainage features throughout the entire section. Much of the trail serves as a conduit for soil and water transportation toward the river. Active erosion was evident in gullied portions. Foot travel is very difficult and dangerous in extremely muddy areas.

This heavily used horse trail was quite variable in width (28 to 147 inches) with a mean of 69. Mean incision (2.7 in) and cross sectional area (106 in^2) measures were less than the average horse trail, yet more than the average of all trails combined. Some points revealed severe erosion, particularly in the elbows of tight switchbacks on the steepest portions. Trail grades ranged up to 32% with a mean of 9%. Tread substrates were predominately exposed soil, though substantial amounts of gravel, organic litter, and muddy soil were also present. Muddiness was a frequent problem in the lower sections approaching Station Camp Road in locations where the trail intercepted mid-slope seeps. Field staff members found foot travel in the lower muddy areas very difficult and unsafe. The problem assessment data revealed 42 occurrences of muddy soil affecting 2048 ft (8%) of the trail's length. Sections of excessive erosion were also common, with 34 occurrences affecting 5% of the trail segment.

Summary/Recommendations: Findings suggest problems are linked with excessive grade in the mid-slope section of the trail, and poor tread drainage in most areas. Aggressive installation of water drainage features and rehabilitative actions at severe erosion points and lower-section muddy areas could dramatically increase recreational and natural values. A preferred response is relocation from steep switchbacks and seeping water sources to more gradual side-hill switchbacks and locations with less seepage.

Point Sampling Indicator	**Mean**	**Median**	**Range**
Tread Width (in)	69	73	28 – 147
Maximum Incision (in)	2.7	2.0	0.0 – 14.8
Cross Sectional Area (in^2)	106	69	0 – 100
Trail Grade	9	8	0 – 32
Tread Substrate (%)			
Vegetation Cover	1.4	0	0 – 10
Organic Litter	17.4	10	0 – 80
Exposed Soil	43.8	40	0 – 100
Rock	3.6	0	0 – 100
Muddy Soil	13.5	0	0 – 100
Water	0.3	0	0 – 15
Gravel	20.1	0	0 – 95

Problem Assessment Indicator	**Occurrences**		**Lineal Distance**		
	(#)	**(#/mi)**	**(ft)**	**(ft/mi)**	**(%)**
Excessive Muddiness	42	8.5	2048	415	8
Excessive Erosion	34	6.9	1178	239	5
Informal Trails	6	1.2			
Secondary Trails	0	0			

Trail Name: Blue Heron Loop Trail
Length: 32,132 ft (6.08 mi) **Use Level:** High
Use Type: Hiking (100%)

The 6.08 mile Blue Heron Loop Trail provides riparian access to the Big South Fork River, then climbs out of the gorge to a ridgeline contour, and returns low through the paved Coal Tipple Interpretive Walk. While near the river, many visitor-created informal trails branch to provide access for hiking, fishing, boating, and camping. This is exclusively a hiking trail, excluding a 731 foot horse/hike segment. The final paved portion was not measured. The tread is generally well designed, avoiding steep climbs in all but a few areas. Steep short informal trails leading directly to the river revealed considerable erosion impacts. Failure to remove blow-downs on the ridge has lead to excessive tread widening. A noted maintenance feature is stone step work ascending at the end of the horse section, which clearly defines the use boundary. Additionally, some water bars exist, but most were clogged with debris and judged ineffective.

This heavily used hiking trail was quite uniform in width (mean of 32 in), with outlying cases only along an old stretch of road bed that also accommodated horses. Mean incision (.8 in) and cross sectional area (18 in^2) measures were consistent with the average hiker trail. Trail grades ranged up to 45% with a mean of 8.1%. Despite some excessive grades, steepness did not appear to be a degrading factor. Tread substrates were predominately organic litter. Muddiness and erosion was not a frequent problem, but the formation of visitor-created informal trails was widespread where the path paralleled the river. There were 34 such trails (5.6 per mile), most of which were created to provide river access.

Summary/Recommendations: Findings reveal that the designated portion of the trail is in good condition. However, the condition of informal trails leading to the river were observed by field staff to be considerably more impacted than the main tread. The construction of a few durable river access side trails to concentrate visitor impacts are recommended, along with closure and rehabilitation of remaining informal trails. Since these impacts result from visitor behavior, educational signs placed at the trailhead targeting off-trail travel (e.g., Leave No Trace) can highlight the sensitivity of riparian soils and encourage use of only designated trails.

Point Sampling Indicator	**Mean**		**Median**	**Range**	
Tread Width (in)	32		25	12 – 135	
Maximum Incision (in)	.8		.5	0.0 – 7.5	
Cross Sectional Area (in^2)	18		0	0 – 445	
Trail Grade	8.1		6	0 – 45	
Tread Substrate (%)					
Vegetation Cover	5.9		0	0 – 100	
Organic Litter	61.3		75	0 – 100	
Exposed Soil	26		15	0 – 95	
Rock	4		0	0 – 60	
Exposed Roots	1.2		0	0 – 30	
Gravel	1.5		0	0 – 100	
Problem Assessment Indicator	**Occurrences**		**Lineal Distance**		
	(#)	**(#/mi)**	**(ft)**	**(ft/mi)**	**(%)**
Excessive Muddiness	6	.99	425	70	.01
Excessive Erosion	3	.5	140	23.03	.4
Informal Trails	34	5.6			
Secondary Trails	1	.2			

Trail Name: Collier Ridge Loop
Length: 28,000 ft (5.3 mi) **Use Level:** High
Use Type: Hiking (50%), Bike (50%)

This 5.3 mile Collier Ridge Loop section follows forested ridgeline around the Bandy Creek drainage. It receives approximately half hike and half bike use.

Trail design is good. Grade is kept to a minimum by trail location and appropriate switchbacks. The trail was relatively clear of blow-downs. A lack of trail drainage features was noted near the few yet extensive muddy areas. A bridgeless stream crossing revealed eminent soil deposition. The loop receives routine maintenance from a local bike club.

This high use hiking and biking trail was fairly uniform in width (15 to 77 inches) with a mean of 29. Mean incision (1.2 in) and cross sectional area (13 in^2) measures were some of the lowest measures in the entire survey. Tread substrates were predominately organic litter. The problem assessment data revealed 14 occurrences of muddy soil affecting 712 ft (2.5%) of the trail's length. Excessive erosion was rare.

Summary/Recommendations: Findings suggest muddiness is the primary concern. Installment of water drainage features such as water bars or minor relocations in muddy areas could provide simple solutions. A small foot/bike bridge would limit active erosion on the stream crossing near the western end.

