New England Mountain Bike Association
Submittal to the
Massachusetts Executive Office of Energy and Environmental Affairs

*The Environmental Impact of Mountain Biking and Compatibility of Mountain Biking with Public Recreation in Public Water Supply/Watershed Lands*

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Matthew Beaton, Secretary
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Dear Secretary Beaton, Assistant Secretary Sieger, and Director Singleton,

Thank you for meeting with us on December 17, 2015.

We are now following up on your request to review the scientific literature about mountain biking that shows that the environmental impact of the activity is on par with hiking. We have printed out three key studies and provided web links to seven others. There are many others as well, but these are the most prominent.

Also per your request, we have compiled a list of selected watersheds both locally and around the country that allow for mountain biking or other types of passive recreation. Generally, watershed trail access falls in three categories: no public access at all, access for foot travel, and balanced access for non-motorized passive recreation. Given all available environmental impact data, we feel that the latter two categories can and should support access for bicycles. In the case of the Ware River Watershed especially, where mountain biking is the only non-motorized recreation prohibited off-road, a policy change like this would make that property consistent with other properties managed by DCR using DCR’s own impact assessments.

We hope that you can play a positive role for the citizens of central Massachusetts to get the equitable recreational access to the Ware River Watershed that they deserve.

Please let me know what the next steps are and what else we can do to find a reasonable solution.

Respectfully,

Brett Russ
Regional Vice President and Secretary, Wachusett Chapter
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Section A: Studies Establishing Mountain Biking As Having Similar Environmental Impact As Hiking on Recreational Trails
Environmental Impacts of Mountain Biking:

Science Review and Best Practices.
By Jeff Marion and Jeremy Wimpey.

Environmental Impacts of Mountain Biking: Science Review and Best Practices

By Jeff Marion and Jeremy Wimpey

Mountain biking is still a relatively new activity whose environmental impact and contribution to trail degradation is poorly understood. As with all recreational pursuits, it is clear that mountain biking contributes some degree of environmental degradation. In the absence of adequate research, land and trail managers have frequently been cautious, implementing restrictive regulations in some instances (Edger 1997). Surveys of managers have shown that they frequently perceive mountain biking to be a substantial contributor to trail degradation but lack scientific studies or monitoring data to substantiate such concerns (Chavez and others 1993; Schuett 1997). In recent years, however, a small number of studies have been conducted that help clarify the environmental impacts associated with mountain biking. This article describes the general impacts associated with recreational uses of natural surface trails, with a focus on those studies that have examined mountain biking impacts.

Trails are generally regarded as essential facilities in parks and forests. They provide access to remote areas, accommodate a diverse array of recreational activities, and protect resources by concentrating visitor trampling on narrow and resistant tread surfaces. Formal or designated trails are generally designed and constructed, which involves vegetation removal and soil excavation. These changes may be considered "unavoidable," in contrast to "avoidable" post-construction degradation from their subsequent use (e.g., trail widening, erosion, muddiness), or from the development and degradation of informal visitor-created trails.

Common environmental impacts associated with recreational use of trails include:

- Vegetation loss and compositional changes
- Soil compaction
- Erosion
- Muddiness
- Degraded water quality
- Disruption of wildlife

This article is organized into four broad categories: impacts to vegetation, soil, water, and wildlife.
Impacts to Vegetation: General Research

On formal trails, most vegetation is typically removed by construction, maintenance, and visitor use. This impact is necessary and "unavoidable" in order to provide a clear route for trail users. One goal of trail construction and maintenance is to provide a trail only wide enough to accommodate the intended use. Trails made wider than this through visitor use or erosion represent a form of "avoidable" impact. For example, a doubling of trail width represents a doubling of the area of intensive trampling disturbance. Wider trails also expose substantially greater amounts of soil to erosion by wind or water.

The creation and maintenance of trail corridors also removes shrubs and trees, allowing greater sunlight exposure that favors a different set of groundcover plants within trail corridors. Occasional trailside trampling within trail corridors also favors the replacement of fragile plants with those more resistant to trampling traffic. For example, shade-tolerant but fragile broadleaved herbs are frequently replaced by grasses and sedges that are trampling-resistant and require more sunlight to survive. Trail construction, use, and maintenance can also be harmful when trails divide sensitive or rare plant communities.

Trampling - the action of crushing or treading upon vegetation, either by foot, hoof, or tire - contributes to a wide range of vegetation impacts, including damage to plant leaves, stems, and roots, reduction in vegetation height, change in the composition of species, and loss of plants and vegetative cover (Leung & Marion, 1996; Thurston & Reader, 2001). Trampling associated with "avoidable" off-trail traffic can quickly break down vegetation cover and create a visible route that attracts additional use. Complete loss of vegetation cover occurs quickly in shady forested areas, less quickly in open areas with resistant grassy vegetation. Regardless, studies have consistently revealed that most impact occurs with initial or low use, with a diminishing increase in impact associated with increasing levels of traffic (Hammit & Cole, 1998; Leung & Marion, 1996). Furthermore, once trampling occurs, vegetative recovery is a very slow process.

Compositional changes in the vegetation along trail corridors can have both beneficial and adverse effects. Trampling-resistant plants provide a durable groundcover that reduces soil loss by wind and water runoff, and root systems that stabilize soils against displacement by heavy traffic. The ecological impacts of such compositional changes are not fully known, except when non-native vegetation is introduced to and spreads along trail corridors. Many of these species are disturbance-associated and are naturally limited to areas where the vegetation is routinely trampled or cut back. However, a few non-native species, once introduced to trail corridors, are able to out-compete native plants and spread away from the trail corridor in undisturbed habitats. Some of these species form dense cover that crowd out or displace native plants. These "invasive" species are particularly undesirable and land managers actively seek
to prevent their introduction and spread. Unfortunately their removal is difficult and expensive.

**Impacts to Vegetation: Mountain Biking-Specific Research**

Only one study found specifically addresses the vegetation impacts associated with mountain biking. Thurston and Reader (2001) conducted an experimental trampling study involving mountain bikers and hikers in Boyne Valley Provincial Park of Ontario, Canada. The researchers measured plant density (number of stems/area), diversity (number of species present), and soil exposure (area of mineral soil exposed) before and after 500 one-way passes by bikers and hikers.

Data analysis and statistical testing revealed that the impacts of hiking and biking were not significantly different for the three indicators measured. They also concluded that impacts from both hikers and bikers were spatially confined to the centerline of the lane (trail).

**Impacts to Vegetation: Management Implications**

Trail managers can either avoid or minimize impacts to vegetation through careful trail design, construction, maintenance, and management of visitor use. Here are some recommendations to reduce vegetation impacts:

- Design trails that provide the experience that trail users seek to reduce their desire to venture off-trail.
- Locate trails away from rare plants and animals and from sensitive or critical habitats of other species. Involve resource professionals in designing and approving new trail alignments.
- Keep trails narrow to reduce the total area of intensive tread disturbance, slow trail users, and minimize vegetation and soil impacts.
- Limit vegetation disturbance outside the corridor when constructing trails. Hand construction is least disruptive; mechanized construction with small equipment is less disruptive than full-sized equipment; skilled operators do less damage than those with limited experience.
- Locate trails on side-hills where possible. Constructing a side-hill trail requires greater initial vegetation and soil disturbance but sloping topography above and below the trail bench will clearly define the tread and concentrate traffic on it. Trails in flatter terrain or along the fall line may involve less initial disturbance but allow excessive future tread widening and off-tread trampling, which favor non-native plants.
- Use construction techniques that save and redistribute topsoil and excavated plants.
There are also important considerations for maintaining and managing trails to avoid unnecessary ongoing impacts to vegetation:

- While it is necessary to keep the trail corridor free of obstructing vegetation, such work should seek to avoid "day-lighting" the trail corridor when possible. Excessive opening of the overstory allows greater sunlight penetration that permits greater vegetation compositional change and colonization by non-native plants.
- An active maintenance program that removes tree falls and maintains a stable and predictable tread also encourages visitors to remain on the intended narrow tread. A variety of maintenance actions can discourage trail widening, such as only cutting a narrow section out of trees that fall across the trail, limiting the width of vegetation trimming, and defining trail borders with logs, rocks, or other objects that won’t impede drainage.
- Use education to discourage off-trail travel, which can quickly lead to the establishment of informal visitor-created trails that unnecessarily remove vegetation cover and spread non-native plants. Such routes often degrade rapidly and are abandoned in favor of adjacent new routes, which unnecessarily magnify the extent and severity of trampling damage.
- Educate visitors to be aware of their ability to carry non-native plant seeds on their bikes or clothing, and encourage them to remove seeds by washing mud from bikes, tires, shoes, and clothing. Preventing the introduction of non-natives is key, as their subsequent removal is difficult and costly.
- Educate visitors about low impact riding practices, such as those contained in the IMBA-approved Leave No Trace Skills & Ethics: Mountain Biking booklet (www.LNT.org).

For further reading see: Cessford 1995; Gruttz and Hollingshead 1995; Thurston and Reader 2001.

**Impacts to Soils: General Research**

The creation and use of trails also results in soil disturbance. Some loss of soil may be considered an acceptable and unavoidable form of impact on trails. As with vegetation loss, much soil disturbance occurs in the initial construction and use of the trail. During trail construction, surface organic materials (e.g., twigs, leaves, and needles) and organic soils are removed from treads; trails built on sidehill locations require even more extensive excavation. In addition, the underlying mineral soils are compacted during construction and initial use to form a durable tread substrate that supports trail traffic.

In contrast, post-construction soil displacement, erosion, and muddiness represent core forms of avoidable trail impact that require sustained management attention to avoid long-lasting resource degradation. This degradation can reduce the utility of trails as recreation facilities and diminish the
quality of visitor experiences. For example, 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, hindering efforts to divert water from the trail and causing accelerated erosion and muddiness. 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, 2006).

Research has shown that visitors notice obvious forms of trail impact, such as excessive muddiness and eroded ruts and tree roots, and that such impacts can degrade the quality of visitor experiences (Roggenbuck and others., 1993; Vaske and others., 1993). Such conditions also increase the difficulty of travel and may threaten visitor safety. Remedying these soil impacts can also require substantial rehabilitation costs. Clearly, one primary trail management objective should be the prevention of excessive soil impacts. Let's examine four common forms of soil impact in greater detail:

**The Four Common Forms of Soil Degradation on Trails:**

- **Compaction**
- **Muddiness**
- **Displacement**
- **Erosion**

Compaction: Soil compaction is caused by the weight of trail users and their equipment, which passes through feet, hooves, or tires to the tread surface.

Compacted soils are denser and less permeable to water, which increases water runoff. However, compacted soils also resist erosion and soil displacement and provide durable treads that support traffic. From this perspective, soil compaction is considered beneficial, and it is an unavoidable form of trail impact. Furthermore, a primary resource protection goal is to limit trailside impacts by concentrating traffic on a narrow tread. Success in achieving this objective will necessarily result in higher levels of soil compaction.

The process of compacting the soil can present a difficult challenge, especially on new trails. Unless soils are mechanically compacted during tread construction, initial use compacts the portions of the tread that receive the greatest traffic, generally the center. The associated lowering of the tread surface creates a cupped cross-section that intercepts and collects surface water. In flat terrain this water can pool or form muddy sections; in sloping terrain the water is channeled down the trail, gaining in volume, speed, and erosive potential.

Displacement: Trail users can also push soil laterally, causing displacement and development of ruts, berms, or cupped treads. Soil displacement is particularly evident when soils are damp or loose and when users are moving at higher rates.
of speed, turning, braking, or other movements that create more lateral force. Soil can also be caught in hooves, footwear, or tire treads, flicked to the side or carried some distance and dropped. Regardless of the mechanism, soil is generally displaced from the tread center to the sides, elevating inslopes or berms, and compounding drainage problems.

Muddiness: When trails are located in areas of poor drainage or across highly organic soils that hold moisture, tread muddiness can become a persistent problem. Muddiness is most commonly associated with locations where water flows across or becomes trapped within flat or low-lying areas. Soil compaction, displacement, and erosion can exacerbate or create problems with muddiness by causing cupped treads that collect water during rainfall or snowmelt. Thus, muddiness can occur even along trails where there is sufficient natural drainage. Subsequent traffic skirts these problem spots, compacting soils along the edges, widening mud holes and tread width, and sometimes creating braided trails that circumvent muddy sections.

Erosion: Soil erosion is an indirect and largely avoidable impact of trails and trail use. Soil can be eroded by wind, but generally, erosion is caused by flowing water. To avoid erosion, sustainable trails are generally constructed with a slightly crowned (flat terrain) or outsloped (sloping terrain) tread. However, subsequent use compacts and/or displaces soils over time to create a cupped or insloped tread surface that intercepts and carries water. The concentrated run-off picks up and carries soil particles downhill, eroding the tread surface.

Loose, uncompacted soil particles are most prone to soil erosion, so trail uses that loosen or detach soils contribute to higher erosion rates. Erosion potential is closely related to trail grade because water becomes substantially more erosive with increasing slope. The size of the watershed draining to a section of trail is also influential - larger volumes of water are substantially more erosive.

Water and the sediment it carries will continue down the trail until a natural or constructed feature diverts it off the tread. Such features include a natural or constructed reversal in grade, an outsloped tread, rocks or tree roots, or a constructed drainage dip or water bar. Once the water slows, it drops its sediment load, filling in tread drainage features and causing them to fail if not periodically maintained. Sediment can also be carried directly into watercourses, creating secondary impacts to aquatic systems. Properly designed drainage features are designed to divert water from the trail at a speed sufficient to carry the sediment load well below the tread, where vegetation and organic litter can filter out sediments. A well-designed trail should have little to no cumulative soil loss, for example, less than an average of one-quarter inch (6.3 mm) per year.
Impacts to Soils: Mountain Biking-Specific Research

Several studies have evaluated the soil impacts of mountain biking.

Wilson and Seney (1994) evaluated tread erosion from horses, hikers, mountain bikes, and motorcycles on two trails in the Gallatin National Forest, Montana. They applied one hundred passes of each use-type on four sets of 12 trail segments, followed by simulated rainfalls and collection of water runoff to assess sediment yield at the base of each segment. Control sites that received no passes were also assessed for comparison. Results indicated that horses made significantly more sediment available for erosion than the other uses, which did not significantly vary from the control sites. Traffic on pre-wetted soils generated significantly greater amounts of soil runoff than on dry soils for all uses.

Marion (2006) studied 78 miles (125 km) of trail (47 segments) in the Big South Fork National River and Recreation Area, Tennessee and Kentucky, measuring soil loss along transects across the trail to evaluate the influence of use-related, environmental, and management factors. Sidehill-aligned trails were significantly less eroded than trails in valley bottom positions, in part due to the influence of periodic floods. Trail grade and trail alignment angle were also significant predictors of tread erosion. Erosion rates on trails with 0-6 percent and 7-15 percent grades were similar, while erosion on trails with grades greater than 16 percent were significantly higher. And there was significantly greater erosion on fall line trails (alignment angles of 0-22 degrees) than those with alignments closer to the contour.

This study also provided an opportunity to examine the relative contribution of different use types, including horse, hiking, mountain biking, and ATV. Trails predominantly used for mountain biking had the least erosion of the use types investigated. Computed estimates of soil loss per mile of trail also revealed the mountain biking trails to have the lowest soil loss.

White and others (2006) also examined trails predominantly used for mountain biking in five ecological regions of the Southwest along 163 miles (262 km) of trail. Two trail condition indicators, tread width and maximum incision, were assessed at each sample point. Results show that erosion and tread width on these trails differed little in comparison to other shared-use trails that receive little or no mountain biking.

Goeft and Alder (2001) evaluated the resource impacts of mountain biking on a recreational trail and racing track in Australia over a 12-month period. A variety of trail condition indicators were assessed on new and older trail segments with uphill, downhill, and flat trail sections. Results found that trail slope, age, and time were significant erosion factors, and that downhill slopes and curves were the most susceptible to erosion. New trails experienced greater amounts of soil compaction but all trails exhibited both compaction and loosening of soils over time.
time. The width of the recreational trail varied over time, with no consistent trend, while the width of the racing trail grew following events but exhibited net recovery over time. Impacts were confined to the trail tread, with minimal disturbance of trailside vegetation.

Bjorkman (1996) evaluated two new mountain biking trails in Wisconsin before and for several years after they were opened to use. Vegetation cover within the tread that survived trail construction work declined with increasing use to negligible levels while trailside vegetation remained constant or increased in areas damaged by construction work. Similarly, soil compaction within the tread rose steadily while compaction of trailside soils remained constant. Vegetation and soil impacts occurred predominantly during the first year of use with minor changes thereafter.

Wohrstein (1998) evaluated the impacts from a World Championship mountain biking race with 870 participants and 80,000 spectators. Erosion was found only on intensively used racing trails in steep terrain where alignments allowed higher water runoff. The mountain biking routes exhibited higher levels of compaction but to a shallower depth in comparison to the spectator areas, where compaction was lower but deeper.

Cessford (1995) provides a comprehensive, though dated, summary of trail impacts with a focus on mountain biking. Of particular interest is his summary of the two types of forces exerted by bike tires on soil surfaces: The downward compaction force from the weight of the rider and bike, and the rotational shearing force from the turning rear wheel. Mountain bikers generate the greatest torque, with potential tread abrasion due to slippage, during uphill travel. However, the torque possible from muscle power is far less than that from a motorcycle, so wheel slippage and abrasion occur only on wet or loose surfaces. Tread impact associated with downhill travel is generally minimal due to the lack of torque and lower ground pressures. Exceptions include when riders brake hard enough to cause skidding, which displaces soil downslope, or bank at higher speeds around turns, which displaces soil to the outside of the turn. Impacts in flatter terrain are also generally minimal, except when soils are wet or uncompacted and rutting occurs.

**Impacts to Soils: Management Implications**

Soil loss is among the most enduring forms of trail impact, and minimizing erosion and muddiness are the most important objectives for achieving a sustainable trail. Soil cannot easily be replaced on trails, and where soil disappears, it leaves ruts that make travel and water drainage more difficult, prompting further impacts, such as trail widening.

Existing studies indicate that mountain biking differs little from hiking in its contribution to soil impacts. Other factors, particularly trail grade, trail/slope
alignment angle, soil type/wetness, and trail maintenance, are more influential determinants of tread erosion or wetness.

There are a number of tactics for avoiding the worst soil-related impacts to trails:

- Discourage or prohibit off-trail travel. Informal trails created by off-trail travel frequently have steep grades and fall-line alignments that quickly erode, particularly in the absence of tread maintenance. Exceptions include areas of solid rock or non-vegetated cobble.
- Design trails with sustainable grades and avoid fall-line alignments. (See p. 112 for more)
- When possible, build trails in dry, cohesive soils that easily compact and contain a larger percentage of coarse material or rocks. These soils better resist erosion by wind and water or displacement by feet, hooves and tires.
- Minimize tread muddiness by avoiding flat terrain, wet soils, and drainage-bottom locations.
- Use grade reversals to remove water from trail treads. Grade reversals are permanent and sustainable - when designed into a trail's alignment they remain 100 percent effective and rarely require maintenance.

Other strategies are more temporary in nature and will require periodic maintenance to keep them effective:

- While the use of a substantial outslope (e.g., 5 percent) helps remove water from treads, it is rarely a long-term solution. Tread cupping and berm development will generally occur within a few years after tread construction. If it is not possible to install additional grade reversals, reshape the tread to reestablish an outsloped tread surface periodically, and install wheel-friendly drainage dips or other drainage structures to help water flow off the trail.
- If it is not possible to install proper drainage on a trail, consider rerouting trail sections that are most problematic, or possibly hardening the tread.
- In flatter areas, elevate and crown treads to prevent muddiness, or add a gravel/soil mixture in low spots.

