SECTION 6

Sustainable Natural Surface Trails



This simple, timeless hiking trail in a Minnesota park has served hikers well for decades with little year-to-year maintenance. The longevity and sustainability of this trail is due entirely to its design.

Overview

Sustainable natural surface trails serve a variety of user groups, including hikers, horseback riders, mountain bikers, and OHV riders. Although these groups are quite varied, the process of designing trails for any of them follows similar principles and design techniques, as defined in this section.

Key Principles of Sustainable Natural Trails

A multiuse paved trail and a sustainable natural surfaced trail are decidedly different. The former is hard surfaced, geometric in form, and comparatively stable, while the latter is soft surfaced, follows the contours of the land, and is much more susceptible to natural forces. These differences dictate decidedly different approaches to trail development. Three key principles set the foundation for designing sustainable natural trails:

1. **Natural surface trails are shaped, not built.** These trails reflect the landscape being traversed and respond to the many nuances of a site that make them interesting to the trail user.
2. **Carefully considered tread alignments, site slopes, and tread grades are favored over extensive grading and other mechanical means to create a trail.** This is especially the case with drainage, where the design of the trail is used to control erosion and prevent displacement of the trail tread.
3. **Potential changes to tread shape due to compaction, displacement, and erosion must be anticipated as part of the design process.** This means the tread must be designed so it will still drain with limited potential for erosion even if it changes shape through years of use.

Natural Trail Classifications

As defined in Section 4 – Trail Classifications and General Characteristics, there are a number of classifications for natural surfaced trails, including:

- Hiking Trail
- Equestrian Trail
- Mountain Biking Trail
- OHV Trails (including ORV, ATV and OHM subclassifications)

Although each of these types of trails has individual nuances, their design follows common principles and techniques.

Important additional information!

The descriptions for each of these trail types in Section 4 includes considerable information on layout configurations and common design features.

Publications That Complement the Guidelines

A number of natural surface trail development-related publications are referenced in this section. Each has relevance to specific trail development issues that require greater detail than can practically be provided here. Trail designers are encouraged to obtain a copy of the relevant publications to become familiar with their content and application.

Trail Solutions – IMBA's Guide to Building Sweet Singletrack

Published by IMBA , this resource provides user-friendly guidelines on building high-quality mountain bike trails. Find it at www.imba.com/resources/trail_building/trail_solutions.html.

Forest Service Trails Reports 2004

This collection of reports related to trails covers a wide variety of subjects pertinent to developing natural surface trails. A CD-ROM of the reports is available at www.fhwa.dot.gov/environment/rectrails/trailpub.htm, under the publication 0423-2C03-MTDC Forest Service Trail Reports 2004.

General Design Guidelines and Considerations

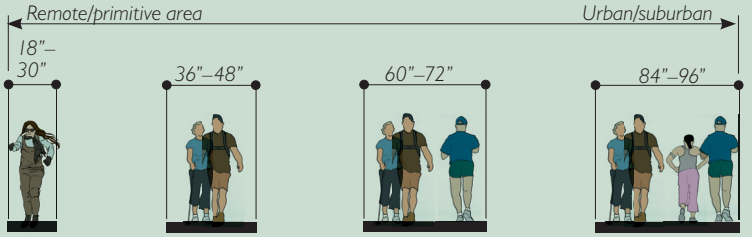
The following guidelines provide general design parameters for creating sustainable natural surface trails. These guidelines are not intended to be a substitute for site-specific design that responds to local conditions and safety concerns.

Trail Tread Widths

The physical space required for different trail users provides the base-line for determining the optimal width for a trail. Even within a given classification, site-specific circumstances often require alternative configurations to accommodate the anticipated types and levels of use. The graphics on this and the following page illustrate the basic trail width requirements for different types of uses associated with natural surface trails.

Typical Trails Widths For Natural Surface Trails – Nonmotorized Uses

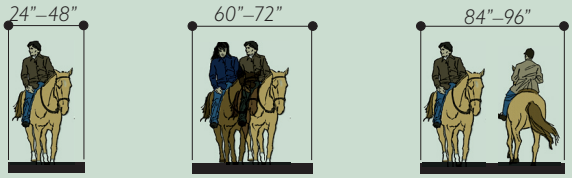
Trail widths vary considerably depending on type of use and whether a trail is single or double track and one or two directions. Trail width must also be based on a solid understanding of how a trail will be used since over time it will take the shape users give it irrespective of how it was originally designed. This is a distinct difference between paved and natural trails and must be accommodated in trail design. The following defines the basic trail widths and directional configurations for each type of natural surface trail use.



Single hiker | Staggered or side-by-side hikers | Staggered and single hikers with room to pass | Staggered or side-by-side hikers with room to pass

Hikers walk alone, staggered, or side by side, depending on the setting and character of the trail. The more remote or primitive an area, the narrower and more rugged the trail tends to be. In more urban areas, hiking trails tend to be wider due to heavier levels of use. For hiking-only trails, a width more than 96 inches (8 feet) is uncommon.

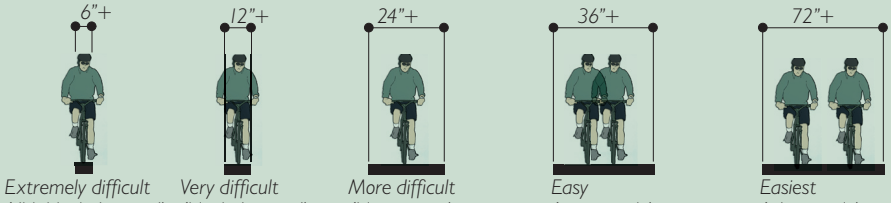
Typical Hiker



Single rider, one-way | Staggered or side by side riders | Side by side and two-way riders and carriages

Horseback riders walk single-file, staggered, or side by side, depending on the setting and character of the trail. As with hiking, the more remote or primitive an area, the narrower and more rugged the trail tends to be. In regional and state parks and along linear trail corridors, equestrian trails tend to be wider due to heavier levels of use and the desire to ride side by side. Carriage trails need to be at least 8 feet wide, plus a shoulder.

Typical Horseback Rider



Extremely difficult (dbl. black diamond) | Very difficult (black diamond) | More difficult (blue square) | Easy (green circle) | Easiest (white circle)

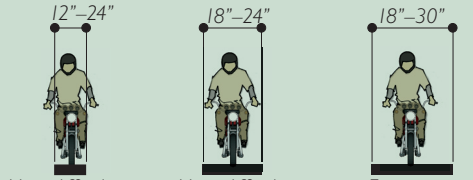
Mountain biking trail widths typically correspond to the trail rating system for difficulty as defined in Section 4 - Trail Classifications and General Characteristics. Two-direction trails are typically easier and wider trails.