Point Sampling Indicator	Mean	Median	Range
Tread Width (in)	29	25	15 – 77
Maximum Incision (in)	1.2	.8	0.0 – 7.5
Cross Sectional Area (in^2)	13	0	0 – 110
Trail Grade	6.8	5	0 – 36
Tread Substrate (%)			
Vegetation Cover	5.7	0	0 – 95
Organic Litter	62.8	90	0 – 100
Exposed Soil	24.2	5	0 – 95
Rock	2.5	0	0 – 90
Muddy Soil	1.2	0	0 – 0
Water	2.7	0	0 – 85
Exposed Roots	.2	0	0 – 10
Gravel	.7	0	0 – 40

Problem Assessment Indicator	Occurrences		Lineal Distance		
	(#)	(#/mi)	(ft)	(ft/mi)	(%)
Excessive Muddiness	14	2.6	712	134	2.5
Excessive Erosion	4	.8	142	27	.5
Informal Trails	4	.8			
Secondary Trails	1	.2			

Trail Name: Grand Gap Loop
Length: 28,161 ft (5.33 mi) **Use Level:** High
Use Type: Hiking (100%)

This 5.33 mile section of the Grand Gap Loop follows ridgeline as it provides access to the western gorge rim -including outstanding views of the gorge and the river below- and the Angel Falls Overlook. It also serves as a connector for the riverside John Muir Trail. Hiking is its primary use.

The Grand Gap Loop is an excellent trail design. The trail's location on a gently sloping ridge and its local congruency with landform contours make it a highly durable footpath. It was relatively free of blow-downs. It was devoid of tread drainage features, but did not seem to need them.

This high use hiking trail was slightly variable in width (16 to 66 inches) with a mean of 26. Mean incision (.6 in) and cross sectional area (4 in^2) were among the lowest of all surveyed trails. Tread substrates were predominately organic litter (69.4 %). The problem assessment data revealed zero occurrences of excessive muddiness or erosion. There were a total of 19 informal trails, most leading to campsites or scenic vistas.

Summary/Recommendations: Findings suggest little maintenance action is needed on the trail. One recommendation, however, is to educate nearby horse trail users of use designations on Grand Gap Loop, as field staff noted the presence of horse use (hoof prints, manure) but assumed the markings as recent and uncommon.

Point Sampling Indicator	**Mean**		**Median**		**Range**
Tread Width (in)	26		23		16 – 66
Maximum Incision (in)	.6		.5		0.0 – 2.0
Cross Sectional Area (in^2)	4		0		0 – 66
Trail Grade	6		7		0 – 15
Tread Substrate (%)					
Vegetation Cover	2		0		0 – 50
Organic Litter	69.4		80		0 – 100
Exposed Soil	26		10		0 – 80
Rock	2.1		0		0 – 30
Exposed Roots	.4		0		0 – 30
Gravel	0		0		0 – 100
Problem Assessment Indicator	**Occurrences**		**Lineal Distance**		
	(#)	**(#/mi)**	**(ft)**	**(ft/mi)**	**(%)**
Excessive Muddiness	0	0	0	0	0
Excessive Erosion	0	0	0	0	0
Informal Trails	19	3.6			
Secondary Trails	0	0			

Trail Name: Grassy Knob Area
Length: 12,882 ft (2.44 mi) **Use Level:** Medium
Use Type: ATV (100%)

This 2.44 mile southern section of the Grassy Knob Area trail provides ridge access to a prominent peninsula east of the Clear Fork and west of the New River. The trail ends south of the nearby confluence, which spawns the Big South Fork River. The southernmost portion of the path has historically provided access to an adjacent oil well. At the time of this study, the entire path was identified to receive, exclusively, ATV use. Trail design is extremely poor. It climbs a steep direct ascent route to the ridge, where it follows a dirt road along the top. The trail rarely follows landform contours and there were no signs of maintenance, such as water drainage features.

This medium use ATV trail was widely variable in width (67-249 inches) with a mean of 104. Mean incision (3.4 in) and cross sectional area (222 in^2; highest in survey) measures were similar to other ATV trails, yet much higher than the average of all trails combined. Some points revealed severe erosion (up to 1302 in^2), particularly the at the beginning where it overlaps a closed service road to the oil rig. Trail grades ranged up to 20% with a mean of 5.5%. Tread substrates were predominately exposed soil, though substantial amounts of organic litter and vegetation (mostly between tire ruts) were also present. Muddiness was a frequent problem in locations where the trail cut deeply into the ridgeline and a complete lack of tread drainage was revealed by deep stagnant puddles. Field staff found these areas difficult and unsafe for foot travel. The problem assessment data revealed 29 occurrences of muddy soil affecting 1131 ft (8.8%) of the trail's length. Sections of excessive erosion were also common, with 29 occurrences affecting 2321 (18%) of the trail segment.

Summary/Recommendations: Findings suggest problems are linked with excessive grade in the mid-slope section of the trail, and poor tread drainage in the flatter ridgeline areas. This trail requires official designation and heavy maintenance or closure. Until this trail can be managed properly to sustain ATV use, such use should be limited or restricted to limit further degradation of Park resources.

Point Sampling Indicator	**Mean**		**Median**		**Range**
Tread Width (in)	104		91		67 – 249
Maximum Incision (in)	3.4		3.0		0.5 – 8.5
Cross Sectional Area (in^2)	222		167		0 – 1302
Trail Grade	5.5		4		0 – 20
Tread Substrate (%)					
Vegetation Cover	17.7		10		0 – 90
Organic Litter	29.8		20		10 – 75
Exposed Soil	42.9		50		0 – 80
Rock	5.2		0		0 – 80
Muddy Soil	2.9		0		0 – 60
Water	.8		0		0 – 10
Gravel	.8		0		0 – 20
Problem Assessment Indicator	**Occurrences**		**Lineal Distance**		
	(#)	**(#/mi)**	**(ft)**	**(ft/mi)**	**(%)**
Excessive Muddiness	29	11.9	1131	464	8.8
Excessive Erosion	29	11.9	2321	951	18
Informal Trails	10	4.1			
Secondary Trails	0	0			

Trail Name: Hicks Ridge Road (aka Montgomery or Buddy Rd)
Length: 9803 ft (1.86 mi) **Use Level:** High
Use Type: Horse (50%), ATV (50%)

The 1.86 mile Hicks Ridge Road trail segment crosses the western arm of BISO, linking road 297 and Darrow Ridge road. From north to south, it undulates irregularly before descending into the head of the Laurel Fork Creek canyon, crosses the riparian zone, and ascends back to a low ridge to the NPS boundary. The path provides access to unique geologic features, such as a large rock den. Use types were identified as 50% horse and 50% ATV.

Trail design is very poor. Trail grade is excessive, especially in the riparian zone where soil deposition is evident. Tread surface water drainage suffers from a consistent incision and no drainage features. Excessive tread width has been caused in places by user circumvention around collapsed or otherwise unusable portions of trail. This trail is undesignated, and receives no maintenance.