Finally, it is important to realize that visitor use of any type on trails when soils are wet contributes substantially greater soil impact than the same activities when soils are dry. Thus, discouraging or prohibiting the use of trails that are prone to muddiness during rainy seasons or snowmelt is another effective measure. Generally such use can be redirected to trails that have design or environmental attributes that allow them to better sustain wet season uses.

For additional information about minimizing soil impacts through trail design, construction, maintenance, and tread hardening, see Trail Solutions.
Impacts to Water Resources: General Research

Trails and their use can also affect water quality. Trail-related impacts to water resources can include the introduction of soils, nutrients, and pathogenic organisms (e.g., Giardia), and alter the patterns of surface water drainage. However, in practice, these impacts are avoidable, and properly designed and maintained trails should not degrade water quality. Unfortunately there is very little research to draw from on these topics, and none that is specific to mountain biking.

Poorly sited and/or maintained trails can be eroded by water, with tread sediments carried off by runoff. Generally, if water control features such as grade reversals and outsloped treads are used to divert runoff from trails, the water drops its sediment close to trails, where it is trapped and held by organic litter and vegetation. Soils eroded from trails rarely enter water bodies, unless trails cross streams or run close to stream or lake shorelines and lack adequate tread drainage features. Since many recreational activities, such as fishing, swimming, boating, and viewing scenery (e.g., waterfalls) draw visitors and trails to the vicinity of water resources, it is often necessary to route trails to water resources or visitors will simply create their own informal trails.

Trails that are close to water resources require special consideration in their design and management to prevent the introduction of suspended sediments into bodies of water. Eroded soil that enters water bodies increase water turbidity and cause sedimentation that can affect aquatic organisms (Fritz and others 1993). Trout and other fish lay their eggs in gravels on the bottom of streams and lakes, and sediments can smother those eggs, reducing reproductive success. Sedimentation can also hurt invertebrate organisms, which serve as food for fish and other creatures. In addition, some sediment may contain nutrients that can contribute to algal blooms that deplete the dissolved oxygen in water bodies when they die off.

Poorly designed trails can also alter hydrologic functions - for instance, trails can intercept and divert water from seeps or springs, which serve important ecological functions. In those situations, water can sometimes flow along the tread, leading to muddiness or erosion and, in the case of cupped and eroded treads, the water may flow some distance before it is diverted off the trail, changing the ecology of small wetland or riparian areas.

Trail users may also pollute water with pathogenic organisms, particularly those related to improperly disposed human waste. Potential pathogenic organisms found through surveys of backcountry water sources include Cryptosporidium spp., Giardia spp., and Campylobacter jejuni (LeChevallier and others, 1999; Suk and others, 1987; Taylor and others, 1983). This is rarely a significant concern where trail use is predominantly day-oriented, and waste issues can be avoided.
by installing toilet facilities or following Leave No Trace practices (i.e., digging cat-holes for waste away from water resources).

**Impacts to Water Resources: Management Implications**

The same trail design, construction, and maintenance measures that help minimize vegetation and soil impacts also apply to water. But there are also some additional efforts needed to protect water resources:

- Trails should avoid close proximity to water resources. For example, it is better to build a trail on a sidehill along a lower valley wall than to align it through flat terrain along a stream edge, where trail runoff will drain directly into the stream.
- It is best to minimize the number of stream crossings. Where crossings are necessary, scout the stream carefully to select the most resistant location for the crossing. Look for rocky banks and soils that provide durable surfaces.
- Design water crossings so the trail descends into and climbs out of the steam crossing, preventing stream water from flowing down the trail.
- Armor trails at stream crossings with rock, geotextiles, or gravel to prevent erosion.
- Include grade reversals, regularly maintained outsloped treads, and/or drainage features to divert water off the trail near stream crossings. This prevents large volumes of water and sediment from flowing down the trail into the stream, and allows trailside organic litter, vegetation, and soils to slow and filter water.
- On some heavily used trails, a bridge may be needed to provide a sustainable crossing.
- Where permanent or intermittent stream channels cross trails, use wheel-friendly open rock culverts or properly sized buried drainage culverts to allow water to cross properly, without flowing down the trail.

**Impacts to Wildlife: General Research**

Trails and trail uses can also affect wildlife. Trails may degrade or fragment wildlife habitat, and can also alter the activities of nearby animals, causing avoidance behavior in some and food-related attraction behavior in others (Hellmund, 1998; Knight & Cole, 1991). While most forms of trail impact are limited to a narrow trail corridor, disturbance of wildlife can extend considerably further into natural landscapes (Kasworm & Monley, 1990; Tyser & Worley, 1992). Even very localized disturbance can harm rare or endangered species.

Different animals respond differently to the presence of trail users. Most wildlife species readily adapt or become "habituated" to consistent and non-threatening recreational activities. For example, animals may notice but not move away from
humans on a frequently used trail. This is fortunate, as it can allow high quality wildlife viewing experiences for visitors and cause little or no impact to wildlife.

Other forms of habituation, however, are less desirable. Visitors who feed wildlife, intentionally or from dropped food, can contribute to the development of food-related attraction behavior that can turn wild animals and birds into beggars. In places where visitors stop to eat snacks or lunches, wildlife quickly learn to associate people with food, losing their innate fear of humans and returning frequently to beg, search for food scraps, or even raid unprotected packs containing food. Feeding wild creatures also endangers their health and well-being. For instance, after food-attracted deer in Grand Canyon National Park became sickly and dangerously aggressive, researchers found up to six pounds of plastic and foil wrappers obstructing intestinal passages of some individuals.

The opposite conduct in wildlife - avoidance behavior - can be equally problematic. Avoidance behavior is generally an innate response that is magnified by visitor behaviors perceived as threatening, such as loud sounds, off-trail travel, travel in the direction of wildlife, and sudden movements. When animals flee from disturbance by trail users, they often expend precious energy, which is particularly dangerous for them in winter months when food is scarce. When animals move away from a disturbance, they leave preferred or prime habitat and move, either permanently or temporarily, to secondary habitat that may not meet their needs for food, water, or cover. Visitors and land managers, however, are often unaware of such impacts, because animals often flee before humans are aware of the presence of wildlife.

**Impacts to Wildlife: Mountain Biking-Specific Research**

The impacts of mountain biking on wildlife are similar to those of hikers and other non motorized trail users.

Taylor and Knight (2003) investigated the interactions of wildlife and trail users (hikers and mountain bikers) at Antelope Island State Park in Utah. A hidden observer using an optical rangefinder recorded bison, mule deer, and pronghorn antelope response to an assistant who hiked or biked a section of trail. The observer then measured wildlife reactions, including alert distance, flight response, flight distance, distance fled, and distance from trail. Observations revealed that 70 percent of animals located within 330 feet (100 m) of a trail were likely to flee when a trail user passed, and that wildlife exhibited statistically similar responses to mountain biking and hiking. Wildlife reacted more strongly to off-trail recreationists, suggesting that visitors should stay on trails to reduce wildlife disturbance. While Taylor and Knight found no biological justification for managing mountain biking any differently than hiking, they note that bikers cover more ground in a given time period than hikers and thus can potentially disturb more wildlife per unit time.
This study also surveyed 640 hikers, mountain bikers, and horseback riders on the island to assess their perceptions of the effects of recreation on wildlife. Most respondents felt they could approach animals far closer than the flight distance suggested by the research, and 50 percent felt that recreational uses did not have a negative effect on wildlife.

Another study evaluated the behavioral responses of desert bighorn sheep to disturbance by hikers, mountain bikers, and vehicles in low- and high-use areas of Canyonlands National Park (Papouchis and others., 2001). Following observations of 1,029 bighorn sheep/human interactions, the authors reported that sheep fled 61 percent of the time from hikers, 17 percent of the time from vehicles, and 6 percent of the time from mountain bikers. The stronger reaction to hikers, particularly in the high-use area, was attributed to more off-trail hiking and direct approaches to the sheep. The researchers recommended that park officials restrict recreational uses to trails, particularly during the lambing and rut seasons, in order to minimize disturbance.

An experimental study in Switzerland evaluated the disturbance associated with hiking, jogging, and mountain biking on high elevation chamois, which are goat-like mammals found in the European mountains (Gander & Ingold 1997). The authors assessed alert distance, flight distance, and distance fled, and found that approximately 20 percent of the animals fled from trailside pastures in response to visitor intrusions. The authors found no statistically significant differences, however, between the behavioral responses of animals to the three different types of user, and authors concluded that restrictions on mountain biking above timberline would not be justified from the perspective of chamois disturbance.

A study of the Boise River in Idaho examined flushing distances of bald eagles when exposed to actual and simulated walkers, joggers, fishermen, bicyclists, and vehicles (Spahr 1990). The highest frequency of eagle flushing was associated with walkers (46 percent), followed by fishermen (34 percent), bicyclists (15 percent), joggers (13 percent), and vehicles (6 percent). However, bicyclists caused eagles to flush at the greatest distances (mean = 148 meters), followed by vehicles (107m), walkers (87m), fishermen (64m), and joggers (50m). Eagles were most likely to flush when recreationists approached slowly or stopped to observe them, and were less alarmed when bicyclists or vehicles passed quickly at constant speeds. Similar findings have been reported by other authors, who attribute the difference in flushing frequency between walkers and bikers/vehicles either to the shorter time of disturbance and/or the additional time an eagle has to "decide" to fly (Van der Zande and others. 1984).

Safety issues related to grizzly bear attacks on trail users in Banff National Park prompted Herrero and Herrero (2000) to study the Morraine Lake Highline Trail. Park staff noted that hikers were far more numerous than mountain bikers on the trail, but that the number of encounters between bikers and bears was disproportionately high. For example, three of the four human-grizzly bear
encounters that occurred along the trail during 1997-98 involved mountain bikers. Previous research had shown that grizzly bears are more likely to attack when they first become aware of a human presence at distances of less than 50 meters. Herrero and Herrero concluded that mountain bikers travel faster, more quietly, and with closer attention to the tread than hikers, all attributes that limit reaction time for bears and bikers, and increases the likelihood of sub-fifty meter encounters. In addition, most of the bear-cyclist encounters took place on a fast section of trail that went through high-quality bear habitat with abundant berries. To reduce such incidents, they recommended education, seasonal closures of the trail to bikes and/or hikers, construction of an alternate trail, and regulations requiring a minimum group size for bikers.

**Impacts to Wildlife: Management Implications**

Many potential impacts to wildlife can be avoided by ensuring that trails avoid the most sensitive or critical wildlife habitats, including those of rare and non-rare species. There are a number of tactics for doing this:

- Route trails to avoid riparian or wetland areas, particularly in environments where they are uncommon. Consult with fish and wildlife specialists early in the trail planning phase.
- For existing trails, consider discouraging or restricting access during sensitive times/seasons (e.g., mating or birthing seasons) to protect wildlife from undue stress.

The education of trail users is also an important and potentially highly effective management option for protecting wildlife. Organizations should encourage Leave No Trace practices and teach appropriate behaviors in areas where wildlife are found:

- Store food safely and leave no crumbs behind - fed animals too often become dead animals.
- It's OK for wildlife to notice you but you are "too close" or "too loud" if an animal stops what its doing and/or moves away from you.
- It's best to view wildlife through binoculars, spotting scopes, and telephoto lenses.
- All wildlife can be dangerous - be aware of the possible presence of animals and keep your distance to ensure your safety and theirs.

**Conclusion**

While land managers have long been concerned about the environmental impacts of mountain biking, there are still very few good studies published in peer-reviewed journals. White and others (2006) and Hendricks (1997) note that the majority of mountain biking research has focused on social issues, such as
conflicts between trail users. As a consequence, the ecological effects of mountain biking on trails and natural resources remain poorly understood.

Still, an emerging body of knowledge on the environmental impact of mountain biking can help guide current management decisions. All of the existing scientific studies indicate that while mountain biking, like all forms of recreational activity, can result in measurable impacts to vegetation, soil, water resources, and wildlife, the environmental effects of well-managed mountain biking are minimal.

Furthermore, while the impact mechanics and forces may be different from foot traffic, mountain biking impacts are little different from hiking, the most common and traditional form of trail-based recreational activity.

Key observations about the environmental impacts of mountain biking:

1. Environmental degradation can be substantially avoided or minimized when trail users are restricted to designated formal trails. Many studies have shown that the most damage to plants and soils occur with initial traffic and that the per capita increase in further impact diminishes rapidly with increasing subsequent traffic. Many environmental impacts can be avoided and the rest are substantially minimized when traffic is restricted to a well-designed and managed trail. The best trail alignments avoid the habitats of rare flora and fauna and greatly minimize soil erosion, muddiness, and tread widening by focusing traffic on side-hill trail alignments with limited grades and frequent grade reversals. Even wildlife impacts are greatly minimized when visitors stay on trails; wildlife have a well-documented capacity to habituate to non-threatening recreational uses that occur in consistent places.

2. Trail design and management are much larger factors in environmental degradation than the type or amount of use. Many studies have demonstrated that poorly designed or located trails are the biggest cause of trail impacts. As evidence, consider that use factors (type, amount, and behavior of trail visitors) are generally the same along the length of any given trail, yet there is often substantial variation in tread erosion, width, and muddiness. These impacts are primarily attributable to differences in grade and slope alignment angle, soil type and soil moisture, and type of tread construction, surfacing, and drainage. This suggests that a sustainable trail that is properly designed, constructed, and maintained can support lower-impact uses such as hiking and mountain biking with minimal maintenance or degradation.

3. The environmental degradation caused by mountain biking is generally equivalent or less than that caused by hiking, and both are substantially less impacting than horse or motorized activities. In the small number of studies that included direct comparisons of the environmental effects of different recreational activities, mountain biking was found to have an impact that is less than or comparable to hiking. For example, Marion and
Olive (2006) reported less soil loss on mountain bike trails than on hiking trails, which in turn exhibited substantially less soil loss than did horse and ATV trails. Similarly, two wildlife studies reported no difference in wildlife disturbance between hikers and mountain bikers (Taylor & Knight 2003, Gander & Ingold 1997), while two other studies found that mountain bikers caused less disturbance (Papouchis and others. 2001, Spahr 1990). Wilson and Seney (1994) found that horses made significantly more sediment available for erosion than hikers or mountain bikers, which were statistically similar to the undisturbed control. One final point to consider, however, is that mountain bikers, like horse and vehicle users, travel further than hikers due to their higher speed of travel. This means that their use on a per-unit time basis can affect more miles of trail or wildlife than hikers. However, an evaluation of aggregate impact would need to consider the total number of trail users, and hikers are far more numerous than mountain bikers.

**Mountain Bike Management Implications**

So what does this mean for mountain biking? The existing body of research does not support the prohibition or restriction of mountain biking from a resource or environmental protection perspective. Existing impacts, which may be in evidence on many trails used by mountain bikers, are likely associated for the most part with poor trail designs or insufficient maintenance.

Managers should look first to correcting design-related deficiencies before considering restrictions on low-impact users. By enlisting the aid of all trail users through permanent volunteer trail maintenance efforts, they can improve trail conditions and allow for sustainable recreation.

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**Sources**


Impacts of Experimentally Applied Mountain Biking and Hiking on Vegetation and Soil of a Deciduous Forest, (2001)

Edon Thurston & Richard Reader.

RESEARCH

Impacts of Experimentally Applied Mountain Biking and Hiking on Vegetation and Soil of a Deciduous Forest

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ABSTRACT / Many recent trail degradation problems have been attributed to mountain biking because of its alleged capacity to do more damage than other activities, particularly hiking. This study compared the effects of experimentally applied mountain biking and hiking on the understory vegetation and soil of a deciduous forest. Five different intensities of biking and hiking (i.e., 0, 25, 75, 200 and 500 passes) were applied to 4-m-long × 1-m-wide lanes in Boyne Valley Provincial Park, Ontario, Canada. Measurements of plant stem density, species richness, and soil exposure were made before treatment, two weeks after treatment, and again one year after treatment. Biking and hiking generally had similar effects on vegetation and soil. Two weeks after treatment, stem density and species richness were reduced by up to 100% of pretreatment values. In addition, the amount of soil exposed increased by up to 54%. One year later, these treatment effects were no longer detectable. These results indicate that at a similar intensity of activity, the short-term impacts of mountain biking and hiking may not differ greatly in the undisturbed area of a deciduous forest habitat. The immediate impacts of both activities can be severe but rapid recovery should be expected when the activities are not allowed to continue. Implications of these results for trail recreation are discussed.

Managers of natural areas consider recreational impacts along trails and on campsites to be their most common management problem (Godin and Leonard 1979, Washburne and Cole 1983). The field of recreation ecology, which developed to address this problem, initially focused largely on the impacts of hikers (Cole 1987a). Impacts of recreation on trails can vary between activity types (e.g., hikers, horses, and motorcycles) (Weaver and Dale 1978), so it is important to know the impacts of new forms of recreational activity, such as mountain biking.

The addition of mountain biking to trails in recreation areas has caused considerable concern. Some hikers feel that bikers should be excluded from existing trails because of the potential damaging effect of moving wheels (Cessford 1995). The Sierra Club cited potential degradation of the environment as a reason for developing guidelines and policies on biker access to trails (Coello 1989). Some park supervisors and managers have also attributed trail damage to mountain biking (Chavez 1996, Schuett 1997). A number of factors may contribute to trail degradation following the addition of mountain bikes, including biker behavior and the physical impact of bikes.

Numerous studies have focused on the behavior basis for mountain biking impacts (Watson and others 1991, Chavez and others 1993, Ruff and Mellors 1993, Cessford 1995, Schuett 1997, Goeft 1999, Symmonds and others 1999, 2000). Much less research has focused on the physical impacts of mountain biking. One study (Wilson and Seney 1994) appears in the primary literature and several others are unpublished (Petit and Pontes 1987, Goeft 1999). Wilson and Seney (1994) compared the soil erosion caused by mountain bikes, hikers, horses, and motorcycles using experimentally applied passes in Montana. They found that horses made more sediment available to erosion than mountain bikes, hikers or motorcycles, which did not differ significantly from each other or from the control. Their experiment was conducted on an existing trail with a history of prior, multiple use. Additional studies are needed to answer questions about how mountain bikes impact vegetation and soils at early stages of trail formation and how these impacts compare with those caused by other activities (e.g., hiking).

In areas with established trail systems, a common problem reported by managers is the tendency of users to go off-trail, creating impromptu paths (Cole 1985). Off-trail use can result in parallel tracks or trail widening where the main trail is more difficult to traverse.

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Materials and Methods

Study Area

The study was conducted in Boyne Valley Provincial Park (44°05’N, 80°08’W), located 60 km northwest of Toronto, Ontario, Canada. A site was selected within the park that satisfied two criteria: (1) a mature deciduous forest with continuous canopy, and (2) absence of timber harvesting. The site occupies an area of approximately 270 ha, at an elevation of 420–470 m. The dominant tree cover is sugar maple (*Acer saccharum* L.), and the predominant soil type is a well-drained fine sandy loam of the Hillsburgh soil series (Hoffman and others 1964).

Experimental Design

The experiment consisted of two treatments: activity type (hiking or biking) and pass intensity (0, 25, 75, 200, and 500 passes), resulting in ten treatment combinations. A maximum of 500 passes was chosen based on the finding of Cole and Bayfield (1993) that 500 passes was sufficient to cause at least a 50% reduction in vegetation cover for most vegetation types. Each of the ten treatment combinations was randomly assigned to one of ten treatment lanes within a 50-m-long × 5-m-wide block. Lanes were 5 m long and 1 m wide (Figure 1A). Lanes were separated by a buffer zone of 5 m to avoid potential treatment carryover effects and to allow access for taking measurements. The 50 cm at each end of the 5 m lane were used as buffer zones so that the sampled portion was 4 m long × 1 m wide. The meter-wide plots were divided into three zones (center, middle, and outer) to allow for spatial variation in biking and hiking impacts (Figure 1B). The ten blocks were set up at least 5 m away from one another and at least 25 m from the edge of the forest.