Typical Mountain Biker

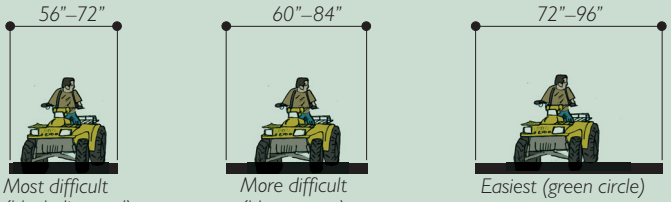
Typical Trails Widths for Natural Surface Trails – Motorized Uses

For OHV trails, tread widths vary considerably with type of use and level of difficulty. As with nonmotorized natural trails, trail width must also be based on a solid understanding of how a trail will be used since over time it will take the shape users give it irrespective of how it was originally designed. The following defines the basic trail widths and directional configurations for each type of natural surface trail use consistent with the difficulty levels defined in Section 4 – Trail Classifications and General Characteristics. Note also that trail widths are only one aspect of difficulty levels for OHV trails. Grades, curve radius, clearances, tread surface, and other characteristics are other factors in establishing a trail difficulty rating.

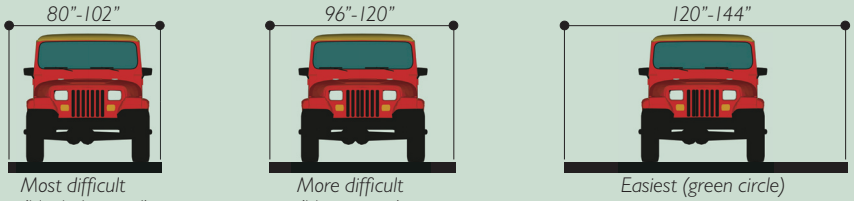
The tread widths shown for each type of use are for one-way travel, especially on the "more" and "most" difficult trail levels. For two-way use, provisions need to be made for passing. This can take the form of a wider trail or a series of well-placed pullouts. Refer to Section 4 – Trail Classifications and General Characteristics for additional information on trail layout configurations for OHV trails.



OHM Rider



ATV Rider



ORV

Forces Acting Upon Natural Surface Trails

Three fundamental forces acting upon all natural surface trail treads:

- **Compaction** – a downward force from the weight and impact of feet, hooves, and wheels
- **Displacement** – a sideways shearing force from friction and impact of feet, hooves, and wheels
- **Erosion** – the transport of materials by water or wind

Every tread problem is caused by one or more of these three forces acting alone or in combination. While standing water (mud and mudpits) and moving water (erosion) are generally perceived as the most obvious tread problems, compaction and displacement create the conditions for both to occur. The following considers each of these forces in more detail.

Compaction and Displacement

Different uses impart different compaction and displacement forces. Walking humans produce mostly compaction with slight displacement as particles are scraped and kicked forward and to the sides. The tread is deepened and hardened as the voids in the soil collapse and soil particles are pressed into tighter contact.

Horses exert a much higher compaction force and more displacement as they flip their hooves. Since horses tend to walk single file, the tread tends to deepen into a narrow slot while displaced material piles up on each side. OHMs with knobby tires and quick acceleration and braking exert more displacement force, which tends to throw soil completely out of the tread.

Compaction and displacement nearly always lowers the tread. On level ground, the sunken tread becomes the lowest point around and its compacted bottom prevents or slows water percolation. In wet conditions, this sunken tread will collect water. Trail users may try to make dry detours around the mud and water, which unfortunately spreads the tread across a larger area.

Displacement increases in wet or muddy conditions when bonding between soil particles is weakened or lost. Mudpits result from concentrated displacement and erosion as loosened soil is sloshed out of the pits.



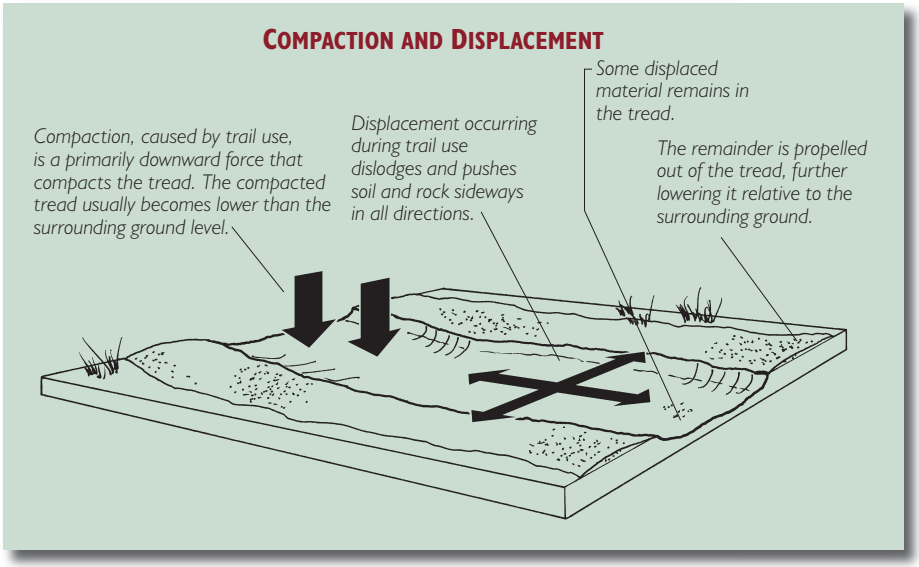
Foot tread. *Compaction and displacement from extensive use deepened this tread. The compacted tread is firm. Some soil loss is due to erosion from water flowing down the trench initially formed by compaction and displacement.*



Horse tread. *Horses flip their hooves as they walk, displacing soil a short distance in all directions. In loose soil, displacement forms distinct berms on each side of the trail. In firmer soils, horse trails can be firmly compacted (desirable).*



OHM tread. *Rapidly spinning knobby tires can cause high displacement, especially in looser soils. While soil is displaced in all directions, the throw pattern changes in response to curves and grades. This causes patterned displacement such as banked curves.*





Compacted treads, with reduced air spaces between particles, are firmer and more resistant to displacement and erosion. But they also absorb less water, increasing the amount standing on or flowing down the trail. In this level area, water puddles on the tread, while it sinks into the ground everywhere else.



On level or near-level ground, compaction and displacement sink the tread below the surrounding soil level. The tread then ponds water, causing mud and mudpits.

The extent to which compaction and displacement occur on natural surface trails is greatly affected by the type of use. Heavier, more powerful uses tend to have a greater propensity for compaction and displacement. The following graphics illustrate the compaction and displacement characteristics of six types of trail uses.

Natural Trail Uses and Impact on Trail Stability and Sustainability (Part 1 of 2)

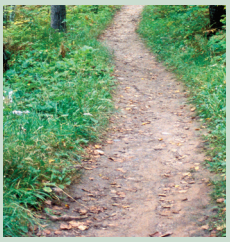
Human – Hiking, Walking, and Running

Compaction: Low–Medium.
Displacement: Low.

Most force is concentrated at one part of a person's foot, creating a relatively high force per square inch. As the foot rolls through a step, most of the force is angled downward at slow speed, causing moderate compaction. Part of the force is angled laterally (more or less parallel to the ground), creating some displacement. At walking speed, there is no appreciable centrifugal displacement on curves. Running increases speed, downward force and lateral force, causing somewhat faster compaction and a bit more displacement, especially on curves.