This heavily used horse and ATV trail was quite variable in width (34 to 129 inches) with a mean of 62. Mean incision (3.9 in) and cross sectional area (118 in^2) measures were less than the average horse trail, yet more than the average of all trails combined. Some points revealed severe erosion (up to 503 in^2), particularly in the rolling hills which crossed several drainages. Trail grades ranged from 2 to 32% with a mean of 6.6%. Tread substrates were predominately exposed soil. The problem assessment data revealed 10 occurrences of muddy soil affecting 386 ft (3.9%) of the trail's length. Sections of excessive erosion were frequent and widespread, with 32 occurrences affecting 2778 (28.3%) of the trail.

Summary/Recommendations: Findings suggest problems are linked with excessive grade, poor tread drainage, and heavy use. Since almost a third of the trail revealed excessive erosion, water drainage must be improved through maintenance features. Maintenance options verses closure and relocation alternatives are preferred since the trail seemed to be located in a potentially sustainable plateau area. Alternative actions include limiting the amount of ATV use.

Point Sampling Indicator	**Mean**	**Median**	**Range**
Tread Width (in)	62	57	34 – 129
Maximum Incision (in)	3.9	2.6	1.0 – 12.5
Cross Sectional Area (in^2)	118	77	0 – 503
Trail Grade	6.6	6	2 – 16
Tread Substrate (%)			
Vegetation Cover	7.5	5	0 – 50
Organic Litter	25.3	27.5	0 – 50
Exposed Soil	58	60	0 – 90
Rock	6.3	0	0 – 90
Exposed Roots	1	0	0 – 10
Gravel	1.5	0	0 – 30

Problem Assessment Indicator	**Occurrences**		**Lineal Distance**		
	(#)	**(#/mi)**	**(ft)**	**(ft/mi)**	**(%)**
Excessive Muddiness	10	5.4	386	208	3.9
Excessive Erosion	32	17.2	2778	1494	28.3
Informal Trails	12	6.5			
Secondary Trails	0	0			

Trail Name: Honey Creek Loop
Length: 10,755 ft (2.04 mi) **Use Level:** High
Use Type: Hiking (100%)

This 2.04 mile section of the Honey Creek Loop provides the foot traveler a unique wilderness experience. For many years it has been managed as wilderness while most other areas of park are recovering from extensive logging and/or mining activities. Exemplary natural resources, such as Echo Rock, old growth trees, and waterfalls exist. It provides access both to Honey Creek Overlook and Big South Fork. Beginning at the Honey Creek trailhead it descends east gradually to the Big South Fork riparian zone. Next, it climbs directly through the Honey Creek drainage until reaching the proposed extension of the John Muir Trail, where this section ends. Hiking is the primary use.

Trail design is unorthodox and average. The slope is quite steep, generally, but little impacts seem to result given the use type. One section follows a wet, rocky creek bed with no single route. A lack of tread drainage features on steep sections raise concern with continued or increasing use levels. The trail was clear of blow-downs. The trail offers much in scenic and historic quality without sacrificing environmental integrity.

This heavily used hiking trail was quite uniform around the tread width mean (26 in), ranging from 14 -72 inches. Mean incision (1 in) and cross sectional area (22 in^2) measures were consistent with the average hiker trail, substantially less than the average of all trails combined. Trail grades ranged up to 40% with a mean of 15.7%. Despite regularly excessive grades, steepness did not appear to be a major degrading factor. Tread substrates were predominately organic litter. Muddiness and erosion was not a frequent problem, but the formation of visitor-created informal trails was widespread where the path approached the river and several campsites. Some of these informal trails were extremely steep and moderately impacted near the closest point to the river and a series of campsites in that area. There were 22 such trails (10.8 per mile).

Summary/Recommendations: Findings suggest the trail is in good condition. However, the condition of informal trails leading to the river and campsites are suspect. Since these impacts are effects of user behavior, visitor education signs placed at the trailhead targeting off-trail travel (such as Leave No Trace) which highlight the sensitivity of steep and riparian soils could mitigate the problem.

Point Sampling Indicator	**Mean**	**Median**	**Range**
Tread Width (in)	26	24	14 – 72
Maximum Incision (in)	1	.5	0.0 – 9.0
Cross Sectional Area (in^2)	22	0	0 – 347
Trail Grade	15.7	15	0 – 40
Tread Substrate (%)			
Vegetation Cover	8.4	7.5	0 – 25
Organic Litter	54.3	55	0 – 100
Exposed Soil	17.3	10	0 – 50
Rock	15.7	0	0 – 95
Exposed Roots	4.3	0	0 – 20

Problem Assessment Indicator	**Occurrences**		**Lineal Distance**		
	(#)	**(#/mi)**	**(ft)**	**(ft/mi)**	**(%)**
Excessive Muddiness	3	1.47	41	20	.4
Excessive Erosion	15	7.4	442	216.7	4.1
Informal Trails	22	10.8			

Trail Name: John Muir Trail (Segment C)
Length: 14,966 ft (2.83 mi) **Use Level:** High
Use Type: Hiking (100%)

This 2.83 John Muir Trail (Segment C) is the western half of the Honey Creek Trail described above. Besides acting as a loop for the Honey Creek Loop Trail, it is a key link in the uncompleted John Muir Trail, which is proposed to extend from the north end of this trail and connect with JMT Segment D. The path gives users a one-way path back to the Honey Creek Loop along Honey Creek and tributary. Large rock domes along the trail offer a unique geologic experience. It is primarily a hiking trail.

Trail design is average. Much of this section generally follows the creek bed, allowing the user to choose his path. However, a clearly defined foot trail is present in many locations. Appropriate blazes mark the way. Several steep areas exist without needed drainage features.

This heavily used hiking trail was quite steady around the tread width mean (32 in). Mean incision (1.3 in) and cross sectional area (25 in^2) measures were consistent with the average hiker trail. Trail grades ranged from 1 to 48% with a mean of 14%. Excessive grades appeared to be a major contributing factor to some isolated erosion problems. Tread substrates were predominately organic litter. Muddiness was not a frequent problem, but 21 erosion problems covered 723 feet of the trail (4.8%). The formation of visitor-created informal trails were found where the path paralleled Honey Creek. There were 13 such trails (4.6 per mile), which is less than most other hiking trails.

Summary/Recommendations: Findings suggest the designated portion of the trail is in good shape. Isolated occurrences of steep trail grades should be further examined to decide whether the installation of tread maintenance features or small relocations would be more appropriate.