Treatment Application

Each block was positioned on a slope so that the treatment lanes ran perpendicular to slope contours. An effort was made to position each block so that terrain microtopography was as homogeneous as possible from one end to the other. Slopes were measured with a clinometer at each of the ten lanes along the base of each block. The mean slope measurements for the ten chosen blocks ranged from 9.0° to 14.7°. Block locations were also selected to share the same southerly aspect. The centerline of each lane was marked by five wire pegs tied with flagging tape to indicate the path to be followed by bikers and hikers.

Biking and hiking treatments were applied by the same four participants, weighing between 57 and 73 kg. To apply hiking passes, three hikers wore lug-soled hiking boots and one wore rubber-soled running shoes. Three mountain bikes, two Norco Kokanees and one Raleigh Legend, each weighing 13.5 kg, were used to apply biking passes. All three bikes had 18-inch chrom-alloy frames, with heavily lugged tires (65.4 cm diameter, and 4.9 cm width), with 21 speed Shimano front and rear derailleur gears, and Shimano cantilever hand brakes. The total weights of bikes plus riders ranged from 70.5 to 86.5 kg.

Biking and hiking treatments were applied from the start of the last week of June to the middle of the second week of August 1997. The total number of passes required for an individual block (1600) was scheduled to be completed over a one-week period. The number of passes to be completed on a particular lane was distributed over the same number of days so that on a given day a 25-pass lane might receive two passes per person while a 500-pass lane would receive
40. As well, the number of passes scheduled to be completed on a given day were distributed among all participants in order to balance weight differences.

A pass was a one-way walk or bike trip down a lane following the premarked centerline path. Bikers could not make uphill passes, even in the lowest of 21 gears, due to slope, rough terrain, and tree sapling density, so passes by both hikers and bikers were only made downhill. Hikers moved at a natural gait, adjusting their pace on steeper slopes and over rough terrain to maintain balance. During the initial passes down a given lane, hikers would occasionally stumble away from the lane centerline, or slide their boots over steeper sections, until a path developed. Bikers traveled at a moderate speed, usually allowing bicycles to roll down lanes without pedaling where the slope would allow. Brakes were applied as needed to keep bicycles under control. Over rough terrain, some firm braking, occasional skidding, and some side-to-side movement of the front tire was required to maintain balance until a path developed. Once participants reached the bottom of a lane, they would turn and circle around the nearest end of the block back to the top of the lane to make a second pass. Treatment application schedules were adjusted to avoid heavy rain events for the safety of bikers and hikers. Blocks received approximately 19 mm of rain during treatment application.

To calculate the surface area covered by one pass of a hiker or bicycle, and the contact pressure applied by each, boot sole and tire measurements were taken. Hiker footwear had a mean single sole contact area of 215.1 cm² (range 200.0–228.8 cm²). The surface area

Figure 1. (A) Location of the ten treatment lanes per 50m × 5m block. (B) Enlargement of a 1-m × 1-m quadrat showing the three quadrat zones (center, middle, outer).
Contacted by two bicycle tires on the ground at any given moment (without a load being applied) was calculated as 224.3 cm² from an equation based on the tire geometry of agricultural vehicles: \( S = 0.7 \times \) undelected tire radius \( \times \) tire width (Soane and others 1981a, 1981b), where \( S \) is the contact area of one tire, radius = 32.7 cm, and tire width = 4.9 cm. The total surface area contacted by a biker would therefore be (assuming six steps per 4 m of lane) 1290.6 cm², and that by a biker would be tire width \( \times \) 4 m \( \times \) 2 wheels = 3920 cm². The pressure applied over one foot step was calculated as the weight of each hiker divided by the area covered by their boot sole. Hikers applied a mean pressure of 0.29 kg/cm² (range 0.27–0.32 kg/cm²). A similar approach was used to calculate the pressure applied over two bicycle tires at rest. Using bike plus biker weights and the contact area calculated above, the mean pressure applied by bicycle and rider was 0.35 kg/cm² (range 0.31–0.39 kg/cm²).

Response Variables

Three variables commonly used to assess recreational impacts were measured. First, the loss of vegetation following treatment application was measured by the change in vascular plant stem density from pretreatment stem density. Second, the loss of species richness was measured by the change in the number of plant species present. Third, the increase in the amount of soil exposed was measured.

Measurements were made immediately before biking and hiking passes were applied, and then two weeks after treatment application and again one year after treatment application.

Pretreatment measurements. A 1-m² wooden frame quadrat was positioned on the ground so that the lane centerline marked the center of the quadrat as well. String was attached to the 1 m² frame to divide it into twenty-five 20-cm \( \times \) 20-cm cells (Figure 1B). To accommodate the presence of saplings and other obstacles in the sampling area, a second quadrat was prepared that used removable thin wooden planks, instead of string, to outline the 25 cells. To consider the spatial differences in treatment effects from the center of the lane to its edges, the five columns of quadrat cells were grouped into three categories, or quadrat zones. The center column of five cells was referred to as the center zone, the two columns on either side of the center (i.e., ten cells) were called the middle zone, and the two outside columns of cells (i.e., ten cells) became the outer zone (Figure 1B). Measurements were made and recorded for each individual cell before being summarized for the three zones. Once measurements were completed for a quadrant, its position was marked at four corners using pegs tied with flagging tape so that the same exact spot would be used again during post-treatment sampling.

Vascular plants present in a cell were identified to species and species were each categorized as one of six growth forms: tree-seedlings (stem <1 cm diameter, height <1 m), tree saplings (stem >1 cm diameter, height >1 m), shrubs and vines, ferns, forbs (broad-leaved herbaceous plants), and graminoids (grasses and sedges). Mature trees were not encountered within the sampled lane areas. Once identified, the plants in each quadrat cell were counted. To avoid the problem of how to define individual plants (complicated by clonal growth), plants were counted by their aboveground stems only. Due to the dense clustered growth of the graminoids, they could not be enumerated as discrete stems with confidence. Instead, each graminoid species was simply observed as either present or absent in a given quadrat cell. Graminoid data were therefore only used in species richness calculations.

Exposed soil was defined as bare ground of the A horizon, free of macroscopic vegetation, leaf litter, twigs, moss, or humus. Soil exposure was visually estimated for each quadrat cell using a five-point scale: 0 (0–20%), 1 (21–40%), 2 (41–60%), 3 (61–80%), and 4 (81–100%).

Two weeks after treatment application. Effects of biking and hiking were first measured two weeks after treatment application. A two-week waiting period was recommended by Cole and Bayfield (1993) as the amount of time required to allow damage to vegetation to become apparent. Quadrats were repositioned using corner markers to ensure identical placement and the procedure used to measure pretreatment conditions was repeated during posttreatment sampling. Vascular plant stems present were classified as intact, damaged, dead, or absent. Intact stems were those found in their original condition. Damaged stems were those found with evident tissue loss (missing leaves), with impact-induced injury (broken stems, crushed plant body), or with yellowing or wilting plant parts. Dead stems were those with no green pigment and were brittle to the touch. Absent stems were simply missing. New shoots (<10 in total) were not included in the posttreatment vegetation survey. Soil exposure was estimated visually as in the pretreatment sampling, using the same five-point scale (0–4).

One year after treatment application. Posttreatment sampling was repeated one year after treatment application. A one-year period was recommended by Cole and Bayfield (1993) as the amount of time required for damage to either diminish or become more apparent, depending on the resiliency of the vegetation type.
Vascular plant stems were classified as present or absent. Soil exposure was estimated visually as in pretreatment sampling, using the same five-point scale (0–4).

Treatment Effects

Measurements taken during pretreatment and posttreatment sampling were used to calculate the following response variables. For each variable, data for the four quadrats per treatment lane were summed for each quadrat zone (center, middle, outer).

Loss of vegetation after two weeks. This was defined as the percentage of original vegetation found damaged, dead, or absent two weeks following treatment application. It was calculated as follows:

\[
\frac{\text{number of original stems found damaged, dead, or absent 2 weeks after}}{\text{number of stems present before}} \times 100\%
\]

where the words before and after refer to pre- and posttreatment measurements.

Loss of vegetation after one year. This was defined as the percentage of original vegetation that was absent one year following treatment application. It was calculated as follows:

\[
\frac{\text{number of original stems found absent 1 year after}}{\text{number of stems present before}} \times 100\%
\]

Treatment lanes where no plant stems were present initially (14 of 300 lanes) were not included in the analysis.

Loss of species after two weeks. This was defined as the percentage of initial species that were not present (i.e., all stems were dead or absent) two weeks following treatment application. It was calculated as follows:

\[
\frac{\text{number of species found dead or absent 2 weeks after}}{\text{number of species present before}} \times 100\%
\]

Loss of species after one year. This was defined as the percentage of initial species that were absent one year following treatment application. It was calculated as follows:

\[
\frac{\text{number of species found absent 1 year after}}{\text{number of species present before}} \times 100\%
\]

Increase in soil exposure after two weeks or one year. This was defined as the difference in cover estimates before and either two weeks or one year after treatment application. It was calculated as follows:

\[
\% \text{ exposed soil (2 weeks or 1 year) after} - \% \text{ exposed soil before}
\]

Statistical Analysis

To determine whether there were any preexisting differences among lanes assigned to different treatments, pretreatment (before) values for each response variable were compared using a three-factor split-plot analysis of variance (ANOVA). The two whole-plot factors were activity type (biking or hiking) and pass intensity (number of passes made). The split-plot factor was quadrat zone. This analysis was carried out using the PROC MIXED procedure of SAS (SAS Institute Inc., 1996). Data were square-root transformed to help meet assumptions of normality and equality of variance. This analysis revealed no significant pretreatment effects (Thurston 1998).

To assess statistical significance of posttreatment (after) effects, the three-factor analysis described above was repeated for each of the three response variables. Significant interaction terms involving quadrat zone made it necessary to analyze treatment effects for each zone separately. Data for each zone were analyzed with a two-factor ANOVA for a randomized complete-block design, using the PROC GLM procedure of SAS (SAS Institute Inc., 1996). The two treatment effects were activity type (biking and hiking) and pass intensity (0, 25, 75, 200, and 500 passes). Data were arcsine square-root-transformed for loss of vegetation and loss of species data after two weeks, square-root-transformed for soil exposure data, and log-transformed for loss of vegetation after one year data.

Results

Vegetation Composition

Fifty-five vascular plant species were encountered in pretreatment sampling (Appendix 1). The most common species were two forbs, Arisaema triphyllum (L.) Schott. (20 stems per lane), and Caulophyllum thalictroides (L.) Michx. (11 stems per lane), and seedlings of the tree Acer saccharum (7 stems per lane). A total of six different growth forms were encountered: forbs, tree seedlings, ferns, shrubs and vines, tree saplings, and graminoids. Based on total stem density, forbs ranked first with 77% of all stems, followed in turn by tree seedlings (17%), ferns (3%), shrubs and vines (2%), and tree saplings (1%).

Treatment Effects After Two Weeks

Loss of vegetation. Vegetation loss was significantly affected by pass intensity, by quadrat zone, and by the
Analysis of variance results for treatment effects on loss of vegetation, species richness, and increase in soil exposure after two weeks in three rat zones (Combined or Separated)\(^a\)

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>Loss of vegetation</th>
<th>Loss of species richness</th>
<th>Increase in soil exposure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Activity type (A)</td>
<td>0.6</td>
<td>0.5</td>
<td>2.3</td>
</tr>
<tr>
<td>Pass intensity (P)</td>
<td>40.1**</td>
<td>16.3**</td>
<td>53.7**</td>
</tr>
<tr>
<td>× Z</td>
<td>1.8</td>
<td>0.8</td>
<td>0.8</td>
</tr>
<tr>
<td>Quadrat zone (Z)</td>
<td>225.2**</td>
<td>188.6**</td>
<td>186.6**</td>
</tr>
<tr>
<td>× Activity type</td>
<td>2.4</td>
<td>1.1</td>
<td>0.9</td>
</tr>
<tr>
<td>× Pass intensity</td>
<td>11.8**</td>
<td>6.0***</td>
<td>25.0**</td>
</tr>
<tr>
<td>× Quadrat zone × Activity type</td>
<td>0.9</td>
<td>0.4</td>
<td>0.3</td>
</tr>
</tbody>
</table>

\(^a\)Blank symbols indicate a significant interaction. *P < 0.05, **P < 0.01, ***P < 0.001.

Species loss generally increased with increasing pass intensity for the two activity types combined (Figure 2b). In the center zone, species loss increased significantly from 28% on control lanes (0 passes) to 74%–99% on treated lanes (25–500 passes). In the middle zone, species loss differed significantly from 4% on control lanes (0 passes) to 22%–41% on treated lanes (25–500 passes). In the outer zone, no significant treatment effects were found, with species loss ranging from 6% to 14%.

Mean species loss did not differ significantly between biking and hiking treatments (Table 1, Combined), or were there any significant interactions between activity type and pass intensity in any zone (Table 1, Separated). Mean species loss was not affected by activity type or by any other interaction (Table 1).

Species loss generally increased with increasing pass intensity for the two activity types combined (Figure 2b). In the center zone, species loss increased significantly from 28% on control lanes (0 passes) to 74%–99% on treated lanes (25–500 passes). In the middle zone, species loss differed significantly from 4% on control lanes (0 passes) to 22%–41% on treated lanes (25–500 passes). In the outer zone, no significant treatment effects were found, with species loss ranging from 6% to 14%.

Mean species loss did not differ significantly between biking and hiking treatments (Table 1, Combined), or were there any significant interactions between activity type and pass intensity in any zone (Table 1, Separated). Mean species loss was not affected by activity type or by any other interaction (Table 1).

Increase in soil exposure. Soil exposure was significantly affected by activity type, by quadrat zone, and by the interaction of the two (Table 1). The interaction resulted from the significant pass intensity effect being detected in both the center and middle zones but not in the outer zone (Table 1). Neither activity type nor any interaction involving activity type was statistically significant when all three zones were considered together (Table 1).

In the center zone, mean soil exposure increased gradually and significantly from 1% on control lanes (0 passes) to 49% on treated lanes (Figure 2c). In the middle zone, mean soil exposure increased significantly with pass intensity but to a lesser extent than in the center zone, ranging from 1% for control lanes (0 passes) to a maximum increase of 21% for treated lanes. In the outer zone, no significant treatment effects were found. Mean increase in soil exposure ranged from −0.2% to 1%.

Mean soil exposure did not differ significantly between biking and hiking treatments in any zone (Table 1). Mean soil exposure over all pass intensities was greatest in the center zone (30% for biking lanes, 23% for hiking lanes), moderate in the middle zone (55% for biking, 47% for hiking), and least in the outer zone (19% for biking, 22% for hiking).
zone (10% for biking lanes, 8% for hiking lanes), and least in the outer zone (0.6% for both activities) (Figure 3c).

Analysis of variance results for soil exposure in the middle zone indicated a significant interaction between activity type and pass intensity (Table 1, Separated). This interaction was due to the fact that soil exposure following biking was only significantly greater than hiking at one pass-intensity (i.e., 500 passes) (Thurston 1998).

**Treatment Effects After One Year**

*Loss of vegetation.* Vegetation loss did not differ significantly between activity types or among pass intensities (Table 2). There was a significant difference among zones, however. Mean vegetation loss in the outer zone (7%) and in the middle zone (11%) were significantly less than in the center zone (31%) for all pass intensities and activity types combined. None of the interaction effects involving zone, activity type or pass intensity were statistically significant.

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**Figure 2.** Effect of increasing pass intensity on the mean (±1 SE) loss of vegetation, loss of species richness, and increase in soil exposure two weeks after treatment in the three quadrat zones for the two activity types (biking and hiking) combined.
Mean vegetation loss for all pass intensities combined ranged from 1% in the outer zone to 34% in the center zone (Figure 4a). Mean vegetation loss for activity types combined ranged from 2% in the outer zone to 42% in the center zone (Figure 5a). The negative value indicates an increase in posttreatment stem density over pretreatment stem density.

Species loss. Species loss did not differ significantly between treatments but it did differ among zones (Table 2, Combined). Mean species losses in the outer zone (6%) and in the middle zone (8%) were significantly less than species loss in the center zone (24%) for all pass intensities and activity types combined. None of the interaction effects involving zone, activity type or pass intensity were statistically significant.

Mean species loss for activity types combined ranged from 3% in the outer zone to 30% in the center zone (Figure 4b). Mean species loss for all pass intensities combined ranged from 2% in the outer zone to 25% in the center zone (Figure 5b).

Increase in soil exposure. Soil exposure did not differ significantly between activity types or among pass intensities (Table 2, Combined). However, the interaction of activity type × pass intensity was significant. This interaction resulted from soil exposure being greater on biking 500 pass lanes than hiking 500 pass lanes but not at lower pass intensities (0–200 passes) (Thurston 1998). There was also a significant difference in soil exposure among quadrat zones, with the center (4%) and middle zones (2.4%) greater than the outer zone (0.2%). None of the other interaction effects involving zone, activity type, or pass intensity were statistically significant.

**Table 2. Analysis of variance results for treatment effects on loss of vegetation, species richness, and increase in soil exposure after one year in the three quadrat zones (Combined or Separated)**

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>F-value</th>
<th>Loss of vegetation</th>
<th>Loss of species richness</th>
<th>Increase in soil exposure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combined</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Activity type (A)</td>
<td>0.07</td>
<td>0.9</td>
<td>0.2</td>
<td></td>
</tr>
<tr>
<td>Pass intensity (P)</td>
<td>0.8</td>
<td>0.6</td>
<td>1.8</td>
<td></td>
</tr>
<tr>
<td>A × P</td>
<td>1.1</td>
<td>1.6</td>
<td>4.1**</td>
<td></td>
</tr>
<tr>
<td>Quadrant zone (Z)</td>
<td>6.1**</td>
<td>6.1**</td>
<td>9.0***</td>
<td></td>
</tr>
<tr>
<td>A × Z</td>
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<td>0.6</td>
<td>0.2</td>
<td></td>
</tr>
<tr>
<td>P × Z</td>
<td>0.3</td>
<td>0.4</td>
<td>0.9</td>
<td></td>
</tr>
<tr>
<td>A × P × Z</td>
<td>0.3</td>
<td>0.4</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>Separated</td>
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<td>0.03</td>
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<td>0.6</td>
<td>2.1</td>
<td></td>
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<tr>
<td>A × P</td>
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<td>1.2</td>
<td>0.7</td>
<td></td>
</tr>
<tr>
<td>Middle zone</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Activity type</td>
<td>0.8</td>
<td>1.3</td>
<td>0.4</td>
<td></td>
</tr>
<tr>
<td>Pass intensity</td>
<td>0.5</td>
<td>0.7</td>
<td>2.2</td>
<td></td>
</tr>
<tr>
<td>A × P</td>
<td>0.5</td>
<td>0.5</td>
<td>1.9</td>
<td></td>
</tr>
<tr>
<td>Outer zone</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Activity type</td>
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<td>1.0</td>
<td>0.3</td>
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</tr>
<tr>
<td>Pass intensity</td>
<td>0.5</td>
<td>0.3</td>
<td>0.9</td>
<td></td>
</tr>
<tr>
<td>A × P</td>
<td>0.9</td>
<td>0.8</td>
<td>1.5</td>
<td></td>
</tr>
</tbody>
</table>

*Blank = P > 0.05, **P < 0.01, ***P < 0.001.
significant. Mean values for exposed soil over both activity types ranged from \(-1.1\%\) to \(7.0\%\) (Figure 4c). Mean soil exposure for all pass intensities combined ranged from \(-0.6\%\) to \(4\%\) (Figure 5c).