Hiking treads develop a pan-shaped tread with a nearly flat bottom and rounded edges. Most of the indentation is from compaction.



This typical shallow pan of a hiking trail reflects the tendency to walk in the center.



Compaction and erosion leave rocks and roots protruding from an otherwise smooth trail.

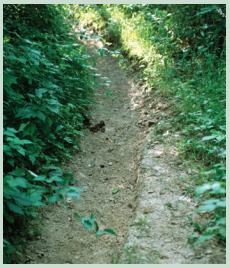
Horse – Riding or Pack

Compaction: High.
Displacement: Medium.

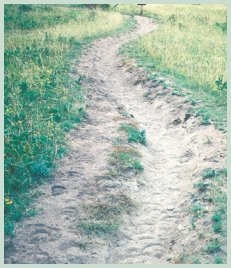
High force created by the weight and motion of animal and rider is concentrated on a small foot, imparting very high force per square inch and a high compaction force. A high displacement force is also created as horses kick their hooves, displacing soil entirely out of the tread and forming berms on both sides. These factors can quickly cause ruts in soils lacking displacement resistance. If the tread does become compacted, it typically is hard and strong enough to resist additional displacement. At walking speeds, no appreciable centrifugal displacement occurs on curves. The typically low speed of the animals also keeps most displaced material close to the tread.



Horse hooves create 18"-wide treads with flat bottoms and vertical side. In sandy soils, the tread can become quite deep from displacement.



Frequent horse use typically produces an 18"–wide entrenched tread.



Horses rapidly displace sandy soil. Displaced soil forms a berm at the edge of the used trail.

Mountain Bike

Compaction: Low.
Displacement: Low–Medium.

Tires with knobby tread impart a quick but strong downward force on a trail tread, creating a strong compaction force on the small area of the knobs. Since the tires are spinning, usually with acceleration or deceleration forces, they also impart lateral force. Most of this force is parallel to the tread and displaces soil accordingly. Some soil, however, is displaced out the tread, especially dust and larger particles. The faster the tire spins and the more force is applied, the more displacement occurs. In time, mountain bike trail treads tend to develop a gentle depression in the middle from compaction and displacement. On curves, bikes create strong centrifugal force that displaces soil toward the outside, tending to cause superelevated curves to form.



Mountain bike tires form gently swaled treads from compaction and displacement. Displaced material can go completely out of the tread.



Mountain bikes can cause extensive displacement in sandy soils.



This superelevated curve resists horizontal displacement while draining well.

Natural Trail Uses and Impact on Trail Stability and Sustainability (Part 2 of 2)

OHM

Compaction: Medium. **Displacement:** Extreme

The type and direction of forces of OHM tires are almost identical to those exerted by mountain bikes, but OHMs have far greater weight, speed, and acceleration forces. Coupled with deep knobby tires designed to dig in to soft soils, OHMs create more compaction and many times more displacement force than bicycles. Displacement on a narrow OHM tread can be severe and highly focused, resulting in deep ruts where tread lacks resistance. Displaced tread material is often thrown far from the tread. On curves, strong centrifugal force tends to form superelevated curves in many tread materials. Note, however, that while displacement force can be extreme, the point of contact and the amount of material moved is small. Displacement can be high in dry, wet, and muddy conditions.



OHM treads develop a narrow, rut-shaped tread with high displacement.





(Left) At best, dedicated OHM treads are bowl-shaped swales with no vertical edges.

(Right) OHM treads are prone to rutting in soils with low cohesion.

ATV

Compaction: Medium. **Displacement:** Very High.

The relatively low weight of ATV and rider are distributed across four wide tires. This imparts relatively little compaction force per unit area, leaving trail tread only partially compacted. Yet ATVs, with engine power and relatively small-diameter tires, produce great torque. Combined with high travel speeds, quick acceleration and braking, and aggressive tread designed to dig partway into soft soil, ATVs create a very high displacement force. The impact of little compaction but very high displacement can quickly rut a trail tread, with displaced material flung wide. At higher speeds, ATVs tend to skim along the surface, imparting extreme displacement force on the tread particles they do touch. On curves, especially tight curves, rapid displacement and centrifugal force nearly always creates superelevated tread over time unless the tread is well compacted. Displacement can be high in dry, wet, and muddy conditions.



ATVs create dual depressions through displacement by small tires with high torque.





(Left) ATVs can cause rapid displacement on new trails in uncompacted soils.

(Right) ATVs on this compacted former roadbed cause little displacement.

ORV (SUVs and Pickups)

Compaction: High. **Displacement:** Low–Very High.

Greater vehicle weight creates much more compaction than ATVs, while greater weight and engine power can create greater lateral displacement force. ORVs, however, tend to travel much more slowly than ATVs or OHMs, reducing the displacement that would occur at higher speeds. High compaction force tends to strengthen the tread under the wheels, often greatly reducing the amount of displacement that actually occurs. High-flotation, low-pressure "mudder" tires create less compaction than stock highway tires. Generally, though, the visitor-hardened tread of ORV trails tend to be strong unless the tread material cannot be compacted or has lost internal strength due to moisture. On sharp curves, most ORV drivers travel slowly and hence centrifugal force is low. On steeper slopes and in muddy tread, displacement can be very high.



Heavy weights and slower speeds create less displacement on ORV trail than on ATV or OHM trails.





(Left) Like most unpaved roads with room to move side to side, ORV treads tend to be smooth and hard.

(Right) Confining horizontal movement concentrates ORV forces in two narrow ruts.

Erosion

Even on slight grades, erosion caused by water can wash away tread material. Soil already loosened by displacement is the first to go. The higher the water volume, the more extensive erosion will be, especially on steeper trail segments. Although light rains may not cause much erosion, heavy rains can cause significant damage to the trail.

Compaction through trail use actually helps prevent erosion by hardening the tread materials, except in cases of pure sand and other large particles without binders. Even compacted tread, however, can be overwhelmed by high runoff volumes or speeds. Although a given segment of tread may be able to withstand erosion during a rainstorm that drops 1 inch per hour, it may erode under the onslaught of 2 or more inches per hour (a likely event in much of Minnesota). To be sustainable, the trail needs to be able to accommodate any conceivable runoff event, even a "catastrophic" one.



This five-foot-wide sandy tread is eroded up to 30 inches deep. Subsequent trail use displaces more soil that quickly smooths over the ruts. This smoothing can disguise the severity of erosion, making it seem as if the problem is not as bad as it actually is.



Years of truck traffic compacted the tread of this long-established on-road trail. The trail erodes, but the eroding channel stays to the softer edge of the active tread. Note that even this gentle grade erodes because it has a large surface area that captures a large amount of rainfall and runoff from the slope at left. Because trail users impart far less compaction force than trucks, trails tend to erode inside their treads rather than beside them.

Using Native Soil for Natural Surface Trail Treads



Tomorrow's problem! *While this new OHM tread may seem sustainable today, it has already compacted and displaced into a trench. Since it runs directly up the fall line of this slope, it will soon erode as water follows the tread straight downhill. After only one year, erosion has already begun, with the bottom of the tread being deeper than the top.*

Natural surface trails typically use native soils and rocky materials as the trail surface, with little or no vegetative cover. To be sustainable, the tread must accommodate the compaction, displacement, and erosion caused by trail use. With well-designed treads, abrupt, unanticipated changes in shape through use or erosion should not routinely occur. The tread should also not require major maintenance, reconstruction, or relocation for decades as long as frequent light maintenance is performed.