Point Sampling Indicator	**Mean**	**Median**	**Range**
Tread Width (in)	32	27	17 – 81
Maximum Incision (in)	1.3	.6	0.0 – 5.5
Cross Sectional Area (in^2)	25	0	0 – 240
Trail Grade	14	10.5	1 – 48
Tread Substrate (%)			
Vegetation Cover	1.7	0	0 – 30
Organic Litter	68.2	70	0 – 100
Exposed Soil	14.7	0	0 – 95
Rock	13.5	0	0 – 100
Exposed Roots	2	0	0 – 20
Gravel	0	0	0 – 0

Problem Assessment Indicator	**Occurrences (#)**	**(#/mi)**	**Lineal Distance (ft)**	**(ft/mi)**	**(%)**
Excessive Muddiness	4	1.4	146	52	1
Excessive Erosion	21	7.4	723	255	4.8
Informal Trails	13	4.6			
Secondary Trails	0	0			

Trail Name: John Muir Trail (Segment D)
Length: 11,800 ft (2.23 mi) **Use Level:** High
Use Type: Hiking (100%)

This popular 2.33 mile John Muir Trail (Segment D) offers riverside access from the Leatherhead Ford parking area, and connects south with the O & W Bridge area. It is a scenic walk with an easy grade. Informal trails along the way provide access to the river, campsites, and sandstone rock formations.

Trail design is average. It generally follows an old riverside road bed on a low grade, yet rises around rock outcroppings. One draw back is that its consistent proximity to the river allows the creation of many informal trails, which suffer extensively from erosion and are not maintained. It contrasts sharply with other riparian roadbeds due to maintenance actions and use type. Boxed gravel tracts provide a durable surface and drainage, and are appropriate given the proximity to the popular parking area. A lack of attention to informal trails raises concern about peripheral impacts. Tread width is excessive due to the prominence of the old road bed width.

This very high use hiking trail was quite variable around the mean width of58 in, ranging from 16 -102 inches, because the trail follows and old road bed in varying stages of rehabilitation. Mean incision (1.6 in) and cross sectional area (52 in^2) measures were higher than the average hiker trail. Trail grades ranged up to 25% with a mean of 6%. Tread substrates varied, as the north side of the path from the parking area was graveled (7.1 %), and the rest was rock (12.3), exposed soil (39.4), and organic litter (38.8). Muddiness and erosion was not a frequent problem, and informal trails were well managed.

Summary/Recommendations: Findings suggest the designated portion of the trail is in good condition. Furthermore, the application of management actions were appropriate and successful, especially when compared to the Blue Heron Loop Trail, in regards to management of informal trails (some informal trails were discretely blocked using natural barricades). Also, placement of gravel near the highest use area was effective in distinguishing tread boundaries and preventing soil loss, and it faded away as did the need for it as the trail continued into less traveled area. As an extension from the parking lot, gravel use was both appropriate and effective.

Point Sampling Indicator	**Mean**	**Median**	**Range**
Tread Width (in)	58	61	16 – 102
Maximum Incision (in)	1.6	1	0.0 – 9.5
Cross Sectional Area (in^2)	52	0	0 – 510
Trail Grade	6	4	0 – 25
Tread Substrate (%)			
Vegetation Cover	2.5	0	0 – 25
Organic Litter	38.8	25	0 – 100
Exposed Soil	39.4	20	0 – 90
Rock	12.3	0	0 – 75
Exposed Roots	0	0	0 – 30
Gravel	7.1	0	0 – 90

Problem Assessment Indicator	**Occurrences**		**Lineal Distance**		
	(#)	**(#/mi)**	**(ft)**	**(ft/mi)**	**(%)**
Excessive Muddiness	1	.5	34	15	.3
Excessive Erosion	3	1.4	106	48	.9
Informal Trails	2	.9			

Trail Name: John Muir Trail (Segment I)
Length: 14,952 ft (2.83 mi) **Use Level:** High
Use Type: Horse (70%), Hiking (30%)

This 2.83 mile John Muir Trail (Segment I) parallels the River Trail West along the Big South Fork. It links the JMT from Station Camp Crossing to Big Branch Creek. It is intended to provide hiking access to the riparian area. The use types are horse (70%), and hiking (30%).

Trail design is average. Its weaving with River Trail West causes confusion about the use designation for each use. This trail receives most of its impact from horse traffic avoiding collapsed sections on the River Trail West. Grade is kept low by following natural contours. The placement of this trail, slightly on the contour and off the riverside banks like River Trail West, helped minimize mud problems. Note that most of the mud problems occur when this route overlaps River Trail West. Maintenance is sporadic. Much of the trail appears abandoned entirely. Some blazes exist. Other parts, clearly used by River Trail West horse traffic, are in need of maintenance measures. A new 70 inch-wide bridge has been installed over a river tributary. There are no use designation signs on the many weaving sections of the two parallel trails.

This heavily used hiking trail has a mean width of 32 in, with outlying cases only along an old road bed stretch which also accommodated horse use. Mean incision (.8 in) and cross sectional area (18 in^2) measures were consistent with the average hiker trail, yet substantially less than the average of all trails combined. Trail grades ranged up to 45% with a mean of 8.1%. Despite some excessive grades, steepness did not appear to be a degrading factor. Tread substrates were predominately organic litter. Muddiness and erosion was not a frequent problem, but the formation of visitor-created informal trails was widespread where the path paralleled the river. There were 34 such trails (5.6 per mile), most of which were created to provide river access.

Summary/Recommendations: Findings suggest the designated portion of the trail is in good condition. However, the condition of informal trails leading to the river was observed by field staff to be considerably more impacted than the main tread. Construction of durable river-access trails, closure and rehabilitation of impacted trails and educational signs are recommended.

Point Sampling Indicator	**Mean**	**Median**	**Range**
Tread Width (in)	41	19	11 – 123
Maximum Incision (in)	1.1	5	0.0 – 8.5
Cross Sectional Area (in^2)	45	0	0 – 514
Trail Grade	4.6	4.5	0 – 12
Tread Substrate (%)			
Vegetation Cover	20.3	20	0 – 50
Organic Litter	48.2	50	0 – 100
Exposed Soil	25.3	20	0 – 90
Rock	1.3	0	0 – 20
Muddy Soil	4.5	0	0 – 90
Gravel	.3	0	0 – 10

Problem Assessment Indicator	**Occurrences**		**Lineal Distance**		
	(#)	**(#/mi)**	**(ft)**	**(ft/mi)**	**(%)**
Excessive Muddiness	9	3.2	502	177	3.4
Excessive Erosion	10	3.5	377	133	2.5
Informal Trails	5	1.8			

Trail Name: Lee Hollow Loop (aka Laurel Branch Horse Trail)
Length: 25,399 ft (4.81 mi) **Use Level:** High
Use Type: Horse (100%)

The 4.81 mile Lee Hollow Loop offers horse users access to the Blue Heron area, Blue Heron Road, and Bear Creek Horse Camp. The path undulates around small ridges until it fords Blair Creek twice, Lee Hollow Creek once, and then follows the bed of Laurel Branch Creek. Primary use is horse (100%).