Discussion

Three principal findings emerged from this study. First, impacts on vegetation and soil increased with biking and hiking activity. Second, the impacts of biking and hiking measured here were not significantly different. Third, impacts did not extend beyond 30 cm of the trail centerline. These findings are discussed in turn below, followed by suggestions for future research and the management implications of our results.

Pass-Intensity Effects After Two Weeks

In the center zone, both vegetation loss and species loss occurred rapidly with biking or hiking activity. After only 25 passes nearly every plant stem present in the center zone was damaged. Effects were less pronounced in the middle and outer zones because bikers and hikers only came in contact with vegetation when they strayed from the lane centerline. The asymptotic

**Figure 4.** Effect of increasing pass intensity on the mean (±1 SE) loss of vegetation, loss of species richness and increase in soil exposure one year after treatment in the three quadrat zones for the two activity types (biking and hiking) combined.
A pattern of vegetation loss with increasing amount of recreational activity found here is characteristic of deciduous forests with understories dominated by erect forbs. Numerous studies have identified closed-canopy forests among the habitats most susceptible to recreational impact (Kuss 1986, Cole 1979, 1987a, b, 1995a, b). The loss of species due to recreational activity is likely controlled by several species attributes. First, growth forms with tall, succulent stems and broad leaves, such as the erect forb species observed in this study, are easily crushed and broken by recreational activity, while growth forms with narrow leaves and flexible stems, such as graminoids, are more resistant (Sun and Liddle 1993a, b). Second, rare species are more likely to be lost than common species. Both attributes may have contributed to species loss in this study because erect forbs dominated the sampled lanes and approximately one third (35%) of the species present initially in treatment lanes were represented by five or fewer stems.

Soil exposure increased almost linearly from the lowest pass lanes to the highest rather than asymptotically, as was observed for vegetation loss. Mean values for increased soil exposure did not exceed 49% on the 500 pass lanes of the center zone, whereas vegetation loss reached 99% on the same lanes. These results indicate that the loss of organic horizons does not occur as rapidly or does not become as severe at low trampling intensities as does vegetation loss. This is explained simply by the fact that as vegetation is damaged and killed by low levels of use, surface organic layers (i.e., leaf litter) are only just beginning to be scuffed away (Cole 1987a). Cole (1987b) found that soil exposure below 100 passes per year was negligible, and Quinn and others (1980) observed that bare ground did not appear until after at least 250 passes were made.

**Pass-Intensity Effects After One Year**

One year following treatments, neither vegetation loss nor species loss was significantly greater on treated lanes than on control lanes. Most of the herbaceous plant species at the study site were perennials, with their perennating buds located at or below the soil surface (Gleason and Cronquist 1991). In these species, aboveground stems may be damaged or removed in a given season, but if the perennating organ remains intact, plants should be able to replace lost stems in following seasons. Presumably, resprouting from dormant buds would account for the absence of any treatment effect after one year. Our results support Cole’s (1987a, 1995b) suggestion that deciduous forest understory plants have high resilience (i.e., the ability to subsequently recover) when the recreational activity is not continuous.

The amount of soil still exposed after one year in treated lanes did not differ significantly from control lanes. The absence of a detectable treatment effect was likely due to the addition of deciduous tree leaves to the forest floor in the autumn following treatment application. Over-winter reduction in exposed soil has been attributed to leaf fall by a number of investigators.

![Figure 5](image-url)
Activity-Type Effects

For the response variables measured in this study, there were no significant differences between hiking and mountain biking treatments. One possible explanation is that when vulnerable plants are directly contacted by a weight-bearing surface they will be affected no matter what the weight-bearing surface is, once a certain weight threshold is met. If weights of user groups are only slightly different, as with hikers (e.g., 60 kg) and mountain bikers (e.g., 75 kg, bike and biker included), there should be little difference in their impact on vegetation and soil. In this study, the weight applied per unit area of ground contacted (i.e., contact pressure) was very similar. Biker contact pressure (0.35 kg/cm²) was only 0.06 kg/cm² more than the contact pressure of a hiker balanced on one foot (0.29 kg/cm²). However, when the weights of two user-groups are considerably different, as with hikers (e.g., 85 kg) and horses (e.g., 550 kg), the magnitude of damage to vegetation is clearly greater for the larger weight-bearing activity (Weaver and Dale 1978).

Spatial Dependency of Effects

The magnitude of biking and hiking effects on vegetation and soil declined sharply with distance from the center of the treatment lane. After a maximum of 500 passes, visible impact was concentrated within a narrow zone, no greater than 30 cm from the lane centerline. The center zone of a treatment zone received the most concentrated use, and consequently, revealed the most severe impact even at low pass intensities. The middle zone received only occasional passes of bikers and hikers when they strayed from the lane centerlines, therefore revealing only moderate impact. In the outer zone almost no foot or bike tire contacted the ground and no changes in parameters could be detected after treatments were applied.

Identifying the scale of impact for recreational activities puts into perspective the relative amount of damage they cause.

Future Research

Our study compared the impacts of biking and hiking under a particular set of conditions so additional studies conducted under other conditions are needed to test the generality of our findings. In these studies, it would be useful to compare impacts for (1) a maximum of more than the 500 passes applied here, (2) uphill rather than downhill passes, (3) established rather than new trails, (4) habitats other than deciduous forest, and (5) wet rather than dry conditions.

If future research confirms our finding that the physical impacts of mountain biking on vegetation and soil seem to be no worse than those of hiking, then there must be other reasons for the belief that mountain biking is to blame for recent trail degradation problems. One possibility is that behavioral differences between bikers and hikers are responsible for reports of greater biking impact. Bikers, in general, enjoy the challenge of obstacles on the trail, such as bumps and jumps, gullies, roots, rocks, and surface water (Symmonds and others 1999, 2000). Many of these features are the result of erosion. If mountain bikers seek out eroded areas, and hikers do not, then bikes will in fact contribute further to soil erosion problems. A second possibility is that mountain bikers simply contribute further to the overuse of trails. In other words, it may not be the activity of mountain biking per se that is to blame for these problems but rather the addition of this user group to hikers and others that has exacerbated overuse problems on already crowded trails (Ruff and Mellors 1993).

Mountain bikes are also be alleged to cause damage because of the inherent conflict between recreational user groups sharing the same space. Conflicts between user groups that differ in technology and methods of travel are common, such as between cross-country skiers and snowmobilers, or canoeists and those using motorboats (Watson and others 1991). Bikers move faster than hikers and equestrians, and these slower-paced users have complained that bikers startle them and present a safety hazard (Keller 1990). Mountain bikes have also been characterized as mechanized by hikers and managers and are therefore judged as inappropriate in a natural setting (Cessford 1995). In recreational conflict research, conventional wisdom states that users of more physically obtrusive technologies are resented by users of less obtrusive technologies (Devall and Harry 1981). Since mountain bikes are visually obtrusive, objectionable to other users, and leave easily identifiable evidence of their passing in the form of tire marks, they are commonly assigned as the cause of environmental damage (Cessford 1995).

Management Implications

Resource managers have no objective basis for managing biking activity in natural areas without research results. If further research on mountain biking impacts confirms our finding that biking and hiking can have similar physical impacts, then managers should be able to use results of past hiking impact studies to predict where and when biking impacts are likely to occur.
Appendix 1. Species composition and mean stem density of vascular plants present in the 100 experimental lanes before treatments were applied.  

<table>
<thead>
<tr>
<th>Species</th>
<th>Mean stem density (stems per lane)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forbs</td>
<td></td>
</tr>
<tr>
<td>Arisaema triphyllum</td>
<td>20.05</td>
</tr>
<tr>
<td>Carex pedunculata</td>
<td>11.43</td>
</tr>
<tr>
<td>Other species</td>
<td>14.84</td>
</tr>
<tr>
<td>Total</td>
<td>46.32</td>
</tr>
<tr>
<td>Tree seedlings</td>
<td></td>
</tr>
<tr>
<td>Acer saccharum</td>
<td>6.86</td>
</tr>
<tr>
<td>Fraxinus americana</td>
<td>1.76</td>
</tr>
<tr>
<td>Other species</td>
<td>1.53</td>
</tr>
<tr>
<td>Total</td>
<td>10.15</td>
</tr>
<tr>
<td>Ferns</td>
<td></td>
</tr>
<tr>
<td>Dryopteris carthusiana</td>
<td>0.54</td>
</tr>
<tr>
<td>Athyrium filix-femina</td>
<td>0.40</td>
</tr>
<tr>
<td>Other species</td>
<td>0.82</td>
</tr>
<tr>
<td>Total</td>
<td>1.76</td>
</tr>
<tr>
<td>Shrubs and vines</td>
<td></td>
</tr>
<tr>
<td>Cornus alternifolia</td>
<td>0.55</td>
</tr>
<tr>
<td>Solanum dulcamara</td>
<td>0.51</td>
</tr>
<tr>
<td>Other species</td>
<td>0.08</td>
</tr>
<tr>
<td>Total</td>
<td>1.14</td>
</tr>
<tr>
<td>Tree saplings</td>
<td></td>
</tr>
<tr>
<td>Acer saccharum</td>
<td>0.62</td>
</tr>
<tr>
<td>Ostrya virginiana</td>
<td>0.12</td>
</tr>
<tr>
<td>Other species</td>
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</tr>
<tr>
<td>Total</td>
<td>0.79</td>
</tr>
<tr>
<td>Graminoids</td>
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</tr>
<tr>
<td>Carex pedunculata</td>
<td>4.21</td>
</tr>
<tr>
<td>Carex radiata</td>
<td>0.42</td>
</tr>
<tr>
<td>Other species</td>
<td>0.44</td>
</tr>
<tr>
<td>Total</td>
<td>5.07</td>
</tr>
</tbody>
</table>

Managers of natural areas also need to know how quickly impromptu or informal trails can form when people leave the main path and whether this threshold number of passes differs for hiking or biking. From the results of this study, it would appear that informal trails should not form any more quickly for biking than for hiking. However, managers should be aware that the immediate impacts of both activities can be severe, and obvious trails will form after relatively very few passes (i.e., less than 500). If these initial trails are not allowed to persist, rapid recovery should be expected in a deciduous forest habitat with a forb-dominated understory, at least for the range of use intensities employed here.

Acknowledgments

We thank the Natural Sciences and Engineering Research Council of Canada, Ontario Parks, and Mountain Equipment Co-op for their financial support. We also appreciated the assistance of Brian Huis and Brad Warren of Ontario Parks. Sincere thanks are extended to Pete Kelly for fieldwork and analysis, Carol Ann Lacroix for plant identification, and to Doug Larson, Brian Husband, David Cole, Michael Schuett, and Kenneth Barrick for their helpful comments on previous versions of the paper.

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Erosional impact of hikers, horses, motorcycles, and off-road bicycles on mountain trails in Montana, (1994)

Wilson, John, and Seney, Joseph.

Mountain Research and Development, Volume 14, Issue 1, p. 77-88.
EROSIONAL IMPACT OF HIKERS, HORSES, MOTORCYCLES, AND OFF-ROAD BICYCLES ON MOUNTAIN TRAILS IN MONTANA

JOHN P. WILSON1 AND JOSEPH P. SENY2

ABSTRACT This study examined the relative impact of hikers, horses, motorcycles, and off-road bicycles in terms of water runoff and sediment yield from 108 sample plots on existing trails in or near Gallatin National Forest, Montana. A modified Meinweg drip-type rainfall simulator was used to reproduce natural rainstorm events. Treatments of 100 passes were applied to each plot. The results confirmed the complex interactions that occur between topographic, soil, and geomorphic variables noted by others, and the difficulty of interpreting their impact on existing trails. None of the hypothesized relationships between water runoff and slope, soil texture, antecedent soil moisture, trail roughness, and soil resistance was statistically significant. Five independent variables or cross-products explained 42% of the variability in sediment yield when soil texture was added as a series of indicator variables. Ten variables combined to explain 70% of the variability in sediment yield when trail user was added as a second series of indicator variables. Terms incorporating soil texture (37%), slope (35%), and user treatment (35%) accounted for the largest contributions. Multiple comparisons test results showed that horses and hikers (hooves and feet) made more sediment available than wheels (motorcycles and off-road bicycles) and that this effect was most pronounced on prewetted trails.

RESUMÉ Impact érosif des randonneurs à pied, des chevaux, des motocyclettes et bicyclettes tous-terrains, sur les sentiers de montagne du Montana. Cette étude examine l’impact relatif des randonneurs à pied, des chevaux, des motocyclettes et bicyclettes tous-terrains, en termes de ruissellement d’eau et de production de sédiments sur 108 parcelles échantillons de sentiers de montagne situées à l’intérieur ou au voisinage de la forêt nationale de Gallatin, dans l’État du Montana. Un simulateur de pluies de Meinweg modifié, type dégouttement, a été utilisé pour reproduire des tempêtes de pluie naturelles. Les traitements de 100 passes ont été appliqués à chaque parcelle. Les résultats confirment les interactions complexes entre les variables topographiques, édaphiques et géomorphiques qui avaient été observées par d’autres chercheurs, et la difficulté d’interpréter leur impact sur les sentiers de montagne existants. Aucune des supposées relations entre le ruissellement d’eau et la pente, la texture du sol, l’humidité antérieure, l’inégalité du sentier et la résistance du sol n’est statistiquement significative. Cinq variables indépendantes ou produits en croix expliquent 42 pour cent de la variabilité de la production de sédiments lorsque la texture du sol est ajoutée en tant que série de variables indicatrices. Dix variables se combinent pour expliquer 70 pour cent de la variabilité de la production de sédiments lorsque l’utilisateur du sentier est ajouté en tant que seconde série de variables indicatrices. Les termes incorporant la texture du sol (37 pour cent), la pente (35 pour cent) et le traitement par l’utilisateur (35 pour cent) rendent compte des contributions les plus importantes. Des comparaisons multiples des résultats de tests indiquent que les chevaux et les randonneurs (sabots et chaussures) produisent plus de sédiments que les motocyclettes et bicyclettes tous-terrains (roues) et que cet effet est plus prononcé sur les sentiers déjà humides.


INTRODUCTION

The tremendous increase in outdoor recreation during the past two decades has created crowded conditions and increased environmental impact in national forests and parks and other recreation areas (McQuaid-Cook, 1978; Cole, 1989). A 1975 survey of land managers reported substantial erosion on mountain trails during the previous decade that was attributed to dramatic increases in horse and foot travel on trails not designed to accommodate higher volumes of traffic (Godin and Leonard, 1979). Traffic has increased further during the past
fifteen years as trail use has grown to include motorcycles and off-road bicycles in addition to horse and foot traffic.

Today's land managers need to assess the carrying capacities of their trail systems as they struggle to build and maintain trails that can accommodate the increased types and numbers of users. The recent popularity of off-road bicycles in particular has increased user conflicts and erosional concerns among land managers and environmental organizations (Jacoby, 1990). Land managers must evaluate the trail impacts of all users and differentiate the emotional and environmental arguments that are invoked to support and/or challenge one or more of these uses. These conflicts emphasize the need for research that: (1) develops tools to estimate the carrying capacities of trail systems, and (2) compares the impacts of different trail users.

Most of the trail studies to date have examined either the natural processes and controls that influence trail condition and/or the relationships between specific uses and impacts (e.g., Bates, 1935; Dozenko et al., 1967; Dawson et al., 1974; Helgath, 1975; Bryan, 1977; Cole, 1978; Kuss and Morgan, 1980, 1984; Summer, 1980, 1986; Coleman, 1981; Fish et al., 1981; Kuss, 1986; Jablonski and O'Sullivan, 1987; Hall and Kuss, 1989; Kuss and Hall, 1991). Trampling and removal of vegetation are generally the first consequences of trail formation. Trampling often increases the bulk density of the soil which, in turn, decreases soil porosity and changes moisture content, aeration, and the availability of soil nutrients in ways that contribute to further losses of existing vegetation along trails (Liddle and Greig-Smith, 1975; Weaver and Dale, 1978; Kuss, 1983; Hall and Kuss, 1989; Kuss and Hall, 1991).

Accelerated soil erosion becomes the primary problem once the vegetation is lost, especially where trails channel water which is not diverted from the trail (Cole, 1987). Slope gradient and soil loss are positively correlated (Wischmeier and Smith, 1978; Leonard and Plumley, 1978; Coleman, 1981). Slope gradient, in turn, is closely associated with type of landform (Helgath, 1975). Trails that follow the slope channel water down the trail and increase erosion compared to trails running across the slope (Bratton et al., 1979). The erosion rate is also influenced by the position of the trail with respect to the top or bottom of a slope and the gradient of the slope along and across the trail. Summer (1986), for example, found that trails located below the crests of hillslopes in Rocky Mountain National Park, Colorado, had more erosion than trails located on other parts of the slope.

Another smaller group of studies has examined the differences in the impacts of foot, horse, and motorcycle traffic on trails (e.g., Ketchledge and Leonard, 1970; Dale and Weaver, 1974; Liddle, 1975; Helgath, 1975; Weaver and Dale, 1978; Bratton et al., 1979; Kuss, 1983; Burde and Renfro, 1986). These studies show that different trail uses result in different erosion rates, presumably because different users exert different forces. Weaver and Dale (1978) found that horses caused greater increases in soil compaction, litter, trail width and depth compared to hikers and motorcycles. Horse traffic applies the greatest force (weight per unit area) among hikers, horseback riders, off-road bicyclists, and motorcyclists.

Weaver and Dale (1978) also compared motorcycle erosion with horse and foot erosion. Motorcycles moving uphill established a narrow rut which increased the velocity and sediment transport capacity of trail runoff. The development of this linear channel was the direct result of the imprint of the tire and the torque applied by the motorcycle which then led to increased erosion. However, motorcycles moving downhill, when torque is not needed, caused less erosion than hikers and horses which tend to loosen soil when descending a steep trail because greater forces are applied when decelerating and moving down a steep trail. Shear stresses are increased and compressional stresses are reduced on steeper slopes and this increases the quantities of loose sediment available for transport (Quinn et al., 1980). Weaver and Dale (1978) suggested that motorcyles ascend gentle slopes and descend steep slopes and hikers/horses ascend steep slopes and descend gentle slopes to minimize erosional impacts.

The studies referred to above have important implications for this project, although the majority of these studies did not examine erosion along existing trails or from off-road bicycles. In particular, their results indicate: (1) the importance of rainfall intensity and slope gradient as key factors in explaining variations in soil loss on trails, and (2) that soil properties such as structure, texture, and moisture content determine the resistance to erosion and play secondary roles. Overall, these studies demonstrate the difficulty of quantifying relationships between natural variability, recreation activities, and trail degradation rates. Although several studies show trail degradation occurs regardless of specific uses and is more dependent on the geomorphic processes that occur in different landscapes, most studies to date have focused on specific trail segments or plots and on only one type of trail use.

Trail systems in national and state forests and parks weave their way through many different bedrock types, slope gradients, aspects, soils, and habitat types. Management of these trail systems requires knowledge of how people affect the environment at landscape scales in addition to knowledge of how human activities affect randomly selected sample plots and other micro-environments. Applying the results of the site-specific studies cited above to landscapes is problematic (Cole, 1987), although Helgath (1975) and Kuss and Morgan (1980, 1984) have proposed methodologies to anticipate and cope with the challenges of extending site-specific results to broader areas. Helgath (1975) suggested an index system based on "biophysical" units which would divide landforms and vegetation habitats into homogeneous environments. Each unit would have a specific potential for deterioration attached to it such that managers could strive to avoid those units where the erosive potential is high. Kuss and Morgan (1980) and Morgan and Kuss (1986) proposed using the Universal Soil Loss Equation (USLE) to estimate the carrying capacity of hiking trails. The equation, as modified by Kuss and Morgan, is written as T = RKLSC. The maximum rate of
soil erosion that will permit the productivity of the land to be sustained economically and indefinitely is represented by T and calculated in terms of rainfall (R), soil erodibility (K), slope gradient (S), slope length (L), and type and extent of vegetative cover (C). Kuss and Morgan (1980, 1984) argued that this modified USLE model would help the land manager to determine when the conditions warranted measures to prevent further erosion.