Ideal Tread Soil Material

An ideal tread material is a mix of all soil textures that exhibits high stability, becomes firm and stable when compacted, holds its shape even when wet, and has sufficient drainage to prevent saturation under most conditions.

The behavior of soil in terms of stability for trails is fairly predictable, with particle size classifications being the most important determining factors. Clays are very small particles, silts a bit larger, sands considerably larger, and stones (of various sizes) are the largest particles. Each particle size has advantages and disadvantages in treads.

Soils composed primarily of particles of one size have some inherent limitations. Pure sand, for example, has excellent drainage but almost no cohesion, making it difficult to sustain any distinct tread shape. In a soil with a mix of various particle sizes, the strengths of each size combine to help counteract their inherent weaknesses. The ideal tread soil has mineral-based particles of many sizes, including some rock. It also becomes hard and cohesive when compacted and remains firm even when wet.

Loams, which are blends of two or more soil textures, make much more suitable trail treads than treads principally composed of mostly clay, mostly silt, or mostly sand. Wherever displacement and erosion are likely, rocky material can greatly improve the strength of the tread by adding large structure that helps resist displacement and erosion. Mixing humus with loams usually weakens the loams as trail tread, but mixing humus with pure sand, pure silt, or pure clay may improve the tread slightly.

General Properties of Native Soils for Natural Surface Trail Uses

A basic understanding of how different soils function for trail treads is critical to creating sustainable trails. The following provides a general overview of the properties of the most common native soils types.



Silty clay is firm when dry but slippery when wet. The quarter provides a sense of scale.

Clays

Clay consists of extremely fine-grained particles less than 0.002 mm in diameter. The fine-textured particles have undergone mineralogical change for millennia resulting from decomposition of minerals in water. Clay particles are platelike and oily, and each particle carries ionic (electric) charges that attract and hold water in two layers – a tightly held layer close to the clay particle and a weakly held layer farther away. Compared to silts and sands, clays have tremendous surface area and can attract and hold large amounts of water, which is why clays tend to be muddy and poorly drained when wet. The platelike shape of the particles and the weakly held outer water layer helps explain why clays are slippery when wet – the plates slide past each other on water cushions. When clay is dry, the charges cause the particles to bond to each other, especially when compacted, giving dry clay a strength useful for trail treads. When rubbed between the fingers, wet clays feel smooth and sticky.

Characteristics of clay tread:

- Clay is very strong and dusty when dry, but extremely slippery when wet
- Undisturbed clays remain firm even when covered with ponded water, but disturbed or uncompacted clays become soupy when saturated
- A tread on undisturbed clay will compact to an extremely hard surface
- Once disturbed, clays may settle for years unless mechanically compacted
- Due to high internal strength, displacement of clays is minimal unless wet and disturbed, in which case strong shear forces can severely damage the tread
- The surface hardness of compacted clay makes it very resistant to erosion
- Mudholes will develop slowly wherever water ponds – the high strength of clay tends to resist rapid mudhole enlargement



Loess (windblown mineral silt from glacial grinding) on the Southeast Minnesota ATV Trail becomes so hard in places that the surface is polished with tire marks and is difficult to scratch with a coin. Soil this strong is found only in a few Minnesota locations.

Silts

Silt consists of mineral particles from 0.002 to 0.05 mm in diameter. Silt particles are medium-textured, small pieces of minerals knocked off of rocks with no subsequent mineralogical change. Silts sometimes have natural binders (raggedly shaped small particles with electrically charged edges) that can form very firm trail treads once compacted and when dry. Because Minnesota's four major glaciations ground so much rock into dust, many of Minnesota's soils contain some silt. Silts hold water to varying degrees but not nearly as much as clay, so silts are generally considered moderately to well drained. When rubbed between the fingers, silts feel slightly gritty. A more accurate test is to put some on your tongue – if it feels at all gritty, there is some silt or sand present, whereas pure clay is smooth.

Characteristics of silt tread:

- Silt is smooth, firm and dusty when dry but can be soupy when saturated under disturbed or uncompacted conditions, or during spring thaw when frost action breaks soil bonds
- Undisturbed and compacted silt high in mineral content, such as loess (windblown rock silt from glacial grinding) in southern Minnesota, can be remarkably resistant to displacement and erosion
- In general, treads high in silt have varying resistance to displacement and erosion depending on particle size, size mix, particle shape, mineral content, and other factors
- When wet, treads high in silt are usually slippery and partially to very muddy.
- Muddiness decreases with compaction
- With less internal strength and small particles, mudholes can form quickly wherever water chronically ponds



Round-grained "sugar sand" has zero cohesive strength and cannot hold any tread shape.

Sand

Sand consists of mineral particles from 0.05 to 2.0 mm in diameter, usually quartz. Sands are coarse-textured, carry no electric charge, and have no natural binders that can form firm and strong trail treads. Because of repeated glacial grinding, many of Minnesota's sands lack sharp edges that could create mechanical interlock and instead have rounded edges. Hence sand is loose and does not hold its shape, even when wet. Because the silicon and oxygen that comprise sand are both lightweight elements, sand is light in weight compared to other minerals. Sands are usually excessively drained, meaning that they can't hold much water.

Characteristics of sand tread:

- Treads high in sand content undergo little compaction and cannot maintain detailed specific shape
- With its light physical weight and lack of binders and charge, sand is easily displaced and eroded
- Sharp-grained sands are stronger than rounded grains due to increased mechanical interlock
- Trails in very sandy soil with high-displacement use typically become ruts with berms of displaced sand along one or both sides. If erosion is not a factor, the rut stops getting deeper when displaced particles are no longer propelled out of it
- Predominantly sandy soils are so well drained that muddiness is eliminated, runoff from surrounding areas is minimal, runoff puddles in the trail tread quickly percolate into the tread, and mudholes are impossible

Loam

Loam is a varying blend with a high percentage of silt, a moderate percentage of sand, and a low percentage of clay, making it medium textured. Most Minnesota upland soils are loams of varying blends—sandy loam, silt loam, clay loam, silty clay loam, loamy sand, or sandy clay loam. Like most blended soils, loams have the strengths of their constituent classes while the weaknesses of any given class tend to be compensated by the other classes. In loam, silt provides moderate structure and moderate binders, sand provides more structure and good drainage, and clay provides excellent binders and excellent water-holding capabilities that keep soil moist but not soaked.

Rocky material adds structure that usually improves soils used for trail treads, especially for heavier types of uses. Use of organic soil from decomposed vegetation as trail tread is discouraged due to its inherent limitations, as defined on the next page under humus.



A slightly gravelly loam has clay, silt, sand and small rock particles. It is firm when dry and makes a relatively durable tread surface. Shrinkage cracks indicate the presence of expansive clays, which are excellent binders but very slippery when wet.