Trail design quality varies. Other than the creek crossings, trail design is very good. It follows contours, traversing an exceptionally durable surface, and steepness is reasonably low. However, riparian crossings suffer badly from muddiness and excessive erosion. In these areas, the trail generally takes a direct descent route to the streams (deposition and increased water turbidity were evident). The higher portions had many more water drainage features than most other trails in the survey. Around the streams, they were not present or judged ineffective.

This heavily used horse trail was moderately variable in width (43 to 109 inches) with a mean of 77. Mean incision (2.7 in) and cross sectional area (112 in^2) measures were less than the average horse trail, yet more than the average of all trails combined. Trail grades ranged up to 35% with a mean of 10.6%. Tread substrates were predominately gravel and organic litter, though substantial amounts of exposed soil were also present. Muddiness and clumped soil was a frequent problem around stream crossings and several prominent mid-slope seeps. The problem assessment data revealed 17 occurrences of muddy soil affecting 921 ft (3.6%) of the trail's length. There were 17 sections of excessive erosion, with 17 occurrences affecting 3.7% of the trail segment.

Summary/Recommendations: Findings suggest that the trail is in generally good condition. This is attributed to good trail design and maintenance for most areas. The substantial amount of gravel present seems to be effective, but subsequent monitoring will be necessary to better evaluate effectiveness. Bridges may be necessary to limit soil deposition at stream crossings, and rehabilitative efforts around water resources demands management attention.

Point Sampling Indicator	Mean	Median	Range
Tread Width (in)	77	77	42 – 109
Maximum Incision (in)	2.7	2.3	0.3 – 11.0
Cross Sectional Area (in^2)	112	82	0 – 753
Trail Grade	10.6	10	0 – 35
Tread Substrate (%)			
Vegetation Cover	2.9	0	0 – 20
Organic Litter	34	40	0 – 80
Exposed Soil	21.2	20	0 – 60
Rock	1	0	0 – 100
Muddy Soil	5.2	0	0 – 0
Water	.7	0	0 – 35
Gravel	35	30	0 – 80

Problem Assessment Indicator	Occurrences		Lineal Distance		
	(#)	(#/mi)	(ft)	(ft/mi)	(%)
Excessive Muddiness	17	3.5	921	191	3.6
Excessive Erosion	31	6.4	934	194	3.7
Informal Trails	5	1			

Trail Name: Miller Branch Trail
Length: 8812 ft (1.67 mi) **Use Level:** Medium
Use Type: Horse (100%)

The 1.67 mile Miller Branch Trail provides mid-slope access along the Miller Branch drainage from the No Business trail near Big Island up to the Laurel Hill Trail. Its primary use is horse (100%). Its southern portion lies within the drainage, while the northern segment traverses a ridgeline.

Trail design is extremely poor. Within the drainage, steepness is consistently excessive. This badly rutted trail intercepts tributaries to the creek, and water flows directly down the tread. Above the drainage, the trail contours nicely, but soon regains it direct ascent along a prominent ridge. Tread maintenance features are present in some places, but are mostly ineffective due to a lack of routine maintenance in clearing out debris. This path contributes heavily to increased turbidity, and even threatens to relocate the creek position in areas. Substantial reconstruction work is required to make it ecologically and recreationally sustainable.

This medium use horse trail was variable in width (25 to 125 inches) with a mean of 66.1. Mean incision (3.6 in) and cross sectional area (154 in^2) measures more than the average horse trail, and considerably more than the average of all trails combined. Severe erosion was common in the form of active gullies, with values of cross-sectional soil loss ranging up to 1049 in^2. Trail grades ranged up to 34% with a mean of 8%. Tread substrates were predominately organic litter and exposed soil, though substantial amounts of vegetation cover was also present –likely a result of infrequent use. Muddiness was a severe problem in the mid-slope portion as the path climbed steeply out of the gorge and had become part of the regular drainage system. Field staff members found foot travel in the mid-slope section difficult and unsafe. The problem assessment data revealed 11 occurrences of muddy soil affecting 1580 ft (17.9%) of the trail's length. Sections of excessive erosion were also common, with 19 occurrences affecting 9.1% of the trail segment.

Summary/Recommendations: Findings suggest problems are linked with excessive grade in this primarily mid-slope trail. In many parts, the trail has become the drainage leading down to the gorge. This trail is characterized by severe erosion, deep gullies, and extensive mud flows. The recommendation is closure with aggressive rehabilitation to stop natural forces from carving out deeper gullies and relocation.

Point Sampling Indicator	**Mean**		**Median**	**Range**	
Tread Width (in)	66.1		64	25 – 125	
Maximum Incision (in)	3.6		3	0.5 – 14.0	
Cross Sectional Area (in^2)	154		92	0 – 1049	
Trail Grade	10.1		8	0 – 34	
Tread Substrate (%)					
Vegetation Cover	15		10	0 – 60	
Organic Litter	34		25	0 – 95	
Exposed Soil	32.5		30	0 – 70	
Rock	7.5		0	0 – 80	
Muddy Soil	8.3		0	0 – 90	
Water	2.2		0	0 – 20	
Problem Assessment Indicator	**Occurrences**		**Lineal Distance**		
	(#)	**(#/mi)**	**(ft)**	**(ft/mi)**	**(%)**
Excessive Muddiness	11	6.6	1580	946	17.9
Excessive Erosion	19	11.4	625	374	9.1
Informal Trails	1	.6			

Trail Name: No Business Trail
Length: 16,312 ft (3.09 mi) **Use Level:** High
Use Type: Horse (48%), Hiking (48%), Bike (5%)

The 3.09 mile No Business Trail follows the No Business Creek west to east along a valley bottom leading toward Big Island in the river. This trail receives horse (48%), hiker (48%), and bike (5%) use. Most of the hiker use is on the western portion, as it overlaps the John Muir Trail, which branches off this trail roughly halfway. Foot travel is unlikely in the eastern portion, for it is extremely difficult and dangerous due to extensive muddiness and erosion.

Trail design is moderate to poor. Grade is generally acceptable yet water drainage is extremely poor. Stream crossings are highly impacted, and many streams run down the trail. Trail proximity to the saturated valley floor is too close. Water drainage features are non-existent or ineffective.

This heavily used horse trail was variable in width (21 to 137 inches) with a mean of 67.7. Mean incision (3.2 in) and cross sectional area (141 in^2) measures are similar to the average horse trail, yet more than the average of all trails combined. Trail grades ranged up to 18% with a mean of 6%. Tread substrates were predominately organic litter and exposed soil, though substantial amounts of muddy soil and vegetation cover were also present. Extreme muddiness characterized the trail as it neared the river. The eastern end of the trail, nearest to the river, exhibited severe gullies, mud pits, and braided trails so extreme that field staff members were forced to abandon the main tread. The problem assessment data revealed 37 occurrences of muddy soil affecting 2646 ft (16.2%) of the trail's length. Excessive erosion problems occurred 19 times, affecting 5% of the trail segment. A total of 13 informal trails were found to be mostly formed to circumvent muddy areas.