The approach of this study was different because an attempt was made to separate the user effects from the natural effects. The study had three objectives: (1) quantify the relationships between water runoff and selected topographic and soil variables; (2) quantify the relationships between sediment yield and selected hydrologic, topographic, and soil variables; and (3) quantify the relative impacts of different trail uses in terms of water runoff and sediment yield on two existing mountain trails. The results not only provide new information about the relative erosional impacts of low numbers of hikers, horses, motorcycles, and off-road bicycles on existing trails traversing a variety of slopes and soils, but they also show why a simple statistical model such as the USLE should not be used to measure the carrying capacity of these trails systems.

DESCRIPTION OF STUDY AREA

Two existing trails near Bozeman, Montana were selected as study sites based on ease of access, availability of water from adjacent streams, long consistent sections of trail, and a diversity of slope gradients and soil textures (Figure 1). Both trails have experienced all four types of use (foot, horse, motorcycle, and off-road bicycle traffic) over the past ten years. The study sites were located in or near Gallatin National Forest, and were dominated by lodgepole pine (Pinus contorta) and Douglas Fir (Pseudotsuga menziesii) with a variety of other species occupying smaller, mostly mesic sites.

The Emerald Lake study site consisted of a 1.6 km section of trail in Gallatin National Forest. The land surface (2,000 m elevation) consists of hummocky, rolling glacial till deposits of Pleistocene age derived from layered, volcanic rock at the bottom of a U-shaped valley. These medium-textured deposits contain variable amounts of sub-rounded rock fragments and the sandy loam or loam soils are generally well-drained. Subsoil clay accumulation occurs in some locations and rock fragments in the lower soil horizons range from 35-50 percent. The soils are classified as mixed, loamy skeletal, Typic Cryoboralfs (Davis and Shovic, 1984). A dense lodgepole pine forest surrounds this study site. The understory is composed of a thick groundcover of grouse whortleberry (Vaccinium scoparium), dwarf huckleberry (Vaccinium caespiatum), and twinflower (Linnaea borealis). The annual precipitation is 65-90 cm and 60 percent falls as snow. Trail access for horses, hikers, motorcycles, and off-road bicycles is limited prior to May or June by the remnant snowpack and saturated surface soils.

The New World Gulch study site was located on land immediately outside Gallatin National Forest administered by the State of Montana and consisted of a 0.8 km section of trail (1,600 m elevation). The topography consists of ridges with steep slopes and occasional small valleys or swales (Davis and Shovic, 1984). The location of ridges and swales is controlled by the underlying bedrock, with the more resistant sandstones and limestones forming ridges and shales and shales and limestones forming valleys. The bedrock consists of Lower Cretaceous Mowry and Thermopolis shale, Kootenai Formation sandstone and mudstone, and Jurassic Morrison Formation shale, siltstone, and mudstone (Roberts, 1964). Clay and clay loam soils have formed in material weathered from thickly-bedded sandstones and shales. The soils are moderately well-drained and classified as mixed, fine loamy Typic Cryoboralfs (Davis and Shovic, 1984). Vegetation surrounding this trail consists of perennial grasses and some Douglas Fir. This site also receives approximately 65-90 cm of precipitation and 60% falls as snow. Accessibility for horses, hikers, motorcycles, and off-road bicycles is limited in October-November and April-May due to the saturation of the predominantly clayey soils.

![Figure 1. Location Map for Emerald Lake and New World Gulch Trails. The plots used for the experiments were located on relatively uniform sections of the trails shown on this map.](image-url)
METHODS AND PROCEDURES

A modified Meeuwig drip-type rainfall simulator (Meeuwig, 1971a, 1971b) was used to reproduce natural rainstorm events. Treatments of 100 passes were applied to 54 sample plots located on each of the trails. The 12 sample plots used for each mode of travel represented two antecedent soil moisture conditions (dry and pre-wetted) and two slope gradient classes (0-6 and 8-21 percent) with three replications. The no treatment (control) case combined both antecedent soil moisture conditions and required only six plots.

Sample plot size (66 by 66 cm) was determined by the size of the containment tray for the rainfall simulator. Trail sections with uniform slope and soil conditions were selected for study plots from reconnaissance hikes along both trails in the spring of 1989. Trail sections with protruding rocks or roots were avoided, and litter and loose stones were removed prior to the treatments. Soil pits were dug adjacent to and across each trail section prior to the field experiments and the Keys to Soil Taxonomy (Soil Survey Staff, 1988) was used to describe and classify the soils.

FIELD EXPERIMENTS AND MEASUREMENTS

User treatments were assigned to sample plots based on the availability of the user (hiker, horse and rider, Honda XL125 motorcycle and rider, mountain bike and rider) and the antecedent soil moisture and slope gradient conditions needed for each experiment. Four-to-six experiments consisting of the tasks summarized in Table 1 were completed each field day.

Slope gradient, trail roughness, and soil resistance were measured prior to the treatments (Task 1). Slope gradient was measured with a Brunton compass and a 3.0 by 0.6 m board placed along specific sections of trail. Trail roughness or micro-relief was measured using 12 transverse marks off at 2.54 cm intervals along each sample plot and a 91.5 cm long, 5 by 10 cm board with 13 evenly spaced slots. A metal ruler was then inserted into each slot moving left to right and the depth was measured. High values represented depressions and low values high spots on the trail. The variance was computed and treated as high trail roughness. Soil resistance was measured at 11 points along two transects with a Soiltest, Inc. CN-970 proving ring penetrometer. This cone-type penetrometer consists of a T-handle, 45.7 cm penetration rod, 0.91 m extension, proving ring of 113.4 kg capacity with a dial indicator, and removable cone point (basal area 6.54 cm², conical area 24.69 cm²). When the cone is forced into the ground, the proving ring is deformed in proportion to the force applied. This force is thought to represent the shearing resistance of the soil (Liddle and Moore, 1973). The cone penetration was limited to one-half of the area of the cone (12.35 cm²) because the measurements were used only for relative comparisons between trail users.

Soil samples were also taken prior to each experiment for laboratory texture and moisture determinations (Task 1). Further soil moisture samples were taken after the rainfall events that constituted the second and sixth tasks. Trail roughness and soil resistance measurements also were taken as part of the third, fourth, fifth, and seventh tasks. Different pairs of transects were used for each set of soil resistance measurements.

The second task consisted of no activity for dry treatments and a rainstorm if the treatment was to be applied to a prewetted plot. The rainfall simulator was erected over the plot and a 20-minute rainstorm with a constant intensity of 127 mm hr⁻¹ was applied. The modified Meeuwig simulator used in the study had a 61 by 61 by 2.5 cm plexiglass water chamber with 500 drip needles made from hypodermic tubing. An electric motor was used to rotate the chamber to randomize the raindrops and a 18.9-liter plastic container was elevated 20 cm above the water chamber to provide a continuous supply of water. The Meeuwig simulator was chosen because of its easy assembly and modest water requirements, although its small size (155 cm drop fall height) meant that the kinetic energy of the simulated rainfall events was roughly one-third that of natural rainstorms (Schmid, 1988).

The third and seventh tasks listed in Table 1 included the collection of the surface runoff and sediment yield produced by the simulated rainstorms at the downslope end of each plot. A collection tray which funneled water and sediment into 0.76-liter plastic containers was used and the contents were emptied into larger 3.8-liter containers for transport back to the laboratory.

The application of the appropriate bicycling, hiking, horseback riding, and motorcycling treatments consisted

<table>
<thead>
<tr>
<th>TABLE 1</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Data collection activities</strong></td>
</tr>
<tr>
<td>1. Soil samples collected for laboratory texture and antecedent soil moisture measurements; slope gradient, trail roughness and soil resistance measurements taken.</td>
</tr>
<tr>
<td><strong>Tasks 2 and 3 skipped for dry treatments plots</strong></td>
</tr>
<tr>
<td>2. Meeuwig rainfall simulator erected over plot and 20 minute, 127 mm hr⁻¹ rainstorm applied.</td>
</tr>
<tr>
<td>3. Water runoff and sediment yield collected; soil samples taken for laboratory soil moisture measurements; trail roughness and soil resistance measured (again).</td>
</tr>
<tr>
<td><strong>Tasks 4 through 7 completed for all plots</strong></td>
</tr>
<tr>
<td>4. First 50 bicycle, hiker, horse, and motorcycle passes applied; trail roughness and soil resistance measured (again).</td>
</tr>
<tr>
<td>5. Second 50 bicycle, hiker, horse, and motorcycle passes applied; trail roughness and soil resistance measured (again).</td>
</tr>
<tr>
<td>6. Meeuwig rainfall simulator erected over plot and 20 minute, 127 mm hr⁻¹ rainstorm applied.</td>
</tr>
<tr>
<td>7. Water runoff and sediment yield collected; soil samples taken for laboratory soil moisture measurements; trail roughness and soil resistance measured (again).</td>
</tr>
</tbody>
</table>
Table 2

<table>
<thead>
<tr>
<th>Variable</th>
<th>Parameter estimate</th>
<th>Partial R²</th>
<th>Model R²</th>
<th>Prob &gt; F</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>30.64</td>
<td></td>
<td>0.18</td>
<td>0.0001</td>
<td>29.11</td>
</tr>
<tr>
<td>Slope × clay¹</td>
<td>5.79</td>
<td>0.18</td>
<td>0.18</td>
<td>0.0001</td>
<td>15.85</td>
</tr>
<tr>
<td>TR × sandy clay²</td>
<td>0.20</td>
<td>0.17</td>
<td>0.35</td>
<td>0.0001</td>
<td>48.53</td>
</tr>
<tr>
<td>Slope</td>
<td>1.49</td>
<td>0.04</td>
<td>0.39</td>
<td>0.0055</td>
<td>7.91</td>
</tr>
<tr>
<td>TR × clay³</td>
<td>0.23</td>
<td>0.02</td>
<td>0.41</td>
<td>0.0281</td>
<td>5.26</td>
</tr>
<tr>
<td>SM × loam¹</td>
<td>0.39</td>
<td>0.01</td>
<td>0.42</td>
<td>0.0411</td>
<td>4.24</td>
</tr>
</tbody>
</table>

¹Slope × clay represents the slope continuous variable and clay indicator variable cross-product.
²TR × sandy clay represents the antecedent trail roughness continuous variable and sandy clay indicator variable cross-product.
³TR × clay represents the antecedent trail roughness continuous variable and clay indicator variable cross-product.
⁴SM × loam represents the antecedent soil moisture continuous variable and loam indicator variable cross-product.

of two sets of 50 passes so that soil resistance and trail roughness could be measured after 50 and 100 passes (Tasks 4 and 5). Passes of at least 4 m in length were made so that users could mimic a "natural" trail gait.

**Laboratory Procedures**

The soil moisture, soil texture, water runoff, and sediment yield samples were analyzed at Montana State University’s Soil Testing Laboratory. The soil texture samples taken from each plot (Task 1) were hand-textured using the method described by Thien (1979). Wet soil moisture samples were weighed, oven-dried for 24 hours at 110°C, and then reweighed. Percent soil moisture equaled moist soil weight minus dry soil weight divided by dry soil weight. The water runoff samples were weighed using a Mettler PE 6000 digital scale, placed in a soil drying room (18°C) until all the water had evaporated from the containers, and then reweighed. Twenty-five 3.8-liter containers were weighed to determine the average weight of the containers, and this weight was subtracted from the dry sediment and container weights to determine sediment and water runoff masses.

**Statistical Methods**

Two statistical tests were used to examine the erosional impacts of the different trail users. Bivariate and multiple regression models were used to quantify relationships between the topographic and soil variables (independent variables), water runoff, and sediment yield (dependent variables). Human impacts were superimposed on these natural controls and the multiple comparisons test was then used to evaluate the relative impacts of different trail users.

The REG (regression) module in SAS (Freund and Littell, 1986) was used to develop bivariate and multiple regression models. The bivariate models compared water runoff and sediment yield with slope gradient (X₁), antecedent soil moisture (X₂), trail roughness (X₃), soil resistance (X₄) and water runoff (X₅) (when sediment yield was treated as the dependent variable). The multiple regression models were built in three stages. The first model incorporated the five continuous variables used for the bivariate models. The second and third models incorporated these same continuous variables and indicator variables for soil texture and trail user, respectively.

Three soil texture indicator variables and fifteen cross-product variables representing the interaction effects between these indicator variables and the five continuous variables tried in the first model were added to the second regression model. The inclusion of the indicator variables divided the entire data set into four soil textural classes or subgroups representing clay, sandy clay, loam, and sandy loam soils. The three indicator variables were added such that X₀=1 for clay soils and 0 in all other cases, X₁=1 for sandy clay soils and 0 in all other cases, and X₂=1 for loam soils and 0 in all other cases. The plots with sandy loam soil textures were represented by the default case in which X₀=X₁=X₂=0. This choice was arbitrary (i.e., one of the other texture groups could have served as the default case), although it did mean that the coefficients for the terms incorporating the other indicator variables were computed relative to the sandy loam texture reference group.

Overall, the inclusion of the indicator variables and interaction terms meant that different regression models were prepared for each soil texture class. The coefficients computed with this type of regression model are often referred to as shift coefficients because they permit the coefficients to change or shift from one class to the next. The multicollinearity problems sometimes encountered with this approach were minimized by running the model with all the possibilities (i.e., the 5 continuous variables, 5 indicator variables, and 15 interaction variables), deleting the non-significant terms, and running the model again. The stepwise option was used with the REG procedure and 0.05 significance level to select the variables included in the final regression model reproduced in Table 2.

The addition of a second series of indicator variables representing five trail user classes or subgroups (hiker, horse, motorcycle, off-road bicycle, and null treatment cases) was accomplished with the third multiple regression model. Four indicator variables were added such that X₀=1 for hikers and 0 in all other cases, X₁₀=1 for horses.
and 0 in all other cases, X_{ij} = 1 for motorcycles and 0 in all other cases, and X_{ij} = 1 for off-road bicycles and 0 in all other cases. The null treatment or control plots were represented by the default case in which X_0 = X_{10} = X_{11} = X_{12} = 0. The multicolinearity problems were again minimized by running the model with all the possibilities (i.e., a total of 5 continuous, 7 indicator, and 95 interaction variables), deleting the non-significant terms, and running the model again. The stepwise option and 0.05 level of significance were used to select the terms in this third model as well.

The inclusion of interaction terms with one continuous and two indicator variables in the final model (see Table 3 for details) indicates how the impact of one classification (i.e., user type) varied significantly over the categories (i.e., soil texture classes) of the other classification. The default case in Table 3 refers to the sandy loam soil texture class (as in Table 2) and the control or null treatment plots. This approach allowed the impacts of specific trail users to be differentiated from other trail users based on differences in soil texture as well as the other measured variables.

Although the multiple regression models described above provided information about the relative impacts of the different trail users to the extent that the indicator variables and interaction effects representing one or more trail users were incorporated in the third model, a more direct test was needed to assess the relative impacts of different trail users. The multiple comparisons test within the GLM (General Linear Model) module of SAS (Freund et al., 1986) was used to develop models which compared users in terms of water runoff and sediment yield. The Bonferroni option was chosen to compare means from samples of unequal sizes and least-squared means were used because the use of 108 samples (24 for hiking, horse, motorcycling, and off-road bicycling, respectively; but only 12 for the control case) meant the study design was not balanced.

The multiple comparisons test performs a t test on every pair of means and compiles the results in a series of tables. The rows and columns list pairs of treatments and the numbers reported in Table 4 show the probability that the two means came from samples drawn from the same population. Values of less than 0.05 are in bold and indicate statistically significant differences between the plots in terms of water runoff or sediment yield behavior for different pairs of trail users. Values larger than 0.05 indicate only that the differences between the population means, if any, were not large enough to be detected with the sample sizes used in this study (Ingraham et al., 1988).

### Table 3

<table>
<thead>
<tr>
<th>Variable</th>
<th>Parameter estimate</th>
<th>Partial ( R^2 )</th>
<th>Model ( R^2 )</th>
<th>Prob &gt; F</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>2.93</td>
<td>0.18</td>
<td>0.18</td>
<td>0.0001</td>
<td>46.96</td>
</tr>
<tr>
<td>Slope(^1)</td>
<td>1.72</td>
<td>0.15</td>
<td>0.33</td>
<td>0.0001</td>
<td>15.01</td>
</tr>
<tr>
<td>Slope \times horse(^2)</td>
<td>2.18</td>
<td>0.13</td>
<td>0.46</td>
<td>0.0001</td>
<td>77.74</td>
</tr>
<tr>
<td>TR \times clay(^3)</td>
<td>0.21</td>
<td>0.05</td>
<td>0.51</td>
<td>0.0005</td>
<td>20.66</td>
</tr>
<tr>
<td>Water runoff \times sandy clay \times horse(^4)</td>
<td>0.15</td>
<td>0.04</td>
<td>0.55</td>
<td>0.0001</td>
<td>12.86</td>
</tr>
<tr>
<td>Water runoff \times loam \times horse(^5)</td>
<td>0.06</td>
<td>0.04</td>
<td>0.59</td>
<td>0.0001</td>
<td>27.31</td>
</tr>
<tr>
<td>SM \times clay(^6)</td>
<td>1.17</td>
<td>0.04</td>
<td>0.63</td>
<td>0.0001</td>
<td>17.93</td>
</tr>
<tr>
<td>SM \times loam \times motorcycle(^7)</td>
<td>0.91</td>
<td>0.03</td>
<td>0.66</td>
<td>0.0012</td>
<td>11.17</td>
</tr>
<tr>
<td>SM \times clay \times hiker(^8)</td>
<td>-1.04</td>
<td>0.02</td>
<td>0.68</td>
<td>0.0039</td>
<td>8.73</td>
</tr>
<tr>
<td>SM \times sandy clay \times horse(^9)</td>
<td>-2.12</td>
<td>0.02</td>
<td>0.70</td>
<td>0.0142</td>
<td>6.24</td>
</tr>
<tr>
<td>Slope \times clay \times motorcycle(^10)</td>
<td>-4.60</td>
<td>0.02</td>
<td>0.70</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(^1\)Slope represents the slope continuous variable and default cases for the soil texture (sandy loam) and user treatment (control) indicator variables.
\(^2\)Slope \times horse represents the slope continuous variable and horse indicator variable cross-product.
\(^3\)TR \times clay represents the antecedent trail roughness continuous variable and clay indicator variable cross-product.
\(^4\)Water runoff \times sandy clay \times horse represents the water runoff continuous variable and clay and horse indicator variable cross-products.
\(^5\)Water runoff \times loam \times horse represents the water runoff continuous variable and loam and horse indicator variable cross-products.
\(^6\)SM \times clay represents the antecedent soil moisture continuous variable and clay indicator variable cross-product.
\(^7\)SM \times loam \times motorcycle represents the antecedent soil moisture continuous variable and loam and motorcycle indicator variable cross-products.
\(^8\)SM \times clay \times hiker represents the antecedent soil moisture continuous variable and clay and hiker indicator variable cross-products.
\(^9\)SM \times sandy clay \times horse represents the antecedent soil moisture continuous variable and sandy clay and horse indicator variable cross-products.
\(^10\)Slope \times clay \times motorcycle represents the slope continuous variable and clay and motorcycle indicator variable cross-products.
### Table 4

Sediment yield multiple comparisons test results

<table>
<thead>
<tr>
<th>User treatment</th>
<th>Mean sediment yield (g)</th>
<th>Bicycle</th>
<th>Control</th>
<th>Hiker</th>
<th>Horse</th>
<th>Motorcycle</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A. Sediment yield prior to user treatments on preswetted plots (n=54)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bicycle</td>
<td>69</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>59</td>
<td>0.46</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hiker</td>
<td>38</td>
<td>0.04</td>
<td>0.14</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Horse</td>
<td>60</td>
<td>0.53</td>
<td>0.93</td>
<td>0.11</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Motorcycle</td>
<td>65</td>
<td>0.81</td>
<td>0.67</td>
<td>0.06</td>
<td>0.70</td>
<td>-</td>
</tr>
<tr>
<td><strong>B. Sediment yield following user treatments on preswetted plots (n=54)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bicycle</td>
<td>63</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>65</td>
<td>0.81</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hiker</td>
<td>63</td>
<td>0.98</td>
<td>0.80</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Horse</td>
<td>96</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Motorcycle</td>
<td>83</td>
<td>0.06</td>
<td>0.08</td>
<td>0.04</td>
<td>0.18</td>
<td>-</td>
</tr>
<tr>
<td><strong>C. Sediment yield differences prior to and following user treatments on preswetted plots (n=54)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bicycle</td>
<td>~2</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>7</td>
<td>0.57</td>
<td>-</td>
<td></td>
<td></td>
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<tr>
<td>Hiker</td>
<td>21</td>
<td>0.19</td>
<td>0.38</td>
<td>-</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Horse</td>
<td>54</td>
<td>0.03</td>
<td>0.09</td>
<td>0.40</td>
<td>-</td>
<td></td>
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<tr>
<td>Motorcycle</td>
<td>15</td>
<td>0.53</td>
<td>0.64</td>
<td>0.70</td>
<td>0.24</td>
<td>-</td>
</tr>
<tr>
<td><strong>D. Sediment yield following user treatments on dry plots (n=54)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bicycle</td>
<td>58</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>61</td>
<td>0.68</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hiker</td>
<td>55</td>
<td>0.76</td>
<td>0.49</td>
<td>-</td>
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<tr>
<td>Horse</td>
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<td>0.02</td>
<td>0.16</td>
<td>0.01</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Motorcycle</td>
<td>59</td>
<td>0.89</td>
<td>0.76</td>
<td>0.65</td>
<td>0.03</td>
<td>-</td>
</tr>
</tbody>
</table>

### RESULTS

**Previous History**

The soil profile descriptions prepared for the soil pits provided information about prior trail use and user impacts. Both the Emerald Lake and New World Gulch trail soil profiles differed from their off-trail counterparts with respect to the A and Bt horizons. The A horizons were missing (eroded) from both trail sites, so that the Bt horizons represented the soil surface. The removal of the A horizon meant that approximately 5 and 7 cm of soil had been eroded along the Emerald Lake and New World Gulch trails, respectively.

