Sustainable Construction and Maintenance Practices for Nonmotorized Forest Recreation Trails[1]

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ABSTRACT

Driven by a rapidly increasing demand for dispersed recreation opportunities, the management of forest trail systems has become a high priority issue for land managers. Trails must be user-safe, environmentally sound, economically affordable, and sustainable. To meet these mandates, engineering practices must employ design, construction, and maintenance technologies that anticipate type, intensity, and timing of trail usage. Trails must be fitted to topography, soils, surface water hydrology, vegetation types, and meteorological regimes. Currently, these essential design considerations are infrequently employed leading to poor trail performance and long-term sustainability consequences. This paper outlines design practices employed on the 100-mile trail system of the Clemson Experimental Forest, Clemson University, Clemson, South Carolina, USA. Design examples include bridge construction, bog and low-water crossings, switchbacks, and structures facilitating surface water drainage. Construction practices identified in this paper provide sound engineering solutions for maintaining the environmental integrity and long-term sustainability of nonmotorized forest recreation trails.

Keywords: Recreational Trail, Sustainable Design, Construction Practices

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INTRODUCTION

Forest recreational trail use involves both motorized and nonmotorized users. This paper addresses nonmotorized trail construction and maintenance practices. The two categories of uses differ greatly in terms of social and environmental issues and how land managers address those issues. With recreational trail use being a high priority issue in United States forests and an increasing number of trail users per year, construction and maintenance concerns are expected to become more prevalent in the future.

In 2005, the Outdoor Industry Association (OIA) estimated that there were 16 million mountain biking and 79 million hiking trail users in the nation (Outdoor Industry Association 2006). Cordell et al. (2005) estimated that in 2000 – 2001 approximately 33% of the population over the age of 16 hiked, 21% biked, and 7% rode horses for recreation. Also, the American Horse Council (AHC) estimated that in 2004 there were 3.9 million horses owned primarily for recreational use in the nation (Deloitte 2005). However, most land managers would agree that not only is the number of trail horse users large, it is increasing throughout most of the nation, as is all other trails related recreation. Furthermore, they are likely to point out that among nonmotorized trail users; horse users have the greatest per capita environmental impact.

The information reported here is based on the accumulation of knowledge gained by testing old construction and maintenance practices and new innovative construction and maintenance practices on the 100-mile trail system of the Clemson Experimental Forest (CEF) which is owned and managed by Clemson University, Clemson, SC, USA.

Approximately 98% of the users of this trail system are mountain bikers and trail horse users. Total trail use ranges from 35,000 to 40,000 user hours per year. While spring and fall seasons are the times of greatest use intensity, because of the mild climate, the system receives substantial use throughout the year.

Existing trail design and the consequences of poor design are among the largest trail problems faced by the CEF manager. Because most of the trail system is user-created, trail designs had little if anything to do with user safety, environmental protection, or the economics of sustainability. Therefore, most trail design work is currently a matter of redesign that involves realignments, relocations, or mitigation of existing conditions. This paper focuses on the mitigation of existing unsustainable trail conditions.

Finally, design/redesign, construction, and maintenance on the CEF trail system is aimed at a standard to accommodate trail horses. Because of the high amount of horse use, and horses causing a higher per capita environmental impact than other nonmotorized uses, trails constructed and maintained to accommodate horses, will automatically accommodate all other nonmotorized users.

Wood et al. (2000) presented an adaptive management plan for the CEF trail system, and Wood (2007) describes the current CEF trail situation and how various management issues are being addressed.

ENVIRONMENTAL IMPACTS OF TRAIL USE

Tread Erosion

In most regions of the United States water caused erosion is the most important consequence of trail use. Within a given ecosystem; types, intensities, frequency, and timing of use collectively determine the risk of erosion. The trail must be designed, constructed, and maintained in anticipation of the effects of these factors if erosion is to be prevented, minimized, or adequately mitigated. Design, construction, and maintenance practices vary between ecosystems due to varying soils, topography, climate, and meteorological regimes. Even within a given system, soils and topography will mandate customization of the trail to accommodate different users and different ecosystem conditions on an almost foot-by-foot basis.