Characteristics of loam tread:

- The blend of the compressive strength, good drainage, and structure of coarse-textured sand; the range of binders and particles of moderate-textured mineral silt; and the excellent binding action of fine-textured clay creates a firm tread with both ionic and mechanical interlocks
- Loams form a firm, compacted tread surface with moderate resistance to displacement and erosion
- When wet, the more sand there is, the less muddy the loam will be and the less it will displace through shear pressure
- Spring thaw or saturation of disturbed or uncompacted loam can suspend soil particles in water and break internal soil bonds, causing extreme mud conditions
- When dry, the more clay or silt binders there are, the more resistant loams will be to dry displacement caused by trail use
- Mudholes can easily form in loams; when they do, all the weaknesses of the constituent soil contribute to mudhole enlargement



Loam with some rocky material on the Superior Hiking Trail makes a durable tread.

Rocky Material

Gravel, cobbles, stones, and boulders are soil particles too large to be considered soil separates and are classed by size:

- Gravel: 2 to 75 millimeters (from sand to 3 inches)
- Cobbles: 75 to 250 mm (3" to 10")
- Stones: 250 to 600 mm (10" to 24")
- Boulders: larger than 600 mm (24")



Rocky soils make some of the most durable treads. The cohesive structure distributes weight and functions equally well wet or dry. Rock size, however, needs to be matched to the type of use or visitors will tend to go around, rather than over, the rocks.

Characteristics of rocky material in tread:

- On trails, all rocky materials resist compaction—the more stone there is in the tread, the more it resists compaction
- Rocky materials also resist displacement—the larger the stones, the more resistance they offer (but the more bumpy the tread can become)
- Rock particles resist erosion themselves, but can accelerate erosion in soils around them as water flows concentrate when passing around individual rocks
- All rocky materials drain extremely well, do not absorb water, do not become muddy, add significant resistance to displacement and erosion, and add traction surfaces, making them highly beneficial to trail treads in mud-prone, slippery, or excessively sandy soils
- Rocky materials, particularly cobbles, stones, and boulders, are ideal for strengthening tread to accommodate high-displacement trail use
- If rocky material is sorted (all the same size), it will always remain loose and prone to displacement; avoid sorted material; use rocky material with a full mix of sizes from dust all the way up to the desired maximum size; with this mix, the larger rocks create the major structure while the smaller rocks and dust fill in the voids and act as binders to lock the entire tread into a single mass
- If the rocky material is angular, it will create more mechanical interlock with additional resistance to displacement and erosion; nevertheless, Minnesota's abundant round granite rocky material is a welcome addition to many trail treads as long as there are enough small particles and binders to create a voidless mass

Humus

Humus (organic soil), while not technically considered a soil texture or soil separate, is sometimes used as trail tread. Often comprising the surface 3/8 inch to 4 inches " in forested and undisturbed areas, humus is the dark, spongy, top soil layer in aerobic soils resulting from the decomposition of organic (vegetable and animal) materials. Essentially an advanced compost, it is very light weight, absorbs water very well, and lacks cohesive strength unless held together by plant roots.



Organic soil makes a relatively poor trail tread because it maintains air spaces between particles that can become replaced with water. Hence this soil lacks bonding between particles, does not become solid when compacted, and holds a high amount of water when wet.

Characteristics of humus tread:

- Although it remains spongy and largely rebounds with light use, under heavier use humus can compact to a fraction of its original thickness; compaction will almost always form a depression in a humus tread
- For lightly traveled trails in areas that dry out quickly, humus can be used as a trail tread, but on more heavily traveled trails its lack of strength, light weight, and water retention cause it to be rapidly displaced and/or eroded
- Humus is too uncohesive to hold any sharp shape, maintain a sharp edge, or withstand displacement and erosion on steep grades
- Unless it is sustainably held together by plant roots, traveled only lightly on well-drained tread grades of less than 5 percent, and protected from splash erosion by a tree canopy, humus is not recommended as a tread material.

Creating Sustainable Natural Surface Trails

Sustainable trails can be created through a combination of good design and the proper use of native soil materials and/or hardening techniques that result in treads that resist compaction, displacement, and erosion. The following considers the fundamentals of creating sustainable treads for natural trails.

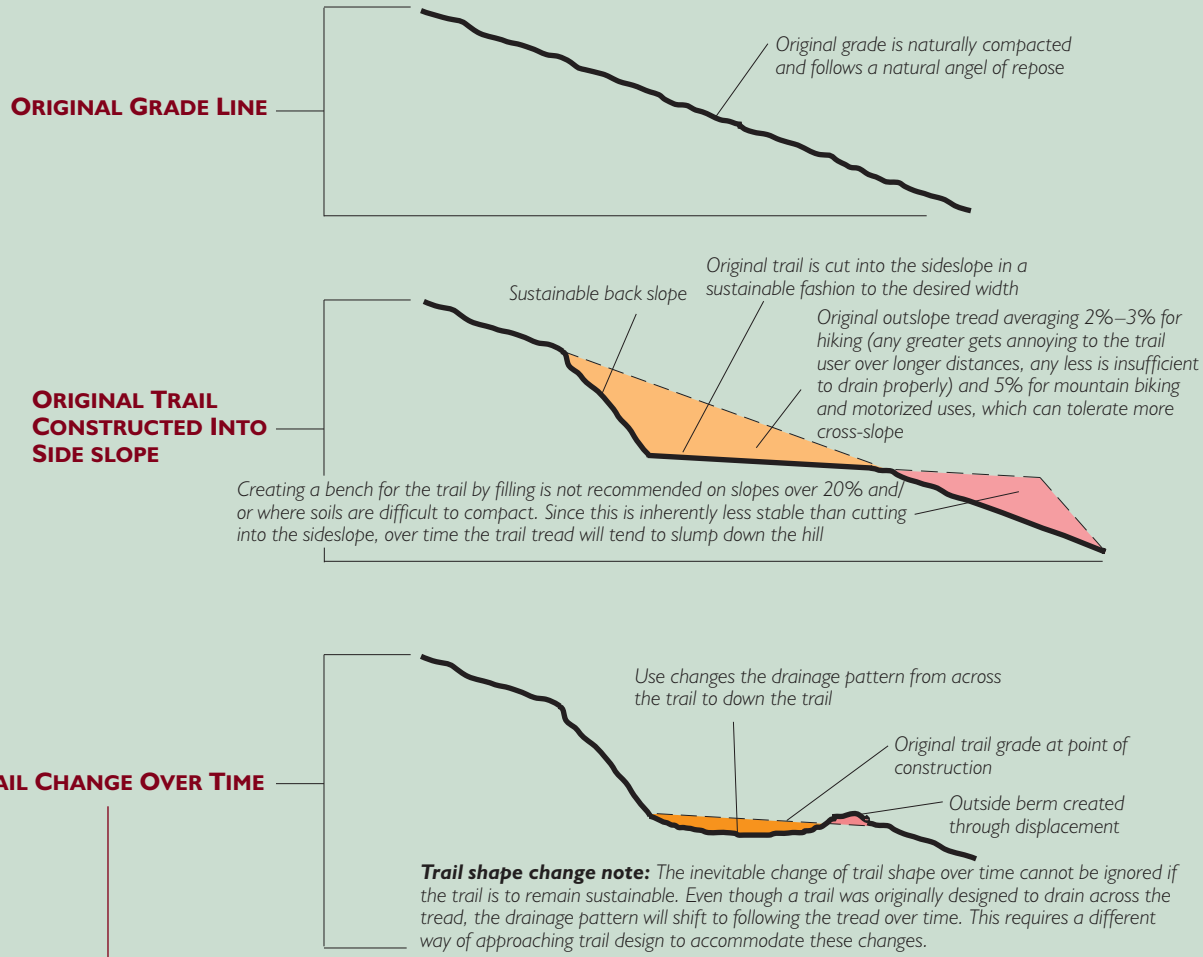
Keys to Sustainability

Sustainability is being able to retain the desired functional shape of the tread over time. For native treads, it is certain that:

- Compaction will tend to deepen the heavily traveled portion of the tread
- Displacement will not only deepens the tread but also raises the untraveled edges somewhat
- Erosion will follow deepened treads with any grade and deepen them further

The following graphic illustrates how properly constructed trails change over time.

Natural Surface Trail Tread Changes Over Time



For new or rebuilt native treads, these changes generally occur within a few months to 3–7 years. Timing and the amount of change depend on the tread material, trail use type and levels, and many other factors – but the direction of change is always the same.

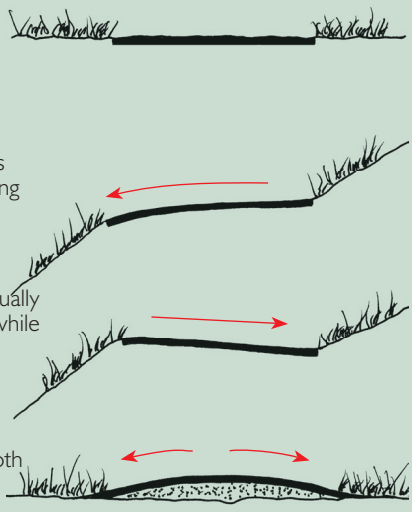
Newly Constructed Tread Cross Section

No tread shaping. Tread formed by clearing vegetation or using the trail

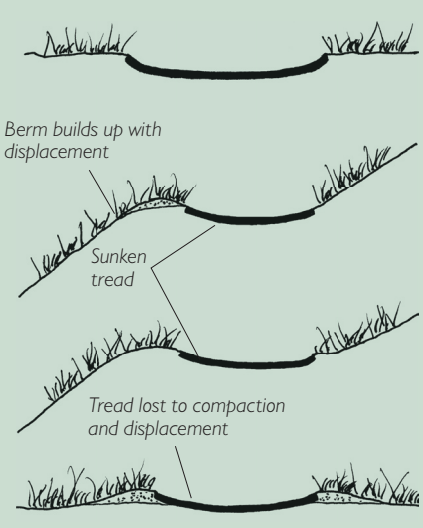
Outslope. Tread continually sheet drains downhill while traversing sideslope—ideal situation

Inslope. Tread continually sheet drains to inside while traversing sideslope

Crowning. Tread continually drains to both sides



Same Tread After Compaction, Displacement and Erosion



Sunken tread. Tread deepens across entire traveled tread area

Outslope is gone. Tread deepens in center, berm builds up on outside edge

Inslope partly works. Tread tends to level into a pan shape which channels water toward its center

Crown turns into a rut. Tread forms depressed pan in center

The key to sustainable native tread is to expect and accommodate predictable change in the tread shape.

Characteristics of Sustainable Natural Surface Treads



Limiting erosion. *Limiting tread grades to short segments prevents major erosion by limiting the amount of water flowing down any segment. Each segment must drain to somewhere lower than itself. This is easiest when a trail traverses a slope.*

Ideally, natural surface tread would continually drain to the side. As the previous images illustrated, outsloping, insloping, and crowning initially effectively drains the tread. Unfortunately, even subtle tread reshaping by compaction, displacement, and erosion will make these trails difficult to sustain except on very firm and stable treads used only by low displacement uses. To be sustainable, a natural trail tread has to have the following characteristics and management:

1. **Stable, compacted tread material.** The tread material exhibits moderate to high stability in both wet and dry conditions. The tread is compacted for increased stability and resistance to displacement and erosion. If the tread material is less stable and/or does not compact well, sustainable tread may still be possible if all of the following characteristics are present.
2. **Limited displacement.** The tread material, tread shape, usage restrictions, and/or maintenance minimize and/or accommodate displacement. Wheeled uses may need superelevation on curves to minimize displacement.
3. **Tread drainage with limited erosion.** Tread shape and location frequently drain surface and subsurface water to somewhere lower than the tread itself, typically to the side, before average runoff from the tread and the site accumulates to erosive volumes and/or speeds. Limited erosion, however, may be expected during very high and extreme runoff events. It is critical that the tread continue to drain during and after tread shape changes from compaction, displacement and erosion. New tread is formed with outslope, inslope or crowning even if that shape is not expected to be sustainable. While they last, those shapes create sheet drainage and minimize erosion from new earthwork. Highly porous tread material (sand, gravel) may improve tread drainage, especially on low or near-level tread grades.
4. **Narrow tread.** To concentrate compaction and reduce impacts, the tread and bare soil width are as narrow as feasible.
5. **Minimal hydrologic impact.** Tread shape, location, and drainage minimize changes in local hydrology.
6. **Trail maintenance and management.** Trail maintenance and management concentrate on proactive, frequent, small actions, including:
   - Performing routine light maintenance
   - Finding and correcting problems while still minimal
   - Predicting and preventing future problems
   - Closing trail during extremely adverse tread conditions, typically during spring thaw and other saturated soil conditions
   - Protecting tread from overuse and from uses it was not designed to support
   - Planning and supporting tread as a permanent facility with an indefinite lifespan

The degree to which any of the above characteristics and management are lacking will limit tread options. Depending on the circumstances, this could include rerouting the trail, reconstruction, making additional drainage improvements, using tread hardening techniques, making management changes, and even decommissioning.

Note that subtle tread shapes cannot routinely be relied upon to ensure a sustainable trail. With drainage, tread can be subtly shaped to initially do the job. With compaction and displacement occurring over time, a subtle shape is easily defeated unless the tread can be reshaped every few weeks. Using larger, more robust shapes and forms to begin with will ensure that more change in the tread can be tolerated before problems occur.



Ideal, but rare. *This new outsloped tread has an ideal combination of steep sideslope, stable and cohesive tread material, narrow tread, and low displacement use (hiking). Even outslope – usually the most difficult tread shape to sustain – is easier to sustain here because of the tread material and use.*

Note which part of the tread the hiker chooses to use. Eventually, visitors staying away from the outside edge will deepen the center of the tread. This will likely cause the outslope to fail unless maintenance reshapes it.

Caution: This tread works because all of its factors work together. To the extent that any of these factors – such as sideslope, stable tread material, narrowness, and low displacement use – are reduced or missing, the tread may need a modified approach for sustainability.