**Natural Controls**

The initial regression results were not very encouraging in that none of the relationships between water runoff and soil texture, slope, antecedent soil moisture, and soil resistance was statistically significant, and only two of five bivariate sediment yield relationships were statistically significant. Variations in slope and antecedent trail roughness explained 12.7 and 10% of the variability in sediment yield, respectively. None of the relationships proposed between sediment yield and antecedent soil moisture, soil resistance, and water runoff was significant.

The switch to multiple regression and the inclusion of soil texture as a series of indicator variables improved model performance. The multiple regression analysis divided the plot data into four groups based on soil texture and produced five independent variables that explained 42% of the variability in sediment yield. The first four terms in Table 2 combined to explain 41% of the variability in sediment yield. The first and third terms indicate that steeper slopes combined with clay and sandy clay soils produced more sediment. Similarly, the second and fourth terms show that increased terrain variability (roughness) combined with sandy clay and clay soils produced more sediment. The inclusion of the slope gradient and antecedent trail roughness continuous variables in these cross-product variables is to be expected given the bivariate regression results, and their inclusion in this model simply indicates that their coefficients (i.e., the response of sediment yield to changes in slope steepness and/or antecedent trail roughness) differed significantly between the four soil texture classes. Steep slopes have been positively correlated with sediment yield in many environments and the cross-products combining antecedent trail roughness and fine-textured (i.e., clay or sandy clay) soils presumably indicate that more sedi-
The fifth cross-product combining antecedent soil moisture and loam soils indicates that the response function for this combination was statistically significant and different from the response functions estimated for the other soil moisture/texture combinations. Even though this fifth cross-product explained only 1% of the variability in sediment yield here, the results from the inclusion of another series of indicator variables representing user types reported in the next section suggest a larger and more complex role for this continuous variable. Overall, the inclusion of cross-products in this model indicates that the relationships between sediment yield and three of the natural controls (i.e., slope steepness, antecedent trail roughness, and soil moisture) varied with different soil textures.

**Relative Impacts**

The addition of four new indicator variables to accommodate trail use meant that as many as five continuous variables, seven indicator variables, and 95 cross-products were considered with water runoff and sediment yield as the dependent variables when multiple regression was used to explore the relative impacts of different trail users. Both models used the results from the rainstorms which followed user treatments (n=108). None of the independent variables was related to water runoff at the 0.05 significance level, suggesting that the variability of water runoff cannot be statistically explained by the independent variables, at least as they were measured in the study. Ten interaction variables combined to explain 70% of the variability in sediment yield from the sample plots (Table 3). The default soil texture (i.e., plots with sandy loam soils) and user subgroups (i.e., the control or null treatment case) appeared in two and three terms, respectively. The variability in slope gradient on the control plots with sandy loam soils, for example, explained 18% of the variability in sediment yield. The variability in slope gradient on horse plots with sandy loam soils and antecedent trail roughness on control plots with clay soils explained 15 and 13% of the variability in sediment yield, respectively. These first three terms combined to explain 46% of the variability in sediment yield. The parameters indicate that steeper slopes and increased terrain variability were associated with higher sediment yields. Some of the other terms are more difficult to explain; for example, wet control plots and wet hiker plots on clay soils were linked with high and low sediment yields, respectively.

This particular model was different from the earlier one in that five trail treatments, represented by as many as four additional indicator variables and 80 additional cross-products, were added. The 67% increase in R² (from 42% to 70%) can be attributed to the inclusion of this second series of indicator variables, although the appearance of terms including both sets of indicator variables means that the impact of user type is modified by the soil texture class in question (Table 3). The contributions of the different variables to the ten significant terms provided a rough guide to their cumulative impacts and confirmed that three variables stood out: soil texture (37%), slope (35%), and user treatment (35%). Antecedent soil moisture, antecedent trail roughness (both 13%), and water runoff (9%) made smaller contributions while antecedent soil resistance had no impact.

User treatments, of course, are of most interest here and following the last approach, their contributions to the ten significant terms can be isolated as follows: horse traffic appeared in four terms that explained 26% of the variability in sediment yield, motorcycle traffic appeared twice (6%), and hiking appeared in one term (3%). It is difficult to take this type of analysis further, although certain relationships are suggested. All four terms including horses were positively correlated with sediment yield, whereas one of the motorcycle terms was positively correlated and the other negatively correlated with sediment yield. The hiking terms are also problematic in that they include other variables that were positively and negatively correlated with sediment yield in different model terms.

The multiple comparisons test in SAS was used to explore the relative impacts of the different trail users with respect to water runoff and sediment yield in more detail. There were no statistically significant different pairs of means for water runoff. These results confirmed: (1) that the trails used for the five treatments were similar in terms of their water runoff behavior prior to the treatments, and (2) the multiple regression results showed that user treatment did not significantly alter runoff behavior.

The results from Part A of Table 4 suggest that the trails used for the five treatment types were not similar in terms of their sediment yield behavior prior to the treatments. Trail plots used for hikers were statistically different from one of the other groups (off-road bicycles) at the 0.05 level and all groups at the 0.15 significance level. Therefore the sample design did incorporate some bias with respect to sediment yield. This particular result suggests that less sediment was available for detachment and entrainment on the hiker plots since the water runoff volumes generated from the plots prior to the user treatments were not significantly different.

The sediment yields reported in Part B of Table 4 indicate that horse plots produced significantly more sediment than the bicycle, control, and hiker trail plots at the 0.05 significance level. Trail plots used by motorcycle were significantly different from one of the other groups (hiker) at the 0.05 level and bicycle and control plots at the 0.15 significance level. Hiker and bicycle plots were not significantly different from each other or the control plots. The treatments were applied to prewetted plots and these results presumably indicate differences in sediment availability. The first sediment yield has been subtracted from the second sediment yield for the plots receiving two rainstorms in Part C of Table 4. These results focus attention on the differences due to the treatments and they remove some or possibly all of the bias inherent in sample plot selection. They confirm that the horse plots are different from the bicycle and hiker plots at the 0.05 and 0.10 significance levels, respectively. Indeed, hikers produced the second largest increase in
sediment yield following horse treatments, and overall the horse and hiker differences suggest that hooves and feet make more sediment available for removal than wheels on prewetted soils. The results in Part D of Table 4 indicate horse traffic produced significantly more sediment than the other users on dry plots as well.

**DISCUSSION**

An understanding of the natural processes and controls operating on trails is necessary before trail users can be added and their impacts isolated from those of the physical site characteristics (Dale and Weaver, 1974; Helgath, 1975; Bratton *et al.*, 1979; Quinn *et al.*, 1980; Summer, 1980, 1986; Kuss, 1986; Jubenville and O’Sullivan, 1987). The results from this study help to clarify some of the important relationships between trail users, water runoff, and sediment yield. The following discussion examines their broader significance.

Two sets of findings emerged from this study which probably apply to many (if not most) environments. The first was that trail use by horses produced greater sediment yields than trail use by other users. This result is similar to those from earlier studies by Dale and Weaver (1974), Weaver and Dale (1978), and Bratton *et al.* (1979), although further comparisons are difficult because of differences in study design. The second and perhaps more important result was that the greatest sediment yields were generated on prewetted trails. This result occurs because the application of rainfall and the increases in soil moisture that follow reduce soil resistance which, in turn, reduces the trail’s ability to bear a moving load. Helgath (1975), Bryan (1977), Weaver and Dale (1978), and Bratton *et al.* (1979) all noted a strong connection between soil moisture conditions and a soil’s ability to bear a moving load. Weaver and Dale (1978), for example, noted that trails located on poorly drained soils are usually wider, deeper, and less uniform (i.e., display greater roughness) than trails located on well-drained sites. These soil moisture results have important implications for trail managers and suggest that trail damage can be minimized by limiting trail use when soils are wet.

The remainder of the results from the current study are noteworthy in at least two other respects: (1) they demonstrate the complexity of the geomorphic, soil, and topographic variables and the difficulty of quantifying their effects on erosion rates, and (2) they serve to highlight some of the challenges and pitfalls that await those attempting to unravel these complex relationships across a range of landscapes. The remainder of the discussion examines these challenges and pitfalls and, in doing so, illustrates the complex interactions which occur between human and environmental variables in most recreational environments.

There are two possible reasons for our failure to identify any significant relationships between water runoff and the slope, soil texture, antecedent soil moisture, trail roughness and soil resistance variables: (1) the study did not evaluate the variables in ways that the natural variability of the sample plots was captured, or (2) the study did not measure all of the relevant variables (i.e., there were no significant relationships between these variables). The first explanation may apply to the antecedent soil moisture, trail roughness, and soil resistance measurements. Trail roughness, for example, may not have been sampled frequently enough (each time) to accurately represent the roughness (micro-relief) of plot surfaces. Trail roughness encourages ponding which increases infiltration and reduces runoff. The density (number) of measurements (each time) may not have been great enough to capture this effect. Similar problems may have affected the antecedent soil moisture and soil resistance measurements.

Turning to the second explanation, two potentially important variables (elapsed time of water application and the swelling properties of clays found at the New World Gulch site) were not measured. Although 41.75 mm of water was applied in every case, the application time varied between 20 and 23 minutes. This variability meant that the application rate was reduced as much as 15% (109 mm hr⁻¹) compared to the desired rate of 127 mm hr⁻¹. Most of these problems occurred on the New World Gulch trail, since these sample plots were located beside a stream which carried a noticeable sediment load. The practice of allowing the water to settle and using only the upper portion of water in the container was able to prevent most but not all of the sediment from being processed through the rainfall simulator. This meant that some of the needles used as drip formers by the rainfall simulator were blocked for some applications. The potential impact was the same as with the measurement problems noted above since lower intensities may produce more infiltration and less runoff. The failure to examine the clay mineralogy at the different sites and to incorporate these results in the regression analysis may represent another important omission. These clays can absorb more water than non-swelling clays and hence the clay mineralogy may have helped to decipher some of the differences in runoff behavior between plots. Smectites (swelling clays) may have been present at the New World Gulch sample plots (Davis and Shovic, 1984).

The potential impact of these shortcomings was greater for water runoff since the same independent variables were much more successful in explaining the variability in sediment yield. Slope and antecedent trail roughness produced significant relationships when bivariate models were developed and five independent variables or cross-products combined to explain 42% of the variability in sediment yield when multiple regression was used. Soil texture (introduced as a series of indicator variables), slope, and antecedent trail roughness were included in at least two of these terms. The influence of these slope and soil characteristics on trail erosion has also been documented in other studies (Bryan, 1977; Weaver and Dale, 1978; Bratton *et al.*, 1979; Quinn *et al.*, 1980; Coleman, 1981; Fish *et al.*, 1981; Kuss, 1983, 1986; Jubenville and O’Sullivan, 1987).
The failure of water runoff to explain any of the variability in sediment yield, either by itself or as part of one or more cross-products, presumably indicates that sediment yield from existing trails is detachment-limited rather than transport-limited. This result may be due to the relatively small size of the sample plots and the low intensity of the storms that were applied, although similar results have been obtained in other erosion studies (e.g., Wischmeier and Smith, 1978). The addition of four new indicator variables and their cross-products to the multiple regression models to examine the relative impacts of the different trial uses confirmed this state of affairs in that: (1) no significant relationships were uncovered between water runoff and the indicator variables, and (2) ten independent variables and cross-products combined to explain 70% of the variability in sediment yield. This second result is impressive. Treating the cumulative contributions of the different variables to the final result as a rough guide to their contributions confirmed that soil texture (37%), slope (35%), and user treatment (35%) had the most impact. Water runoff (9%) was one of three variables that made smaller contributions.

The multiple comparisons test results further clarified the roles of the different treatments and in particular showed that horses and hikers (hooves and feet) make more sediment available than wheels (motorcycles and off-road bicycles) on ermwetted trails and that horses make more sediment available on dry plots as well (Table 4). The failure to distinguish between the other treatments may have been due to three problems with the study design. Two of the shortcomings have to do with the concept of geomorphic thresholds and the third with mechanical removal of sediment from the sample plots.

Schumm (1977) noted that the behavior of geomorphic systems may differ greatly when different external and internal stresses are applied. The thresholds that define when changes are initiated vary across space and through time since the minimum energy that must be applied varies with the environment. Kuss (1986) applied this concept to recreational trails, noting that almost any rainfall or level of use would impact new trails but that very large storms or very heavy use is needed to initiate change on existing trails. These thresholds will vary with the type and quantity of use as well as with climatic, soil, and topographic conditions. Two problems with the current study may have reduced our ability to distinguish between hiker, off-road bicycle, and motorcycle uses: (1) the limitations of the rainfall simulator, and/or (2) the small number of treatments (i.e., 100 passes).

The most important limitation with the modified Meeuwig rainfall simulator is that it produces rainstorms of only one-third the intensity of natural rainstorm events. We experienced several natural rainstorm events in the field and observed greater quantities of water runoff flowing down the trail from these events compared to our rainfall simulator events. The impact of rainfall intensity on the relationships between pre-existing trail conditions (i.e., trail history) and threshold values is not obvious. However, the restrictions placed on the duration and intensity of rainstorms applied in this study decreased the likelihood that threshold values were attained, especially since the study focused exclusively on existing trail segments. The application of only 100 passes (for all four treatments) probably contributed to the failure to attain the appropriate thresholds for all but horse traffic. Lull (1959) suggested impact per unit area could help account for the relative impact of different trail uses. Horses produce the greatest impact per unit area and as a result, horses produced the greatest net change in this study. Other treatments may not have been applied enough times or in conjunction with large enough simulated rainstorms for statistically significant differences to show up between them.

The failure to measure the quantities of soil removed with feet and tires from the prewetted plots may have contributed to the lack of statistically significant differences between the measured sediment yields for the hiker, motorcycle, and bicycle plots as well. The mechanical removal of sediment in these ways was observed on most prewetted plots. Most of the moist soil was removed and a dry soil surface was exposed as the treatments were applied to some plots. The quantities of sediment removed in these ways may need to be combined with those that were measured in order to quantify the relationships between the independent variables and sediment yield more precisely.

The solutions to these last three potential problems would have required the expenditure of more time and effort at each plot. The experiments conducted for this study covered a larger number of sites than most previous studies and required two or three people in the field for approximately 30 days. The choice of a more elaborate rainfall simulator, the application of intense disturbance (i.e., more hiker, horse, motorcycle, and mountain bike passes), and/or the measurement of mechanical erosion from plots would require a larger fieldwork component and/or a study that examined fewer plots.

CONCLUSIONS

Trail use in the last ten years has seen a dramatic increase in off-road bicycles. In many cases off-road bicyclists use the same trails as hikers, horseback riders, and motorcyclists, so that this additional use compounds erosional concerns. The results of this study provide land managers with some new data summarizing the relative impacts of four different users on two existing trails in southwest Montana. In particular, the results indicate that: (1) the natural processes occurring on the two trails used for this study are complicated and difficult to decipher; (2) sediment yield is detachment-limited rather than transport-limited (at least for low intensity storms in the types of environments examined in this study); (3) horses produced significantly larger quantities of sediment compared to hikers, off-road bicycles, and motorcycles; and (4) the greatest sediment yields occurred on wet trails.
The results also indicate why future research may need to examine higher intensities of use (500-1000 passes), increased rainfall intensities, wet soil conditions (longer or heavier rainstorms), and mechanical as well as water-driven erosion processes. Higher levels of use and rainfall would increase the likelihood of exceeding the thresholds at which change is initiated. Site specific studies are required to show when different users exceed these erosion thresholds on new and existing trails. Although the results from these studies would help land managers in assessing the carrying capacities of their trail systems, there remains the challenge of extrapolating the results from small sample plots like those used in this study to other locations and larger areas. The discovery in this study that wet sites are more susceptible than dry sites to erosion damage may help if future studies can demonstrate a link between trail segments that have experienced substantial trail erosion and landscape positions with consistently high soil-water contents.

ACKNOWLEDGEMENTS

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REFERENCES


Extract from Summary of DCR Middlesex Fells RMP (2012, p. iii)
Compliance and Conflict Issues

- Culture of non-compliance with reservation rules and regulations
- Conflicting interests and lack of civility among different users and stakeholder groups
- Design and physical characteristics of the reservation that contribute to these issues
- Lack of enforcement presence
- Cooperation with and among stakeholders

This RMP documents the condition of resources within the reservation as generally quite good, despite high levels of historic and current recreational use. It describes the most significant management issue facing the Fells as the conflicting interests and lack of civility among different users and stakeholder groups. This level of conflict is not typical of Massachusetts state parks has harmed the Fells natural and social environment. This RMP also documents two other significant management issues: the culture of non-compliance with reservation rules and regulations and the environmental impacts of off-trail uses and user created trails.

ISSUES DISCUSSION

Section 4 of this RMP discusses and analyzes four complex and controversial issues:

Land Stewardship Zoning (LSZ). This RMP identifies important resources at the DCR Middlesex Fells Reservation and assesses the sensitivity of each of these resources relative to the specific recreational and management activities occurring at the Fells. Land Stewardship Zone 1s are identified for highly sensitive resources that require special management approaches and practices to protect and preserve their features and values. This RMP concludes that the Spot Pond Brook Archaeological District, locations of four rare species and four watch-listed species, Priority Natural Communities, trail-free areas over 10 acres and a large block of Vernal Pool Core Habitat should be protected as Zone 1 in the Fells. This RMP also establishes specific management guidelines to best protect these important and sensitive resources.