Trail erosion results when water translocates soil particles. As soils become lighter in texture and less stony, they are subjected to more erosive forces. The amount of water coming onto the trail and the velocity with which it flows determines the potential for soil particles to be translocated. Within a given storm event, the amount of watershed area above the trail and the soil conditions in that area determine the amount of water that will come onto the trail. As trail grade and run increase, velocity of water flow on the trail tread increases. This leads to an increased potential for erosion along the trail. The soil particles that are translocated by this water flow are dislodged by any movement on the trail tread, but the force exerted by that movement (foot, wheel, or hoof) increases the amount of soil dislodgement. Heavier objects moving at greater speed will increase soil dislodgement at an exponential rate for a given soil type and trail grade. Although, the physics of trail tread-traffic interactions have never been quantitatively studied there is a great need for this type of information to support design and construction, and to guide regulation of trail use. To determine the tread vulnerability to trail traffic forces soil texture, moisture level, and stoniness must be considered.

The problems due to increased erosion are addressed in several ways: 1) appropriately designing and constructing outsloped trail treads to direct water flow to the downslope side of the trail, 2) setting the trail grade appropriate for the soil and topographical conditions, 3) installing special water control structures, such as grade reversals, turnouts, and rolling dips, and 4) maintenance practices that prevent berm buildup and tread cupping (Wood 2007).

Stream Sedimentation

Wilson (2007) stated: “With respect to trails embedded in watersheds, and particularly those that either cross or lie in close proximity to streams, the greatest threat to water quality is increased rates of deposition of soil sediments that result from the trail and disturbed streambank erosion.” She also felt that protection of water quality should be the foremost environmental protection concern in the design, construction, maintenance, and regulation of trail systems. The deposition or sedimentation of streams causes several impacts; the most commonly thought of are embeddedness and turbidity. Embeddedness is a condition in which sediment has filled the interstitial spaces between stone and gravel components of a streambed. Turbidity is a measure of water clarity. An increase in turbidity is caused by an increase in suspended solids in the water column. Both have been linked to adverse affects to normal biological functioning in a stream. Numerous studies have documented the impacts of both embeddedness, and turbidity including, but not limited to, those of Waters (1997), McKinney (1999), Burkhead (2001), Sweka (2001), and Walters et al. (2003).

While sediments resulting from trail erosion can be a significant cause of embeddedness, the greater effect comes from streambank and streambed degradation where trails cross streams. In the absence of adequate types and amounts of natural pavement (stoniness) in soils of the approaches of the stream crossing and the streambed, the trail tread will need to be hardened and banks armored to minimize and mitigate potential soil erosion.

SOLUTIONS TO UNSUSTAINABLE TRAIL CONDITIONS

Described here are potential solutions to three common issues encountered in sustainable trail construction and maintenance. As described by Wood (2007), numerous other issues are involved in sustainable trail management, but these three introduce basic engineering approaches to problem resolution. Each solution described here heavily involves the use of geosynthetic materials. Use of these materials for trail work has been previously described by Moniux and Vachowski (2000), Stienholtz and Vachowski (2001), and Wood (2007). These materials, which are petroleum based products, are widely used in rural and wildland trail and road construction, but may be prohibited in designated Wilderness Areas.

Bogs

Bogs are places on the trail where the soil is saturated throughout most, if not the entire year. Bogs may be a natural phenomenon where the water table is very close to the soil surface, associated with either a seep or another source of lateral water movement across a hard pan, or they may be the result of surface water flow accumulation at an inadequate drainage point. Normally, the trail manager will try to design to avoid these sites if they can be foreseen before trail construction. However, it is not uncommon for the trail layout to be constrained such that the problem site must be dealt with, or anomalies in the soil (e.g., hardpans or bedrock) may go undetected until the trail is in place.