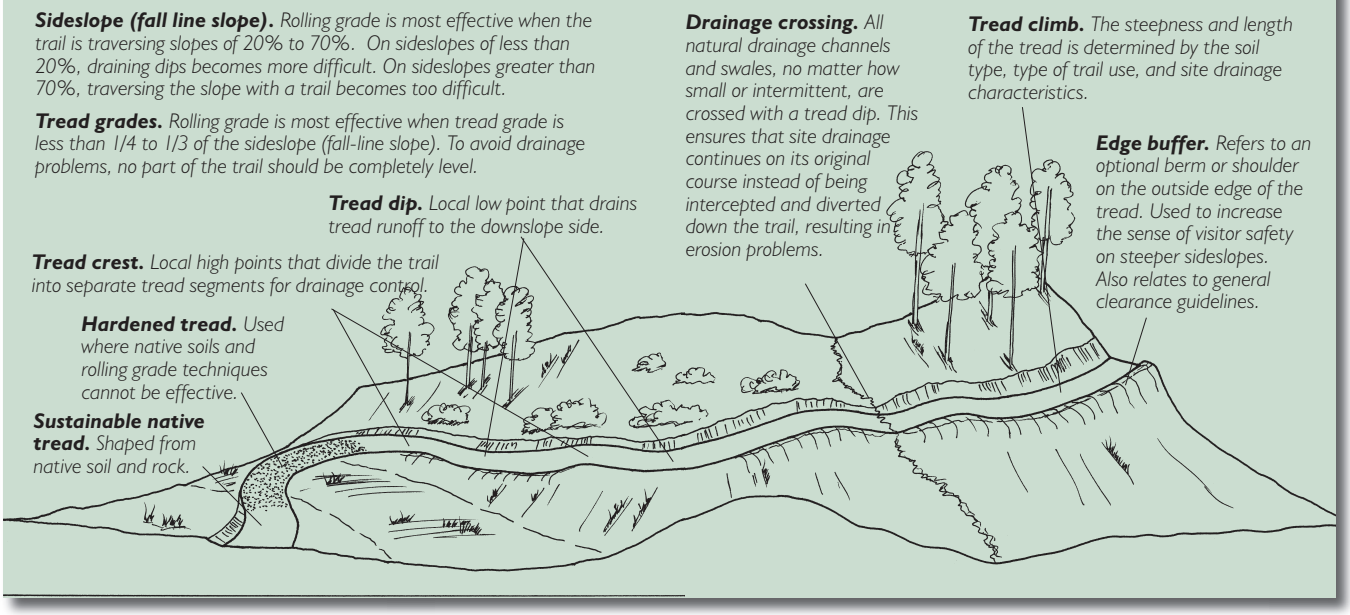
Primary Design Pattern for Sustainable Trails – Rolling Grade

"Rolling grade" is the primary design pattern used for developing sustainable natural surface trails. This pattern is best described as a series of dips, crests, climbs, drainage crossings, and edge buffers that are intrinsically linked and purposefully designed to form a sustainable trail. Unlike the geometric form associated with paved trails, rolling grade is inherently more responsive to the nuances of the landforms encountered on a site.

The rolling grade design pattern takes many variables into consideration, including: tread material and compaction, displacement, and erosion forces; types and amount of use; wet and dry conditions; topography and drainage patterns and flow rates; site vegetation; tread width and grade; and user safety. The following graphic illustrates the fundamental aspects of the rolling grade design pattern for natural trails.

Overview of Rolling Grade as the Primary Design Pattern for Natural Surface Trails

Rolling grade is the primary pattern for designing and building natural surface treads. Rolling grade trails are a series of tread dips, crests, climbs, drainage crossings, and edge buffers. In this illustration, rolling grade is used for portions of a trail traversing a sideslope.

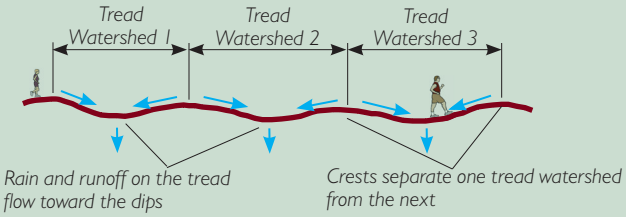




Ideal rolling grade. *Crests and dips are formed through tread alignment. Compacted through trail use, this tread is stable enough to resist displacement in most places. Steep slopes above the trail (to right) pour large volumes of runoff onto the tread, but the tread handles it with gentle grades and small tread watersheds.*

The basic concept behind rolling grade is that a sustainable trail must be able to drain to somewhere lower than itself at all times. Instead of hardening the tread to withstand these forces, rolling grade is used to manage water flows down or across the trail. By using a series of dips and crests like a roller coaster, the tread is divided into a series of small watersheds that drain into a dip, as the following graphic illustrates.

Tread Watersheds



A tread watershed consists of the tread surface plus any uphill area where runoff flows onto the trail and down to a dip between two crests. The only way to prevent erosion is to form tread watersheds so they will not produce enough water to seriously erode the trail. Every dip must also drain to somewhere lower than itself. The most sustainable way to arrange this is by traversing a slope, as the following graphics and accompanying photos illustrate.



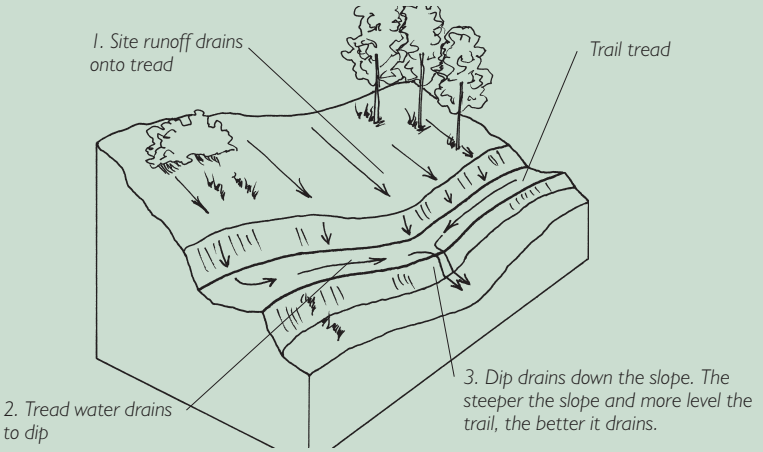
This OHM trail is at least 25 years old and has had virtually no maintenance. Rolling grade, coupled with gentle grades and the tree canopy, prevent erosion. The sandy loam tread absorbs much of the runoff, along with well-placed tread dips draining the rest.



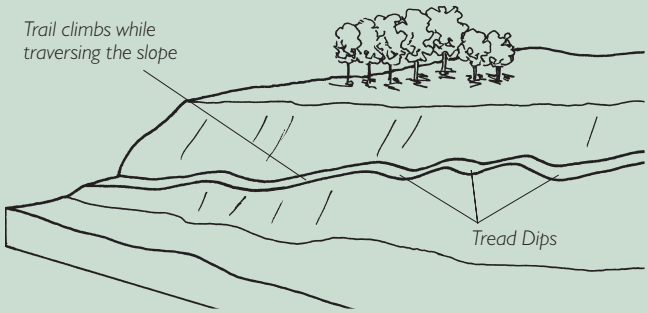
Gentle slopes require careful attention to draining tread dips. Without a steeper slope to quickly drain the dips, puddles and mudpits can quickly form.