Summary/Recommendations: Findings suggest problems are linked with poor drainage in the valley bottom, and very few effective tread drainage features. Such wet soils should be considered fragile and should be drained properly or the trail should be relocated to higher locations along the gorge wall to maintain the natural drainage of the No Business Valley. The eastern end, especially, requires immediate and decisive action.

Point Sampling Indicator	**Mean**	**Median**	**Range**
Tread Width (in)	67.7	66	21 – 137
Maximum Incision (in)	3.2	2.5	0.5 – 12.0
Cross Sectional Area (in^2)	141	74	0 – 836
Trail Grade	6	5	0 – 18
Tread Substrate (%)			
Vegetation Cover	14.9	10	0 – 50
Organic Litter	29.4	25	0 – 90
Exposed Soil	26.5	20	0 – 80
Rock	8.5	0	0 – 90
Muddy Soil	17	0	0 – 100
Water	3.8	0	0 – 40

Problem Assessment Indicator	**Occurrences (#)**	**Occurrences (#/mi)**	**Lineal Distance (ft)**	**Lineal Distance (ft/mi)**	**Lineal Distance (%)**
Excessive Muddiness	37	12	2646	856	16.2
Excessive Erosion	12	3.9	820	265.4	5
Informal Trails	13	4.2			
Secondary Trails	0	0			

Trail Name: Pilot Wines Loop
Length: 21,089 ft (3.99 mi) **Use Level:** High
Use Type: Horse (95%) Bike (5%)

This 3.99 mile eastern section of the Pilot Wines Loop provides access to ridge top forest land near the eastern borders of BISO. It is a part of the Pilot Wines and Big Island loop system. Use is mostly horse (95%), with occasional bike (5%).

Trail design is very good. Along the ridges, it stays along the contours with very little steepness. Tread drainage is a problem, however, due to a consistent incision rate. There are many effective tread drainage features, unlike many other trails surveyed, but not enough to prevent rutting.

This high use hiking trail had a consistent tread width (63-135 inches). Mean incision (3.0 in) and cross sectional area (126 in^2) measures were lower than the average hiker trail, yet higher than the average of all trails combined. Trail grades ranged up to 23% with a mean of 7%. Tread substrates were predominately gravel, exposed soil, and organic litter.

Summary/Recommendations: This trail was one of the most sustainable horse trails in the survey, and may serve as a reference for the potential of other horse trails. Its stable condition can be attributed to a variety of factors, including excellent design, suitable position, and diligent maintenance. Design highlights were minimal trail grades and alignment with contours. The plateau proved to be an excellent position for the trail, as it avoided steep mid-slopes descending to the gorge, which are prone to water channeling, and wet soils found in the valley bottoms. Management actions, such as water drainage features and appropriate gravel treatments were judged effective in the field by survey staff.

Point Sampling Indicator	**Mean**	**Median**	**Range**
Tread Width (in)	87.2	87	63 – 135
Maximum Incision (in)	3.0	2.3	0.5 – 15
Cross Sectional Area (in^2)	126	99	0 – 647
Trail Grade	7.7	7	0 – 23
Tread Substrate (%)			
Vegetation Cover	4.9	0	0 – 35
Organic Litter	24.3	20	0 – 70
Exposed Soil	29.5	30	0 – 80
Rock	1.5	0	0 – 35
Muddy Soil	4.9	0	0 – 95
Water	.8	0	0 – 20
Exposed Roots	0	0	0 – 30
Gravel	34.8	40	0 – 90

Problem Assessment Indicator	**Occurrences**		**Lineal Distance**		
	(#)	**(#/mi)**	**(ft)**	**(ft/mi)**	**(%)**
Excessive Muddiness	20	5	671	168	3.2
Excessive Erosion	12	3	542	136	2.6
Informal Trails	4	1			
Secondary Trails	0	0			

Trail Name: River Trail West
Length: 18,989 ft (3.60 mi) **Use Level:** High
Use Type: Horse (90%), Hiking (10%)

The 3.6 mile River Trail West provides riparian access to the main gorge from Station Camp Crossing to Big Island. In spots it weaves and overlaps with the John Muir Trail (Segment I). It follows, generally, flat riverbank terrain. Primary use is horse (90%), except for the occasional hiker (10%), whom is most likely following the John Muir Trail, which intertwines with River Trail West.

Trail design is extremely poor. The grade is not excessively steep, except in some local areas where water collects in visitor-created mud bogs. Tread water drainage is virtually nonexistent. The trail is simply too close to the saturated riparian area and is churned into mud by heavy horse use. Given periodic flooding the trail cannot support horse use. Pedestrian opportunity is prevented by very deep mud bogs. Peripheral impact is widespread, as users seek to circumvent the many tread problems, and most of it has been shifted over to the John Muir Trail. Maintenance actions are judged ineffective, due to design flaws and use designation.

This heavily used horse trail varied greatly in width (12-135 inches), with the lower tread widths belonging to short stretches were River Trail West has been abandoned in favor of the less impacted John Muir hiking Trail. Mean incision (3.3 in) is similar to the average of horse trails, yet deeper than the mean for all other trails. Mean cross sectional area (197 in^2) was the highest for all designated trails in the survey, and considerably higher than the average of all trails combined. Trail grades ranged up to 14% with a mean of 4.4%. Tread substrates were predominately muddy soil and exposed soil, yet substantial amounts of organic litter were present. Several muddy problems were so deep and severe that field staff found travel difficult and unsafe, and were forced to abandon the trail temporarily, especially in isolated stretches of knee-deep mud. Excessive muddiness was recorded for 42 occurrences, but most of these were short and accounted for only 2% of the trail's length. Excessive erosion was a less frequent occurrence (28 occurrences), but accounted for 11% of the trail's length (2163 ft). A total of 30 informal trails were found, and were used primarily to avoid muddy or abandoned segments of the trail.

Summary/Recommendations: Findings suggest that River Trail West is too close to the river to sustain horse use. When contrasted with the adjacent John Muir hiking Trail, the difference in impacts is apparent. However, the JMT is set further back from the river. Recommendations include relocating the River Trail West horse trail higher on the gorge wall than the JMT, and closing and rehabilitating the current tread. It is suggested that the JMT and River Trail West be separated in a manner that preserves the John Muir Trail's hiking recreational and historical values, while offering horse users a well-designed alternative to sustain horse riding recreation on the West side of the river connecting Station Camp Creek to No Business Creek.