Boggy sites occur in three site conditions: 1) hard bottomed with soil (hard pan) or bedrock within about 8 inches of the topmost soil layer, 2) where a natural occurring depression in the trail accumulates water and has inadequate drainage, and 3) deep, anaerobic soils (often organic) that do not have a solid bottom, or true bogs. Boggy sites can also spread in diameter and length as trail users go around them, increasing the area and size of the problem. Also, as trail users go through them, they deepen the spots by removing soil, and delay drying by keeping the mud stirred. Remediation of these sites should be undertaken as soon as they are discovered.

The first condition, caused by a high water table is associated with a seep or lateral water movement across a hardpan near the soil surface. This condition is almost always exposed with trail construction, and always occurs at the side of a hill. It is managed best with the installation of a French drain (Figure 1). The construction approach to a French drain is to excavate the saturated soil to the hard soil level. Then, cover the hard soil with nonwoven geotextile and add a 4- to 6-inch layer of 3- to 5-inch crushed stone. Cover the cobble layer with another sheet of nonwoven geotextile, over which a 3- to 4-inch layer of crush-and-run gravel is added to provide the trail tread. Care must be taken not to let the geotextile cover either end of the drain so that water from one side of the trail can flow laterally through the porous layer to the other side of the trail.

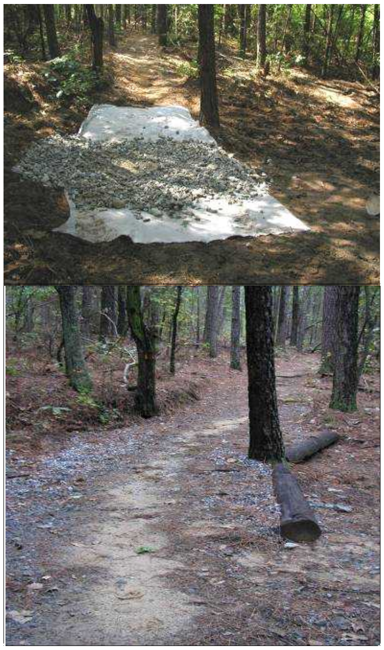

Figure 1. (Top) French drain structure under construction, (Bottom) structure complete, and under use for several

The second condition is typically found where an area on the trail tread accumulates water from surface water flow (Figure 2, top). The construction approach to mitigate this condition is to remove all of the soft, saturated soil (mud) to the hard bottom, line the hole with a non-woven geotextile (5 oz. weight preferred) (Figure 2, bottom), and fill the hole with

Figure 2. (Top) Boggy spot along the trail caused by accumulation of water in a place with inadequate drainage, (Bottom) geotextiles laid over a boggy spot of the same condition after saturated soils have been removed, ready for the application of crush-n-run.

crush-and-run gravel. The geotextile will provide for water movement from the gravel into the soil, but prevents migration of the gravel into the soil. The fines are critically important to holding the larger gravel in place and providing a reasonably smooth tread surface. This process is usually referred to as hardening, and should be a permanent solution that will require minimal future maintenance. Even if new soil is washed in over the gravel, the bogginess will remain resolved.

Figure 3. (Top) Geoweb placed on geotextiles, (Middle) Geoweb filled with crush and run, (Bottom) Hardening techniques after completion, with the combination of geoweb, and crush and run.

The third condition occurs along trails where deep, anaerobic soils (often organic) that do not have a solid bottom exist, or a true bog. These deep bogs require a somewhat more sophisticated approach. Hesselbarth and Vachowski (2000) described the use of subsurface puncheons made of natural materials for crossing these sites. This type of engineering will likely continue to be required in Wilderness Areas, but in other areas, geosynthetic materials provide a preferred option. Figure 3 shows the typical construction, using geosynthetics, which is used to remediate a deeply saturated trail surface. This process shown in Figure 3 is much like the process used to construct a subsurface puncheon.