Pedestrian and Mountain Biking Recreation. This RMP discusses the controversial issues surrounding pedestrian and mountain biking recreation at the DCR Middlesex Fells Reservation. The RMP analyzes and evaluates the issues surrounding the sensitivity of resources to these forms of recreation at the Fells, public safety issues, impacts to the recreational experiences enjoyed at the Fells and the management implications of these uses. This RMP concludes that, with respect to environmental impacts, these two recreational uses have similar impacts and should be evaluated similarly. This RMP recognizes that there is a potential for conflict between these two uses and that some separation of these activities should occur at the Fells through trail designation and layout. This RMP concludes that both official mountain biking opportunities and pedestrian only opportunities should be enhanced at the Fells.

Recreation with Dogs. Section 4.5 of this RMP discusses the issues surrounding recreation with dogs at the DCR Middlesex Fells Reservation. Dogs are currently welcome on-leash with their owners on all official trails at the Fells. The DCR is also working to establish and manage a pilot, designated off-leash area at the Sheepfold. This RMP evaluates additional opportunities for off-leash dog recreation on trails, and in doing so, analyzes the sensitivity of resources to dog recreation, public safety issues, impacts to the recreational experiences and the management implications surrounding recreation with dogs. This RMP concludes that there is a potential for impacts to sensitive resources, public safety and recreational experiences from additional off-leash dog opportunities at the Fells and therefore, does not recommend any additional opportunities beyond the designated area at the Sheepfold at this time.

Rules Compliance and Enforcement. This RMP describes a culture of non-compliance at the Fells as a significant issue that needs to be addressed. Section 4.6 discusses the factors that have contributed to this, including the design and physical characteristics of the park and trail system, the lack of enforcement presence on the part of the DCR and cooperation with and among stakeholder groups. This RMP then recommends a multi-pronged compliance strategy to change the status quo and create a new culture of compliance at the reservation. This strategy includes education, enhanced enforcement presence, coordination with other enforcement agencies, issuance of citations for persistent and flagrant violations, a Park Watch program, stakeholder self-enforcement and
Bibliography of Key Studies Documenting Physical Impacts of Mountain Biking
Key Studies about Physical Impacts of Mountain Biking and Hiking


Natural Resource Impact of Mountain Biking: A summary of the scientific studies that compare mountain biking to other forms of trail travel. By Gary Sprung, IMBA 2004.

Section B: Examples of Watersheds Allowing Mountain Biking as Passive Recreation on Trails Within the Watershed

Haverill, MA
Lynn, MA
Baltimore County, MD
Greensboro, NA
Redmond, WA
Manchester, NH
Norris, TN
Rampart Reservoir, Pike National Forest (Colorado Springs, CO)
Portland, ME
Hartford, CT
Crystal Point Conservation Area

Crystal Street (east side, between Liberty Street and North Broadway)
Haverhill, Massachusetts 01832

The Crystal Point Conservation Area is a 10 acre, City-owned parcel of land that is managed by the Conservation Department and Haverhill Trails Committee for the enjoyment of passive recreation. This land has been designated as a conservation area for a variety of benefits that include:

Watershed Protection - Crystal Lake is a major body of water which contributes significantly to the City's public water supply. The lands surrounding Crystal Lake contain many feeder streams as well as wetlands and marshes which improve water quality by filtering out harmful sediment and nutrients.

Wildlife Habitat - This area is rich in diversity, containing streams, wetlands, mature forests, rocky ledges, Crystal Lake, and all the plant and animal life associated with each of these habitats. Deer, beaver, mink, otter, wild turkey, osprey, owls, and a wide variety of waterfowl are a few of the species you might encounter here.

- Passive Recreation - We encourage you to participate in recreational activities that are compatible with natural resources protection, such as bird-watching, photography, hiking, x-country skiing, or mountain biking.
Welcome to the Lynn Woods Reservation

The Lynn Woods Reservation was founded in 1881, the second largest municipal park in the United States, is a 2,200 acre municipal forest park located in Lynn, Massachusetts. The Woods offers over 30 miles of scenic trails for hiking, running, horseback riding, mountain biking (not allowed during the winter), cross-country skiing, and nature walks. Three active reservoirs provide pretty pond-like scenery among natural forestland, as well as clean water for the City of Lynn. Dungeon Rock is a well-loved underground tunnel with a history of pirate lore and treasure seekers. The Rose Garden, Houghton Horticultural Garden, and Amphitheater areas provide more formal settings to explore.

Lynn Woods Ranger

Contact: Dan Small
Phone: (781) 477-7123
Fax: n/a
Email: LynnWoodsRanger@aol.com

Please select an item from the left hand menu to view information and download links to available files and forms. You may also contact us by mail, phone, or email with your questions or if you require any additional information.
Loch Raven Reservoir Watershed

Loch Raven Reservoir is located just north of the Baltimore Beltway and its watershed occupies almost the entire central portion of Baltimore County. Small parts of Western Harford County and Southern York County, Pennsylvania also drain into this watershed. It encompasses Baltimore County communities from Upperco to Jacksonville including Hereford, Parkton and Cockeysville along the central corridor.

Loch Raven is the largest of three area reservoir watersheds that together provide up to 405 million gallons of water per day to Baltimore City and Baltimore County. The reservoir is protected under the Reservoir Watershed Management Agreement (PWMA), originally established in 1984 and renewed in 2005, which endorsed a broad range of policy and resource commitments by all area jurisdictions. The source of reservoir water is Gunpowder Falls.

The Loch Raven Reservoir watershed begins at the dam on the Prettyboy Reservoir. The Gunpowder Falls then flows across the rural lands of north central Baltimore County. Almost all of the Loch Raven Reservoir watershed is located outside the County’s urban rural demarcation line (URDL). The URDL separates areas in the county that receive public water and sewer infrastructure, with those that rely on private well and septic systems. Areas inside the URDL can accommodate development, including employment, retail and residences while the areas outside are reserved for agricultural, natural resource protection and low density rural residential development. A substantial agricultural community continues to farm on these lands. The County has worked with these landowners to preserve thousands of acres of land with protective easements.

Many portions of the Gunpowder Falls consist of heavily forested lands that are within the Gunpowder Falls State Park. Gunpowder Falls State Park, Maryland’s largest, is a popular destination for fishing, birding, picnicking, hiking, mountain biking and horseback riding. The water quality in these reaches is exceptionally good and supports a healthy, self-sustaining brown trout population.
Negotiated an agreement with a local mountain biking organization. This agreement broke a long stalemate and helped assure access to specified trails at Loch Raven Reservoir, while protecting the forest buffer around this important resource.

Moved to full-scale implementation of the BaltiMeter project, installing more than 100,000 new meters by the end of the fiscal year — a significant milestone for DPW’s new efficient, reliable, accurate water metering and billing system.

Piloted Municipal trash cans program in the Belair-Edison and Greater Mondawmin neighborhoods, reducing service requests for rats, lowering tonnage of mixed refuse, contributing to higher recycling tonnage, and lowering Workers’ Compensation claims by preventing on-the-job injuries for Solid Waste workers.

Deployed three new alley sweepers to some City neighborhoods. The custom-designed sweeping machines clean loose trash, grit, dirt, oils, and other chemicals from the alleys. Pilot neighborhoods are Belair-Edison, Panway-Braddish, Coldstream-Homestead-Montebello, Mondawmin, Parkview Woodbrook, Reservoir Hill, Washington Blvd/Pigtown, McElderry Park/Ellwood Park, and Sandtown-Winchester/Hollins Market.

Boosted recycling rates. The City collected 26,154.2 tons of recyclables in 2014, nearly a 5 percent increase over the 24,973.5 tons gathered in 2013. In addition, the City has shown an 11 percent increase in the recycling of polystyrene.

The City partnered with HomeServe USA in August 2014 to roll out an optional program that covers the cost and facilitates repairs to exterior water or sewer lines on the homeowner’s side of the property line. Such repairs can easily cost several thousand dollars. In addition to the core program, HomeServe has established a special fund to assist low-income Baltimore residents, who meet certain income eligibility criteria, with exterior line repairs.

Swept the Maryland Chapter of the American Society of Civil Engineers’ (ASCE) project award category — for minor and major projects. The Montebello Plant 2 Finished Reservoir received the Outstanding Civil Achievement Greater Than $20 Million Award. In the category of Outstanding Civil Achievement Less Than $20 Million, the ASCE recognized DPW’s work on the Towson Finished Reservoir, a $19 million project.
ACTION REQUESTED OF B/E:

The Board is requested to approve and authorize execution of a Trail Stewardship Agreement with Mid-Atlantic Off Road Enthusiasts (MORE). The period of the Agreement is effective upon Board approval for one-year.

AMOUNT OF MONEY AND SOURCE:

N/A

BACKGROUND/EXPLANATION:

The Loch Raven Reservoir (Loch Raven) is a vital component of Baltimore City’s drinking water infrastructure, but it is also an attractive location for recreation such as hiking, boating and mountain biking. For many years mountain bikers utilized unsanctioned single-track trails that disrupted sensitive areas, cut through the 100 foot forest buffer around the reservoir, which lead to vegetation damage and erosion.

Under this agreement, MORE would be permitted to create a specified network of trails that are not harmful to the reservoir and provide an enhanced mountain biking experience at Loch Raven. MORE also commits to maintaining trails, providing education and outreach to its members and other mountain bikers and to regularly report to the Department of Public Works on its progress on these fronts. The Department of Public Works agrees to continue to work with MORE to provide mountain biking opportunities that are appropriate to the stewardship of the drinking water resource.

UPON MOTION duly made and seconded, the Board approved and authorized execution of the Trail Stewardship Agreement with Mid-Atlantic Off Road Enthusiasts.
MTN BIKE TRAILS

Greensboro Mountain Biking Trails

The Greensboro Parks and Recreation Department is fortunate to have so many well-maintained mountain biking trails within parks and surrounding the City’s Watershed Lakes. Greensboro Fat Tire Society provides our local mountain biking club, has helped build and maintain many of these fantastic trails.

Our City has almost 40 miles of mountain biking trails to experience. These trails provide recreational enjoyment for the experienced BMX biker, those just starting out in the sport, and everyone in between.

The trails are preserved in a primitive manner and are linear -- you ride out and back along the same path from the trailhead where you started. Parking is available at most trail entrances, but is limited to roadside parking in some areas. Most of these trails are shared with hikers so make sure to check out proper mountain biking etiquette before you ride.

Looking for a riding buddy or someone to show you the ropes? Visit Bike Trip’s website and forum to meet other local mountain bike riders.

Due to rain and other weather conditions, mountain biking trails will sometimes close. Check the Greensboro Fat Tire Society website for current trail closure reports or call the Trails Rain Line at 336-373-2MTB.

Mountain Biking Trails Surrounding Watershed Lakes (overview map)

- Bald Eagle - Beginner
- Blue Heron - Beginner
- Owl’s Roost - Advanced
- Reedy Fork - Beginner
- Wild Turkey - Intermediate

Park Trails
General Trail Information

These trails are a perfect getaway close to home that provide miles of enjoyment for everyone! Close to 50 miles of trails and greenways exist around the city’s three lakes: Lake Higgins, Lake Brandt and Lake Townsend.

A few notes for an optimal trail experience:
The trails are maintained in a primitive manner. Most are linear, so be prepared to walk out and back along the same path. At the three lake marinas you can also enjoy year-round fishing and boating, as well as kayaking and canoeing. Restrooms are available at the marinas and in the parks during regular operating hours. Make sure to plan your trip accordingly by dressing appropriately for the weather. Every trip should include water, a cell phone and this map! Help us keep the trails pristine by packing out what you pack in. Be aware that parking is limited in some areas.

Find Us on the Web!
Use #gsotrails to keep the conversation going. www.greensborotrails.org

Trail Rules

- No intoxicants on premises, bikes on posted trails, horseback riding, motorized or off-road vehicles (ORVs), smoking, or camping
- All pets must be on a leash. This is a city ordinance and extends to all Greensboro trails.
- Wear a helmet. All persons 15 years old and under must wear one and everyone should wear a helmet for their safety.

Trail Etiquette

- Pay attention to signs, as some trails are restricted to pedestrians only.
- Be courteous and respectful of other trail users, regardless of their mode of transportation, speed or skill level.
- Keep right; pass on left. Stay as close to the right-hand side of the trail as is safe, except when passing. Faster traffic is responsible for yielding to slower, oncoming traffic.
- Pass with courtesy and care. Make others aware you are approaching. Be prepared to stop if necessary. Check behind you before you change position on the trail.
- Share the trail. Mountain bikers, runners, and hikers must share multi-use trails. Yield to other bikers who are climbing. Bicyclists always yield to hikers and runners.
- Do not block the trail. When in a group (including pets), use no more than half the trail, so that others may pass.
- Leave no trace. Take anything you bring onto the trail back out with you.
- Be quiet on nature trails. To increase your chances of spotting animals, be quiet so as not to scare them away.
- Stay on the trail for your own safety. This will also help protect plants and animals that live near the trail and help keep you from getting lost.
Ride or stride this greenway all the way to High Point! Parking is available at the Old Battleground Rd, Nat Greene Trailhead on Old Battleground Rd, this trail traverses along the west bank of Lake Brandt's southern arm. Here you’ll find interesting geological features and a diversity of flora and fauna year round.

**Trail Names**

- **Bicentennial Greenway, 9.3 miles**
- **Atlantic + Yadkin Greenway, 7.5 miles**
- **King Fisher Trail, 1.25 miles**
- **Palmetto Trail, 1.59 miles**
- **CP**
- **Osprey Trail, 2.3 miles**
- **LB**
- **The Copperhead Trail**
- **Laurel Bluff Trail, 3.25 miles**
- **Piedmont Trail, 2.75 miles**
- **premium walking and biking trails.**

**Special Features**

- **Parallel to Reedy Fork Creek and the backwaters of Lake Townsend, this trail is a great pick for an easy ride**
- **Voted the best urban ride in the country by Bicycling Magazine in 2003, this trail is accessible from both Bur-Mil Park and the National Mall.**

**Sponsors**

- Noble Academy
- Girl Scout Troop 1714
- Janes on the Run
- RunnerDude's Fitness

**Questions?**

For up-to-date information on trail closures, please remember most trails are linear so you have to hike out the way you came in.
Watch For Rescue Markers

Located every quarter mile on the trail, these markers are used by Emergency Services to pinpoint your location if you sustain a life threatening injury while using the trail. Please always be aware of your mile marker number and call 911 in case of an emergency.

Watch For Rescue Markers

MILES

OWLS ROOST TRAIL LOCATION

# 18 3.25

Located every quarter mile on the trail, these markers are used by Emergency Services to pinpoint your location if you sustain a life threatening injury while using the trail. Please always be aware of your mile marker number and call 911 in case of an emergency.

Watch For Rescue Markers

Certain Mountain Biking Trails May Close Due to Wet Conditions!

For instant information on closures, call 336-373-2MTB or follow @FatTireSociety on Twitter.

*Unless otherwise posted.

Trail Hours: Sunrise to Sunset

Minutes

Proposed

NEMBA Submittal to EEA – MTB Impact and Watersheds

66
Watershed Preserve

Watershed Preserve is a natural open space and trail system, perfectly designed for horseback riding, mountain bicycling and hiking. A unique feature of the Watershed Preserve is an ADA interpretive trail. There are also parking areas and restrooms. Entrance off 209th is equestrian/hiking only with parking at Farrel-McWhiter Farm Park. No pets, please.

ACREAGE: 860 acres

Directions

21760 Novelty Hill Rd.

Amenities

Bicycling
Information Kiosk
Natural Areas
Open Space
Parking
Restrooms
Walking Trail

Photos

[Image of the Watershed Preserve]
Biking Manchester Water Works’ Land

There are several fire roads on Manchester Water Works’ land that are accessible to the public for hiking and biking use. The Watershed Map is a useful tool, it illustrates the gravel fire road and land owned by Manchester Water Works as well as areas that are restricted to the public.

Bikers should pay attention to all postings and be aware that the area is patrolled by our Watershed Patrolmen. Rules are posted at various locations on the watershed as well as on this webpage.

Remember this land is a watershed that supplies drinking water.

Friends Of Massabesic Bicycling Association

FOMBA is a private cycling club that maintains trails on watershed land. The FOMBA website has additional maps and information.
TRAILS of the NORRIS WATERSHED

By Joe Feeman

This is a draft document to serve as a user guide to the Norris Watershed. The author will continue to update this guide as new trails are developed, uses change, or any other factors that may affect the user. The trail descriptions are adaptations of a series of articles that were published in the Norris Bulletin. A more concise trail guide is in the works. If you have comments or questions feel free to email me at jcfeeman@comcast.net. Happy Trails!

INTRODUCTION

The Norris Municipal Watershed is a 2300-acre area that is open to the public for multiple uses. It is bordered by Norris Dam State Park, TVA, and private property, and is located in Anderson County, adjacent to the City of Norris. There are currently about 30 miles of trails that are managed for various users; foot traffic only; multiple use, non vehicular; and multiple use, vehicular traffic. (Parts of some trails that are included in this guide are on TVA property, but have been managed by Norris historically; these are indicated in the table below.) Foot traffic only trails are only open to human foot traffic (hiking and running); multiple use, non vehicular uses include hiking, horseback riding, mountain biking, running, and small-game hunting (big game hunting by permit for two drawn hunts). Vehicular traffic is open on designated roads to vehicles that are licensed and registered for street use. No ATVs are allowed on any part of the area. Trail sign posts have been placed at most trail heads and have the trail name painted in a blue diamond shape with the name of the trail. (No signs on Norris Dam road).
Rampart Reservoir Trail System

This easy trail follows the Reservoirs shoreline providing opportunities for fishing access, picnicking and enjoying the beauty of the area. Camping is permitted only at the campgrounds, Meadow Ridge and Thunder Ridge. Foot, horse, mountain bike, and cro

At a Glance

Current Conditions:

Operational Hours:

Rentals & Guides:

Fees:

Permit Info:

Restrictions: Camping is permitted only at the campgrounds, Meadow Ridge and Thunder Ridge. Easy. Motorized vehicles are prohibited.

Closest Towns:

Water: Drinking water is available at promontory picnic area during the summer.

Passes:

Information Center:

General Information

Directions: This easy trail follows the Reservoirs shoreline providing opportunities for fishing access, picnicking and enjoying the beauty of the area. 1. Take the Rampart Range Road north from Woodland Park (turn off Hwy 24 at McDonalds). This road will take yo

Activities

Bicycling

Mountain Biking
Sebago Lake Land Reserve

The Portland Water District announced the opening of its Sebago Lake Land Reserve in 2005. The 1700-acre Land Reserve, located in Standish, is open to the public for passive recreational activities. Most portions of the Land Reserve contain trails, including the Sebago to the Sea Trail and the Mountain Division Trail. The most contiguous trail network is housed within the Otter Ponds parcel. Trail maps are also available at any of the twelve kiosks, or you can pick one up at the Sebago Lake Ecology Center.

Trail Map

Unique Ecological Features

Land Use Policies

Recreational Opportunities

PWD offers guided events on the Land Reserve several times a year. Check back for information about upcoming events, or like us on Facebook to receive updates.

Snowshoe Event, January 23
Intro To Ice Fishing, February 13
Trail Day

Allowed Uses

- Hunting
- Fishing
- Trapping
- Environmental Education (with no more than 25 people)
- Hiking/Walking
- Horseback Riding
- Cross-Country Skiing
- Snowshoeing
- Mountain Biking
- Snowmobiling on Designated Trails or by

Prohibited Uses

- Camping/Tenting
- Fires
- All Terrain Vehicles and Motorcycles
- Night Access (between sundown and sun-up)
- Possession of Alcohol
- Cutting or Defacing Trees or other Vegetation
- Removal of Soil or otherwise Excavating or Grading
- Altering Streams or the Flow of Water in Streams
Reservoirs

WEST HARTFORD RESERVOIRS AND RESERVOIR 6

The West Hartford Reservoirs and Reservoir 6 are the sites of MDC's water treatment facilities, five small reservoirs and more than 3,000 acres of some of the most beautiful woodlands and trails in the region.