Point Sampling Indicator	**Mean**	**Median**	**Range**
Tread Width (in)	94	89	12 – 135
Maximum Incision (in)	3.3	2.5	0.0 – 10.0
Cross Sectional Area (in^2)	197	111	0 – 764
Trail Grade	4.4	4	0 – 14
Tread Substrate (%)			
Vegetation Cover	10	10	0 – 30
Organic Litter	18.6	17.5	0 – 70
Exposed Soil	40.5	45	0 – 90
Rock	1.5	0	0 – 30
Muddy Soil	40.5	45	0 – 90
Water	.5	0	0 – 10

Gravel	2.8	0	0 – 30

Problem Assessment Indicator	**Occurrences**		**Lineal Distance**		
	(#)	**(#/mi)**	**(ft)**	**(ft/mi)**	**(%)**
Excessive Muddiness	42	11.7	380	106	2
Excessive Erosion	28	7.8	2163	601	11
Informal Trails	30	8.3			
Secondary Trails	0	0			

Trail Name: Shotoff Cliff Trail
Length: 9043 ft (1.71 mi)   **Use Level:** High
Use Type: Horse (100%)

This 1.71 mile section of the Shotoff Cliff Trail is a mid-slope trail that spans from the ridge top road closing to Williams Creek before it drains into the Big South Fork River. It follows an abandoned road as it winds down, and traverses the creek at the bottom, where designation changes to hiking.

Trail Design is very poor. The abandoned road was clearly not designed for ecological sustainability. It is steep, has very poor drainage, and in most places retains the original width. Much of the trail has become a new channel for a small creek. Besides witnessing active soil erosion, field researchers also noted amounts of horse manure carried down the trail and drained into Williams Creek. Most of the water drainage problem could be alleviated by a concentrated maintenance effort, but no signs of that were present.

This high use horse trail varied widely in tread width (22-134 inches). Mean incision (4.2 in) and cross sectional area (171 in^2) measures were higher than the average hiker trail, and considerably higher than the average of all trails combined. Trail grades ranged up to 25% with a mean of 8.5%. Tread substrates were predominately organic litter, exposed soil, an unusual amount of rock (primarily because of exposed bedrock from historical erosion), and muddy soil. Excessive muddiness was recorded 23 times, accounting for 14.6% of the trail's length. Erosion problems were extreme, and accounted for one-quarter of the trail's length (1319 ft).

Summary/Recommendations: Findings indicate that this mostly mid-slope trail requires immediate management attention if it is to sustain future horse use. Particularly, this trail needs extensive tread drainage features installed to reverse the consistent erosion gully patterns. Since this trail provides entry into the east end of the park, and is often used by local horse riders, such extensive maintenance is preferred over closure. However, if such actions are not immediately feasible, an alternative would be to block current trail gullies and temporarily close the trail until extensive rehabilitation is possible.

Point Sampling Indicator	**Mean**	**Median**	**Range**
Tread Width (in)	65	56	22 – 134
Maximum Incision (in)	4.2	3.8	0.0 – 8.5
Cross Sectional Area (in^2)	171	111	0 – 868
Trail Grade	9.6	8.5	0 – 25
Tread Substrate (%)			
Vegetation Cover	4.2	0	0 – 30
Organic Litter	32.2	25	0 – 100
Exposed Soil	24.2	25	0 – 90
Rock	18.1	2.5	0 – 90
Muddy Soil	15	0	0 – 80
Water	5.3	0	0 – 30

Problem Assessment Indicator	**Occurrences**		**Lineal Distance**		
	(#)	**(#/mi)**	**(ft)**	**(ft/mi)**	**(%)**
Excessive Muddiness	23	13.45	1316	770	14.6
Excessive Erosion	15	8.77	2256	1319	25
Informal Trails	7	4.1			
Secondary Trails	0	0			

Trail Name: Station Camp Creek Trail
Length: 18,471 ft (3.50 mi) **Use Level:** High
Use Type: Horse (90%), Hiking (5%), Bike (5%)

The 3.5 mile Station Camp Creek Trail provides access from the western Station Camp Creek gorge east to the Big South Fork River and Station Camp Crossing. It is an important link for visitors, as it links trails that lead to special scenic areas, such as the Charit Creek Lodge and the Twin Arches Hiking Loop. Its use is primarily horse (90%), with occasional hiking (5%) and Biking (5%).

Trail design is average. Grade is a concern in many areas. Mud and erosion problem areas are widespread. In most places, the trail is too close to the saturated riparian zone for sustained horse use. Both hiking and bicycling have been made dangerous by excessive tread problems. No effective tread drainage features were discovered. The trail became a creek during a rainy survey period, and disrupted soil from horse traffic was noted being carried down the trail into the main creek, with no tread drainage features to impede the flow.

This heavily used horse trail was variable in width (69 to 154 inches) with a mean of 96 inches. Mean incision (3.0 in) was lower than the average horse trail, yet higher than all other trails combined, and cross sectional area (184 in^2) measures were more than the average horse trail. Some points revealed severe erosion up to 909 in^2. Trail grades ranged up to 16% with a mean of 4%. Tread substrates were predominately exposed soil and organic litter. Muddiness was a frequent problem in the eastern sections approaching the river in deep gullies. The problem assessment data revealed 41 occurrences of muddy soil affecting 2721 ft (14.7%) of the trail's length. Sections of excessive erosion were also common, with 38 occurrences affecting 11.5% of the trail. A total of 13 informal trails were created around muddy areas.

Summary/Recommendations: Findings suggest problems are linked with proximity of horse use to wet riparian soils, and few effective drainage features to impede water-driven erosion of loose soils churned by recreational use. Recommendations include a preferred alternative of aggressive installation of tread drainage features, and other alternatives such as relocating problem areas away from riparian soils and lastly, restricting horse use.

Point Sampling Indicator	**Mean**		**Median**		**Range**
Tread Width (in)	96		93		69 – 154
Maximum Incision (in)	3.0		2.4		0.5 – 9.5
Cross Sectional Area (in^2)	184		123		0 – 909
Trail Grade	5.4		4		0 – 16
Tread Substrate (%)					
Vegetation Cover	1.1		0		0 – 10
Organic Litter	27.2		20		0 – 80
Exposed Soil	30		30		0 – 80
Rock	5.9		0		0 – 30
Muddy Soil	4.3		0		0 – 50
Water	10.3		5		0 – 80
Problem Assessment Indicator	**Occurrences**		**Lineal Distance**		
	(#)	**(#/mi)**	**(ft)**	**(ft/mi)**	**(%)**
Excessive Muddiness	41	11.7	2721	777	14.7
Excessive Erosion	38	10.9	2117	605	11.5
Informal Trails	13	3.7			

Trail Name: West Bandy Creek Bike Trail
Length: 9970 ft (1.89 mi) **Use Level:** Low
Use Type: Bike (90%), Hiking (10%)

This 1.89 mile section of the West Bandy Creek Bike Trail traverses the western plateau adjacent to the Bandy Creek Road. It is primarily a bike trail (90%), but does receive limited hiking traffic (10%).