Subsurface puncheons are constructed by placing a sheet of geotextile over the bog surface, then reinforcing it with a layer of geogrid, not seen in Figure 3, to minimize slippage of the geotextiles. The layers are then nailed to the sides of pressure treated or other decay resistant timbers. Perforated geoweb (also called geocell) that is 4 to 6 inches deep is then positioned between the timbers (4x6 recommended), and filled with crush-and-run, which is the preferred fill material. The depth of the geoweb will be largely dependent on the type of trail traffic and softness of the bog. When organic soils and horse trail traffic are present, a greater depth of geoweb should be used. One important note of precaution is that deep bogs may be associated with jurisdictional wetlands. In such cases, appropriate state or federal permits will be required before any site disturbance can take place.

Low Water Crossings

Low water and deep bog crossings require very similar engineering considerations as described for bogs with the exception that approaches to bogs usually do not involve modification of banks. Streambeds composed of hard sand, large gravel, or bedrock rarely need further hardening to accommodate trail traffic. Soft streambeds should always be hardened to prevent movement of sediments downstream of a trail crossing, caused by trail traffic disturbance. Such hardening may follow the same procedures used for deep bog crossings with added requirements for proper anchoring of the curbing timbers to prevent dislodgement during storm events. Anchorage consists of pinning the timbers in place using 5/8-inch rebar driven 4 to 5 feet into the ground or bedrock, whichever comes first, and slanted at a 45° to 60° angle upstream. Streambank modification may require practices from simple hardening of the surface near the stream to the construction of steps which requires the excavation and hardening of the newly exposed banks of the access. The tread of an access with a grade of more than 5% should always be hardened using combinations of geotextile, geoweb, and crush-and-run fill. The geotextile and geoweb should be held in place with curbing timbers as described above for bog and low water crossings. Regardless of grade, the portion of the access within the flood plane of the stream will need to be hardened using the same design as for the streambed.

Figure 4 (top) shows a stream crossing that does not have natural armoring and the impacts are evident. The streambank access to the crossing has become filled with organic matter. The bottom of Figure 4 shows the proper remediation of the site. The approaches have been hardened, steps have been added to reduce the slope, and the substrate has been properly hardened. In situations such as this, when working in the vicinity of streams, it is important to note that all perennial streams are jurisdictional waters of the United States and therefore regulated by the US Army Corps of Engineers. Individual states have different levels of protection of stream corridors and intermittent and ephemeral streams. The appropriate regulatory authorities should to be consulted in these situations.

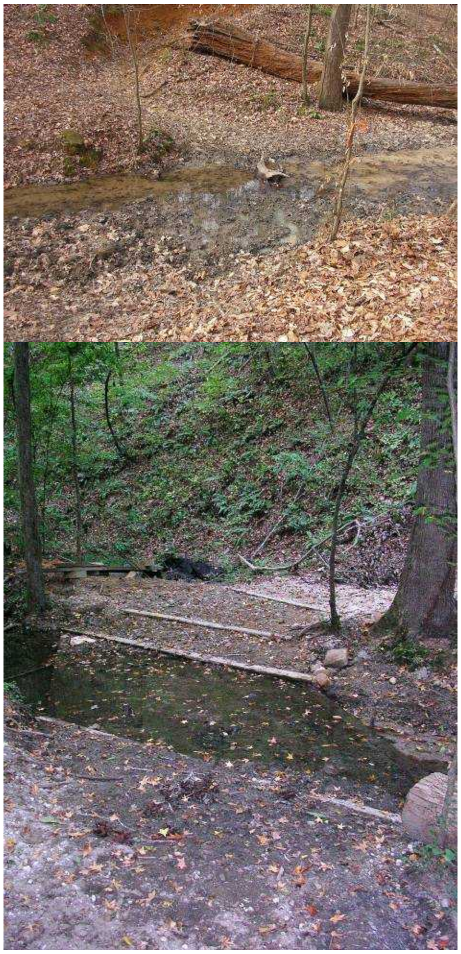

**Figure 4. (Top) A poorly located stream crossing with no natural armoring on access or substrate leading to mucky conditions at the edge of the stream,
(Bottom) Commonly used low water crossing design -- trail access to the stream has been hardened as well as the stream substrate.**

Bridges

Figure 5. A deeply incised stream crossed by a 26-ft bridge designed by E.T. Techtonics.