A nature lover's paradise, the area features 3,000 acres of beautiful forestland; there are more than 30 miles of paved and gravel roads for joggers and bicyclists, hiking trails, wheel-chair accessible picnic groves, cross-country skiing and snow shoeing.

The land is public water supply watershed land that protects the quality of MDC reservoirs and drinking water. Although the beauty of the MDC reservoir areas has long made them an attraction for recreation, they are not public parks. Their public use is regulated by the Connecticut Department of Public Health (Section 24-43c of the Connecticut General Statutes) and enforced by MDC police.
Section C: List of Additional Water Supply or Watershed Properties Allowing Public Recreation

Additional Watersheds that Allow Mountain Biking

- Beaver Brook Watershed Res. #3, Golden CO
- Hahamonga Watershed, Pasadena CA
- Rough Creek Watershed, Canton NC
- Hampton Watershed, Elizabeth TN
- Marin Municipal Water District, Marin CA
- Crystal Springs Watershed, San Mateo CA
- La Grande Watershed, La Grande OR
- Clinton River Watershed, Rochester Hills MI
- Bel Canyon Reservoirs, Sandy City UT
- Santa Fe Municipal Watershed, Santa Fe NM

Watersheds that Allow Pedestrian Access

- New Britain Water Works, New Brittain CT
- Stony Brook Millstone Watershed, Pennington NJ
- East Bay Municipal Watershed, Oakland CA
- Pequannock Watershed, Newfoundland NJ
- Centennial Watershed State Forest, Easton CT
- Ashland Watershed, Ashland NC
- Newark Watershed, Newark NJ
- Panola Mountain Watershed, Stockbridge, GA
- New York City Watershed Lands
- Rochester Water Supply Lands, Rochester NY
- Washington Suburban Sanitary Commission Laurel MD
Section D:
MWRA Water Quality Test Results for Winchester, MA
Fells Reservoir
2008-2014
We are including the following publicly-available MWRA water quality test results issued to the Town of Winchester to document that passive recreation is compatible with public water supplies and watersheds. While no public access is allowed to the reservoirs (with the exception of a limited pilot project by the Town of Winchester around the North Reservoir), the reservoirs are located within the high-use parkland of the Middlesex Fells and its associated 2500 acres containing 122 miles of trails which also have a high use by mountain biking as a managed activity by DCR.

These annual MWRA test results document that high levels of close-proximity passive recreation, including mountain biking, has not affected water quality. In fact, the Turbidity (this would be a sign of soil/solids being washed into a body of water, possibly from trail erosion or other erosive processes nearby) results are consistently 5 times lower than the Maximum Contaminant Levels allowed.
DEAR CUSTOMER,

The 2008 Drinking Water Report to Consumers is a report on the quality of drinking water supplied by the Winchester Water Department (WWD) in partnership with the Massachusetts Water Resources Authority. We are happy to be working with MWRA in this joint communication on the quality of drinking water arriving at your home. This annual report provides detailed information on the Winchester and MWRA’s source water reservoirs and the quality of water determined through federal and state testing guidelines.

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Protection of MWRA’s source reservoirs is discussed in the Report. The Winchester water system is made up of three pressure distribution networks; the Westside High System, the Eastside High System and the Middle Low System. The Westside High System receives water from the MWRA on a daily basis. This system serves streets located west of Cambridge Street. The Eastside High System receives its water from the Winchester Water Treatment Plant from October to April and receives MWRA water from May to September. The Eastside High System serves the area east of Washington Street, east of Main Street to Symmes Corner and the streets east of Grove Street. The Middle Low System receives its water from the Winchester Water Treatment Plant on a daily basis and serves streets west of Washington Street, west of Main Street and west of Grove Street.

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10 THINGS YOU CAN DO TO PREVENT STORMWATER RUNOFF POLLUTION:

- Never dump anything into the storm drain system.
- Pick up after your pet.
- Direct downspouts away from paved surfaces.
- Limit the use of fertilizers and pesticides.
- Compost your yard waste.
- Vegetate bare spots in your yard.
- Take your car to a commercial car wash.
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If you would like additional information on your drinking water, call Stephen Swymer at the Winchester Water Department at (781) 721-7100 or you can call MWRA or US EPA at the numbers in the Report.

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<tr>
<th>Samples</th>
<th>Units</th>
<th>MCL</th>
<th>Detected Level</th>
<th>Violations</th>
<th>How it gets in the water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turbidity</td>
<td>NTU</td>
<td>0.3</td>
<td>0.065</td>
<td>No</td>
<td>Soil runoff</td>
</tr>
<tr>
<td>Fluoride</td>
<td>ppm</td>
<td>4</td>
<td>1.1</td>
<td>No</td>
<td>Water additive that promotes strong teeth</td>
</tr>
<tr>
<td>Sodium</td>
<td>ppm</td>
<td>NS</td>
<td>22</td>
<td>No</td>
<td>Widely present in reservoirs</td>
</tr>
<tr>
<td>TTHM</td>
<td>ppb</td>
<td>80</td>
<td>28.0</td>
<td>No</td>
<td>By product of disinfection</td>
</tr>
<tr>
<td>Haloacetic Acid</td>
<td>ppb</td>
<td>60</td>
<td>7.20</td>
<td>No</td>
<td>Naturally present in water</td>
</tr>
<tr>
<td>Nitrate</td>
<td>ppm</td>
<td>10</td>
<td>ND</td>
<td>No</td>
<td>Present in water system and household plumbing</td>
</tr>
<tr>
<td>Lead</td>
<td>ppb</td>
<td>15</td>
<td>98% passed</td>
<td>No</td>
<td>Present in water system and household plumbing</td>
</tr>
<tr>
<td>Copper</td>
<td>ppm</td>
<td>1.5</td>
<td>100% passed</td>
<td>No</td>
<td>Disinfection</td>
</tr>
<tr>
<td>Chlorine</td>
<td>ppm</td>
<td>4.0</td>
<td>0.59</td>
<td>No</td>
<td></td>
</tr>
</tbody>
</table>

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<tr>
<td>Turbidity</td>
<td>NTU</td>
<td>0.3</td>
<td>0.061</td>
<td>NO</td>
<td>Soil runoff</td>
</tr>
<tr>
<td>Fluoride</td>
<td>ppm</td>
<td>4</td>
<td>1.1</td>
<td>NO</td>
<td>Water additive that promotes strong teeth</td>
</tr>
<tr>
<td>Sodium</td>
<td>ppm</td>
<td>NS</td>
<td>21</td>
<td>NO</td>
<td>Widely present in reservoirs</td>
</tr>
<tr>
<td>TTHM</td>
<td>ppb</td>
<td>80</td>
<td>30</td>
<td>NO</td>
<td>By product of disinfection</td>
</tr>
<tr>
<td>Haloacetic Acid</td>
<td>ppb</td>
<td>60</td>
<td>8.2</td>
<td>NO</td>
<td>By product of disinfection</td>
</tr>
<tr>
<td>Lead</td>
<td>ppm</td>
<td>0.015</td>
<td>98% passed</td>
<td>NO</td>
<td>Present in water system and household plumbing</td>
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<tr>
<td>Copper</td>
<td>ppm</td>
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<td>100%passed</td>
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<tr>
<td>Chlorine</td>
<td>ppm</td>
<td>4.0</td>
<td>0.57</td>
<td>NO</td>
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<tr>
<td>Sodium</td>
<td>ppm</td>
<td>NS</td>
<td>24</td>
<td>NO</td>
<td>Widely present in reservoirs</td>
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<tr>
<td>TTHM</td>
<td>ppb</td>
<td>80</td>
<td>31</td>
<td>NO</td>
<td>By product of disinfection</td>
</tr>
<tr>
<td>Haloacetic Acid</td>
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<td>60</td>
<td>6.45</td>
<td>NO</td>
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<tr>
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<td>ppm</td>
<td>10</td>
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<td>4</td>
<td>1.1</td>
<td>NO</td>
<td>Water additive that promotes strong teeth</td>
</tr>
<tr>
<td>Sodium</td>
<td>ppm</td>
<td>NS</td>
<td>23</td>
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<td>Widely present in reservoirs</td>
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<td>TTHM</td>
<td>ppb</td>
<td>80</td>
<td>29.1</td>
<td>NO</td>
<td>By product of disinfection</td>
</tr>
<tr>
<td>Haloacetic Acid</td>
<td>ppm</td>
<td>60</td>
<td>5.7</td>
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<td>By product of disinfection</td>
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<tr>
<td>Lead</td>
<td>ppm</td>
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<td>97% passed</td>
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<td>Present in water system and household plumbing</td>
</tr>
<tr>
<td>Copper</td>
<td>ppm</td>
<td>1.3</td>
<td>100% passed</td>
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<td>Chlorine</td>
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The 2012 Drinking Water Report to Consumers is a report on the quality of drinking water supplied by the Winchester Water Department (WWD) in partnership with the Massachusetts Water Resources Authority. We are happy to be working with MWRA in this joint communication on the quality of drinking water arriving at your home. This annual report provides detailed information on the Winchester and MWRA’s source water reservoirs and the quality of water determined through federal and state testing guidelines.

Water for the Town of Winchester comes from the MWRA Water System and town-owned reservoirs located in the Middlesex Fells Reservation off of South Border Road. A filtration plant located at the South Reservoir treats the Winchester water. The South Reservoir is protected through Sanitary Surveys, Water Quality Testing, Reservoir Patrolling and Watershed Management. Protection of MWRA’s source reservoirs is discussed in the Report. The Winchester water system is made up of three pressure distribution networks; the Westside High System, the Eastside High System and the Middle Low System. The Westside High System receives water from the MWRA on a daily basis. This system serves streets located west of Cambridge Street. The Eastside High System receives its water from the Winchester Water Treatment Plant from October to April and receives MWRA water from May to September. The Eastside High System serves the area east of Washington Street, east of Main Street to Symmes Corner and the streets east of Grove Street. The Middle Low System receives its water from the Winchester Water Treatment Plant on a daily basis and serves streets west of Washington Street, west of Main Street and west of Grove Street.

The Town of Winchester, through the efforts of the Board of Selectmen and Town Meeting Members, has taken an aggressive approach in ensuring our drinking water meets the highest standards. The following are some system improvements over the last few years:

- Construction of a 2 million gallon-per-day (mgd) water treatment plant; and a million gallon storage tank
- 100% Replacement, cleaning & lining of over 23 miles of water mains in the Winchester distribution system;
- Reconstruction of the east dike at South Reservoir
- The MWRA installed a 24-inch water line on Forest Street that serves as a back up to Winchester’s water system

**SOURCE WATER ASSESSMENT**

The DEP conducted a source water assessment survey in 2003 to assess the susceptibility of the Town’s water supply. The full report is available online at www.mass.gov/dep/water/drinking/swapover.htm

The Town of Winchester and the MWRA analyze water samples on a routine basis to ensure compliance with all state and Federal regulatory requirements. Annual system-wide flushing and gooseneck lead replacement of water services were also performed. Listed below are several substances that were tested in Winchester’s sources of drinking water during 2012. The table also shows the results of each contaminant found in the water compared to the highest levels allowed by law (MCL). Not listed are the more than 200 other substances for which we tested that were not detected in our water during 2012.

<table>
<thead>
<tr>
<th>Units</th>
<th>MCL (mg/l)</th>
<th>Detected Level</th>
<th>Violations</th>
<th>How It Gets In The Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turbidity</td>
<td>NTU</td>
<td>0.3</td>
<td>0.066</td>
<td>NO</td>
</tr>
<tr>
<td>Fluoride</td>
<td>ppm</td>
<td>4</td>
<td>1.1</td>
<td>NO</td>
</tr>
<tr>
<td>Sodium</td>
<td>ppm</td>
<td>NS</td>
<td>21</td>
<td>NO</td>
</tr>
<tr>
<td>TTHM</td>
<td>ppb</td>
<td>80</td>
<td>33.7</td>
<td>NO</td>
</tr>
<tr>
<td>Haloacetic Acid</td>
<td>ppb</td>
<td>60</td>
<td>8.8</td>
<td>NO</td>
</tr>
<tr>
<td>Lead</td>
<td>ppm</td>
<td>0.015</td>
<td>97% passed</td>
<td>NO</td>
</tr>
<tr>
<td>Copper</td>
<td>ppm</td>
<td>1.3</td>
<td>100% passed</td>
<td>NO</td>
</tr>
<tr>
<td>Chlorine</td>
<td>ppm</td>
<td>4.0</td>
<td>1.23</td>
<td>NO</td>
</tr>
</tbody>
</table>

Key: NTU = Nephelometric Turbidity Unit; PPM = Parts per million; TTHM = Total Trihalomethanes; MCL = Maximum Contaminant Level; The highest allowed level of a contaminant in drinking water.

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The Town of Winchester, through the efforts of the Board of Selectmen and Town Meeting Members, has taken an aggressive approach in ensuring our drinking water meets the highest standards. The following are some system improvements over the last few years:

• Construction of a 2 million gallon-per-day (mgd) water treatment plant;
• Construction of a 1 mgd storage tank;
• 100% replacement, cleaning and lining of over 23 miles of water mains in the Winchester distribution system;
• Demolition of an aging water tank;
• The MWRA installed a 24-inch water line on Forest Street that serves as a back up to Winchester’s water system.

SOURCE WATER ASSESSMENT

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The Town of Winchester and the MWRA analyze water samples on a routine basis to ensure compliance with all state and federal regulatory requirements. Annual system-wide flushing and replacement of lead gooseneck water services were also performed. Listed below are several substances that were tested for in Winchester’s sources of drinking water during 2013. The table also shows the results of each contaminant found in the water compared to the highest levels allowed by law (MCL). Not listed are the more than 200 other substances for which we tested that were not detected in our water during 2013.

<table>
<thead>
<tr>
<th>Substance</th>
<th>Units</th>
<th>MCL (mg/l)</th>
<th>Detected Level</th>
<th>Violations</th>
<th>How It Gets In The Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turbidity</td>
<td>NTU</td>
<td>0.3</td>
<td>0.075</td>
<td>NO</td>
<td>Soil runoff</td>
</tr>
<tr>
<td>Fluoride</td>
<td>ppm</td>
<td>4</td>
<td>1.1</td>
<td>NO</td>
<td>Water additive that promotes strong teeth</td>
</tr>
<tr>
<td>Sodium</td>
<td>ppm</td>
<td>NS</td>
<td>22</td>
<td>NO</td>
<td>Widely present in reservoirs</td>
</tr>
<tr>
<td>TTHM</td>
<td>ppb</td>
<td>80</td>
<td>38.7</td>
<td>NO</td>
<td>By product of disinfection</td>
</tr>
<tr>
<td>Haloacetic Acid</td>
<td>ppb</td>
<td>60</td>
<td>11.2</td>
<td>NO</td>
<td>By product of disinfection</td>
</tr>
<tr>
<td>Nitrate</td>
<td>ppm</td>
<td>10</td>
<td>ND</td>
<td>NO</td>
<td>Naturally present in water</td>
</tr>
<tr>
<td>Lead</td>
<td>ppb</td>
<td>15</td>
<td>97% passed</td>
<td>NO</td>
<td>Present in household plumbing</td>
</tr>
<tr>
<td>Copper</td>
<td>ppm</td>
<td>1.3</td>
<td>100% passed</td>
<td>NO</td>
<td>Present in household plumbing</td>
</tr>
<tr>
<td>Chlorine</td>
<td>ppm</td>
<td>4.0</td>
<td>0.59</td>
<td>NO</td>
<td>Disinfectant</td>
</tr>
</tbody>
</table>

Key: NTU = Nephelometric Turbidity Unit PPM = Parts per million TTHM = Total Trihalomethanes MCL = Maximum Contaminant Level: The highest allowed level of a contaminant in drinking water.

10 Things You Can Do To Prevent Stormwater Runoff Pollution:

• Never dump anything into the storm drain system
• Pick up after your pet
• Direct downsputs away from paved surfaces
• Limit the use of fertilizers
• Compost your yard waste
• Vegetate bare spots in your yard
• Take your car to a commercial car wash
• Check your car for leaks and recycle used motor oil
• Sweep up your yard debris rather than hosing down the area
• Properly dispose of hazardous household wastes

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- Construction of a 2 million gallon-per-day (mgd) water treatment plant;
- Construction of a 1 mgd storage tank;
- Replacement, cleaning & lining of over 23 miles of water mains in the Winchester distribution system;
- Replacement of 110 lead goosenecks by contract, and
- The MWRA installed a 24-inch water line on Forest Street that serves as a back up to Winchester's water system.

The Town of Winchester and the MWRA analyze water samples on a routine basis to ensure compliance with all state and federal regulatory requirements. Annual system-wide flushing and lead gooseneck replacement of water services were also performed. Listed below are several substances that were tested for Winchester's sources of drinking water during 2014. The table also shows the results of each contaminant found in the water compared to the highest levels allowed by law (MCL). Not listed are the more than 200 other substances for which we tested that were not detected in our water during 2014. The Town received a 3-year waiver from lead and copper testing from the DEP due to 3 years of not exceeding the 90% Action Level.

### Table of Contaminants

<table>
<thead>
<tr>
<th>Substance</th>
<th>Units</th>
<th>MCL</th>
<th>Detected Level</th>
<th>Violations</th>
<th>How It Gets In The Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turbidity</td>
<td>NTU</td>
<td>0.3</td>
<td>0.059</td>
<td>NO</td>
<td>Soil runoff</td>
</tr>
<tr>
<td>Fluoride</td>
<td>ppm</td>
<td>4</td>
<td>1.1</td>
<td>NO</td>
<td>Water additive that promotes strong teeth</td>
</tr>
<tr>
<td>Sodium</td>
<td>ppm</td>
<td>NS</td>
<td>24</td>
<td>NO</td>
<td>Widely present in reservoirs</td>
</tr>
<tr>
<td>TTHM</td>
<td>ppb</td>
<td>80</td>
<td>34.5</td>
<td>NO</td>
<td>By product of disinfection</td>
</tr>
<tr>
<td>Haloacetic Acid</td>
<td>ppb</td>
<td>60</td>
<td>8.4</td>
<td>NO</td>
<td>By product of disinfection</td>
</tr>
<tr>
<td>Nitrate</td>
<td>ppm</td>
<td>10</td>
<td>ND</td>
<td>NO</td>
<td>Naturally present in water</td>
</tr>
<tr>
<td>Lead</td>
<td>ppb</td>
<td>15</td>
<td>97% passed</td>
<td>NO</td>
<td>Present in water system and household plumbing</td>
</tr>
<tr>
<td>Copper</td>
<td>ppm</td>
<td>1.3</td>
<td>100% passed</td>
<td>NO</td>
<td>Present in water system and household plumbing</td>
</tr>
<tr>
<td>Chlorine</td>
<td>ppm</td>
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<td>1.4</td>
<td>NO</td>
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</tr>
</tbody>
</table>

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- Take your car to a commercial car wash
- Check your car for leaks and recycle used motor oil
- Sweep up your yard debris rather than hosing down the area
- Properly dispose of hazardous household wastes

The Town of Winchester was issued an order of noncompliance for failing to report test results. The samples were collected in the mandated time frame. There were no potential health risks, and all results were well below the maximum contaminant levels set forth by the DEP. If you would like additional information on your drinking water, or on town meetings, call Steve Swymer at the Winchester Water Department at (781) 721-7100 or you can call MWRA or US EPA at the numbers in the Report.