Trail design is excellent. The grade, trail position, and soil type are well suited for bike use. The trail is narrow, and peripheral impacts are minimal. The trail was clear of blow-downs and other barriers. Although an isolated stretch is located on an abandoned road, the old width has been naturalized and a current narrow path persists. This trail receives maintenance from a local bike club.

This low use bike trail varied little in tread width (15-33 inches). Mean incision (1 in) and cross sectional area (6 in^2) measures were slightly lower than the average hiker trail, and considerably lower than the average of all trails combined. Trail grades ranged up to 25% with a mean of 3.5%. Tread substrates were predominately organic litter, exposed soil, and substantial amounts of vegetation cover. Excessive muddiness and erosion were only recorded 2 times each.

Summary/Recommendations: Findings indicate that this trail is in excellent condition, and park managers should use the bike user group maintenance actions as a positive example for other user groups to encourage trail stewardship.

Point Sampling Indicator	**Mean**	**Median**	**Range**
Tread Width (in)	23.8	23.5	15 – 33
Maximum Incision (in)	1.0	1.0	0.0 – 2.5
Cross Sectional Area (in^2)	6	0	0 – 52
Trail Grade	6.9	3.5	0 – 25
Tread Substrate (%)			
Vegetation Cover	11.3	5	0 – 50
Organic Litter	59.3	60	0 – 100
Exposed Soil	29.5	15	0 – 80

Problem Assessment Indicator	**Occurrences**		**Lineal Distance**		
	(#)	**(#/mi)**	**(ft)**	**(ft/mi)**	**(%)**
Excessive Muddiness	2	1.1	58	31	.6
Excessive Erosion	2	1.1	26	14	.3
Informal Trails	0	0			
Secondary Trails	0	0			

Trail Name: West Entrance Bandy Creek Hike Trail
Length: 13,425 ft (2.54 mi) **Use Level:** Medium
Use Type: Hiking (100%)

The 2.54 mile West Entrance Bandy Creek Hike Trail provides foot travel access to the Collier Ridge drainage, west from the West Entrance Area and east to the Bandy Creek Campground area. It follows the drainage creek for the duration. Use is primarily hike (100%).

Trail design is excellent. It uses gently graded switchbacks to descend into the drainage. As it follows the creek, it manages to keep on dry ground. Some new blow-downs existed, but generally the path was well maintained.

This medium use hiking trail varied little in tread width (13-30 inches). Mean incision (.3 in) measures were lower than the average hiker trail, and were the lowest of all trails. There was no incision equal to or over one inch, so the cross sectional area measure was never applied. Trail grades ranged up to 10% with a mean of 4%. Tread substrates were predominately organic litter and substantial amounts of exposed soil was. There were no problems of excessive muddiness or erosion.

Summary/Recommendations: Findings indicate that this trail is in superb condition. While generally similar to other hiking trails, a very low grade is most likely the principle difference in impact conditions. Recommendations are to maintain current use type.

Point Sampling Indicator	**Mean**	**Median**	**Range**
Tread Width (in)	20	19	13 – 30
Maximum Incision (in)	.3	.5	0.0 – 1.0
Cross Sectional Area (in^2)	0	0	0 – 0
Trail Grade	4.8	4	0 – 10
Tread Substrate (%)			
Vegetation Cover	2.8	0	0 – 50
Organic Litter	73.3	95	0 – 100
Exposed Soil	20.9	0	0 – 100
Rock	2.8	0	0 – 75
Exposed Roots	.2	0	0 – 5

Problem Assessment Indicator	**Occurrences**		**Lineal Distance**		
	(#)	**(#/mi)**	**(ft)**	**(ft/mi)**	**(%)**
Excessive Muddiness	0	0	0	0	0
Excessive Erosion	0	0	0	0	0
Informal Trails	1	.5			
Secondary Trails	0	0			

Trail Name: Long Field Branch Trail
Length: 4336 ft (.82 mi) **Use Level:** High
Use Type: Horse (75%), Hiking (15%), Vehicle (10%)

This trail was administratively selected and was not part of our random sample so survey data are only reported here. The 0.82 mile Long Field Branch Trail provides access from the Terry Cemetery Trailhead mid-slope down to No Business Creek, the No Business Trail, and the John Muir Trail. It also serves as a maintenance route for the No Business drainage. Primarily used by horses (75%), hikers may also use it (15%), along with maintenance service vehicles (10%).

Trail design is average (due to high tread grades). The path mostly follows a gravel road that follows a steep grade but there are effective water drainage features. It has received much maintenance, and might serve as an example for other paths that currently do not have proper tread drainage. There are exceptions, however. While many effective tread drainage features exist, some areas have formed small gullies in the path, suggesting that the given steepness requires more maintenance action.

This high use horse trail varied in tread width (85-129 inches). Mean incision (2.7 in) and cross sectional area (115 in^2) measures were lower than the average horse trail and slightly more than the average of all trails combined. Trail grades ranged up to 17% with a mean of 13%. Tread substrates were predominately gravel, giving the appearance more of a gravel road than a recreational trail. Erosion problems were present on 11 occurrences, and accounted for 14.9 % of the trail's length (788 ft).

Summary/Recommendations: Findings indicate that this mostly mid-slope trail is relatively stable when compared to other horse trails. Obvious maintenance actions in the form of gravel application and extensive water bars are likely the cause of the break from the norm of severely degraded mid-slope horse trails. Since this trail is not a featured path, and is reportedly used for maintenance purposes to provide access into No Business valley, the amount of placed gravel may be considered appropriate. However, it is recommended that less permanent and natural means of resource protection be applied as a standard -such as well-placed tread drainage features, relocations, and user behavior influence- before extensive gravelling is selected as a means.

Point Sampling Indicator	**Mean**	**Median**	**Range**
Tread Width (in)	99	93	85 – 129
Maximum Incision (in)	2.7	1.0	0.3 – 9.0
Cross Sectional Area (in^2)	115	0	0 – 573
Trail Grade	11	13	4 – 17
Tread Substrate (%)			
Vegetation Cover	15.6	10	0 – 60
Organic Litter	15.6	10	0 – 60
Exposed Soil	5	0	0 – 15
Rock	1.1	0	0 – 10
Exposed Roots	0	0	0 – 30
Gravel	62.8	60	40 – 90

Problem Assessment Indicator	**Occurrences**		**Lineal Distance**		
	(#)	**(#/mi)**	**(ft)**	**(ft/mi)**	**(%)**
Excessive Muddiness	0	0	0	0	0
Excessive Erosion	11	13.4	646	788	14.9
Informal Trails	0	0			

Appendix 3: Photos