Johansen and Wood (2007) discussed the principles guiding trail bridge design and construction. They defined small bridges as those not greater than 16 feet in length, and large bridges as those greater than 16 feet in length. A 26-foot fiberglass bridge design developed by E. T. Techtonics, Philadelphia, PA has been tested on the CEF for the past 7 years (Figure 5). During this period it has been exposed to one major flood that rose approximately 12 inches above the deck and averaged about 2000 trail horse passes per year. This bridge continues to safely serve CEF trail traffic.

Bridges are almost always preferred to low water crossings where streams are deeply incised. This is due to the fact that bridge construction in these situations usually entails less site disturbance, thus less risk of stream degradation due to siltation or sedimentation. However, bridges inherently carry greater concerns for trail user safety, maintenance issues (including storm event damage), and cost more for both construction and maintenance. As with low water crossing access, when planning a bridge construction, the appropriate state and federal regulatory authorities must be consulted before disturbance of streamside areas can begin.

Switchbacks

Switchbacks are among the more complicated trail structures to build and can be one of the most difficult to maintain. Switchbacks have been described in a number of trail construction manuals, but Wood (2007) is the only author to indicate the importance of hardening the tread for sustainability of the structure. Excessively used, unarmored switchbacks, will often erode in the inside of the turn rather than the outside of the turn, because trail users inherently prefer an inside turn (Figure 6, top). This creates a rut at the apex of the turn, which allows water to flow from the upslope portion of the switchback into this rut and down the downslope portion of the switchback (Figure 6, top). Only where the soil is naturally armored with substantial stone should switchback construction be attempted without hardening. Also, switchbacks should only be used when a climbing turn cannot be used and have the lowest slope possible. There are three parts to a properly functioning switchback and several design components. The first part of the switchback is the upper leg or upslope portion, next the apron, and finally the lower leg or downslope portion. The design components are 1) the grades of the two legs of the switchback should have the least possible slope, 2) there has to be an anchor (i.e., tree or boulder) in the apex of the turn to distinguish the turning point and to act as a natural flow guidance for trail traffic (Figure 6, middle and bottom), 3) the upslope portion of the trail must be

Figure 6. (Top) Erosion in the apex of the turn, caused by users preferring inside of switchback, (Middle) The use of geosynthetics and crush-n-run in the construction of an armored switchback, also shows the outsloping of the lower leg of the switchback, (Bottom) Several years after construction -- notice an insloped upper leg, and a tree holding the apex of the switchback.

insloped to insure diversion of water along the inside of the trail and into the filter area (Figure 6, bottom), 4) the downslope or lower leg and outside half of the apron must be outsloped to drain water away from the trail and into the sideslope (Figure 6, middle), and 5) a rolling dip or water turnout should be placed at the top and bottom of the switchback.

The placement of a rolling dip or water turnout at the top of the switchback diverts water from entering the switchback due to surface drainage of the trail above it. Placement of a rolling dip or water turnout below the lower leg causes water movement down the lower leg of the switchback to be diverted into the sideslope rather than onto the trail. The CEF has found it practical to apply geosynthetics and gravel in similar ways as described in low water crossing and bog hardening processes to harden switchbacks (Figure 6). The design structure shown in Figure 6 has been in use for several years and has alleviated trail degradation caused by high intensity use at this location.

CONCLUSION

As trail use intensity increases, sustainable design and trail hardening techniques will become important tools for trail managers. With help of the innovative and practical designs discussed in this paper, trail degradation issues can be reduced and mitigated. These proactive measures along with sound management can and have been successful in providing a mechanism to curtail negative impacts from forest recreation.

It is a goal of the CEF as a teaching forest to provide a model of how trail degradation issues can be corrected through the implementation of sustainable and practical engineering design practices. These practices allow, if built to the standards of the most consumptive trail user, the trail to better resist trail traffic forces and continue to provide recreational opportunities into the future. For the trail manager to continue to provide user safe and sustainable trails, these designs and techniques must be employed.

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