Traversing a Slope to Prevent Erosion

Every dip must drain to somewhere lower than itself . The most sustainable way to achieve this is by traversing a slope, as illustrated below.



A trail using rolling grade can still climb a hill as long as the climb is not continuous, as illustrated below.





The "easiest" route is not necessarily sustainable. *The "easiest" way to climb the ridge from left to right is along the ridgeline (the horizon). However, if that were the case, the trail would not be able to drain water to the side because the "local" downhill at any point on the trail would be down the ridgeline (and trail), not to the side. By using rolling grade adjacent to the ridgeline, side drainage is created, forcing water to flow off the side of the tread at predictable intervals defined by low points. To work, all tread dips (yellow arrows) must drain to somewhere lower than the tread. As the photo illustrates, it is still possible to climb the hill when using a rolling grade approach with crests and dips in the trail.*



(Left) This trail climbs faster than it might appear. Rolling grade is used to limit tread watersheds on this erosive soil. With tree anchors, it is also used to make the trail more interesting to visitors.

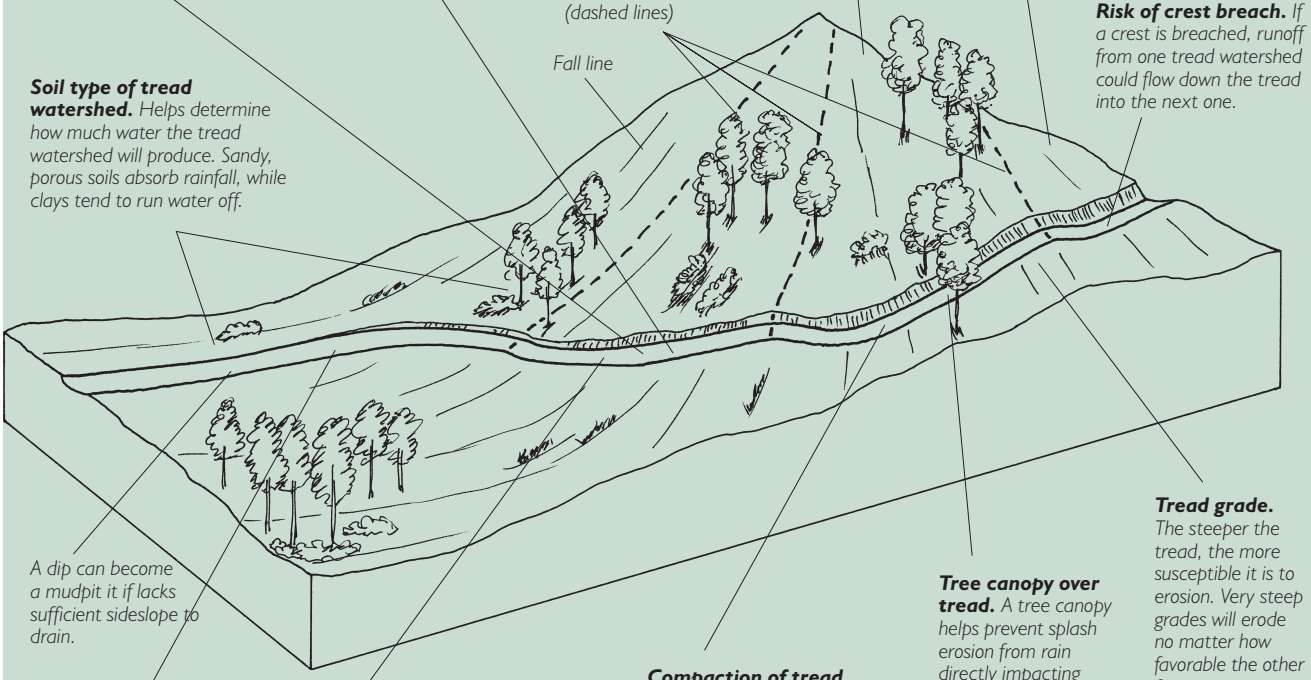
(Right) Rolling grade is used on this OHV trail to drain the tread, control erosion, and create challenges for ORV drivers. The tread is intentionally rough and extreme – yet erosion is limited by very short tread watersheds.



Minimizing the Risk of Tread Erosion

Used properly, rolling grade can prevent large-scale tread erosion, although smaller-scale erosion will always remain an issue within each tread watershed. The following box highlights some erosion risk factors.

Erosion Risk Factors



There are two primary ways to minimize the risk of tread erosion: limiting tread grade and limiting the size of the tread watershed.

Limiting Tread Grade

Important consideration!

Tread grade relative to slope grade is important to creating sustainable natural surfaced trails.

Predictably, less erosion is likely when trail grades are less steep. In highly erosive situations, minimal grades provide the best erosion control.

Tread should traverse slopes with a grade that is ideally less than one-fourth of the fall-line slope grade, with up to one-third being acceptable if soil conditions allow. For example, on a 36 percent slope, the tread grade should be ideally 9 percent. This ratio helps ensure that the tread is not following the fall-line and that side drainage without excessive erosion is possible.

As tread grade increases, native soil treads need to be drained more frequently to prevent accumulation of erosive flow volumes. This is most often accomplished by placing tread crests closer together.

Limiting the Size of the Tread Watershed

Limiting the size of the tread watershed limits the amount of erosive runoff that can be produced and the amount of water the tread has to carry. The total water in each tread watershed is that which lands directly on the tread plus water that drains onto the tread from the surrounding upstream area. Note that the maximum possible flow from a severe storm must be handled without major damage to the trail, although some erosion should be expected. Lesser runoff events should cause no or minimal erosion. By making sure that each watershed is not excessively large, the damage caused by a larger storm can be controlled.

In most cases, the rainfall that will cause the most erosion is that which falls on the tread itself. Compacted or hardened treads produce nearly 100 percent runoff on the entire length and width of the tread. Grass-covered trails hold back more runoff and tend to be less erosive, However, these trails also are only suitable where use is limited. By placing crests closer together the risk of erosion is reduced. Keeping the tread narrow and protecting it with adjacent vegetation also helps.

The watershed draining onto the tread can add additional water, especially in heavier runoff events. The flow rate and quantity varies depending on the size of the watershed, plus its vegetative cover and soil type and porosity. Heavily forested areas with good ground cover or native grasslands adjacent to a trail produce much less runoff than barren land and are less of an erosion concern.

The following table defines some erosion risk factors and suggests adjustments that can be made to the trail to reduce the risk. As the table illustrates, this requires balancing many factors, using some factors to mitigate others, and using judgment and experience to form appropriately sized tread watersheds with appropriately aligned treads.

Tread Erosion Risk Factors for Watersheds

Risks are classified as "lower," "moderate," or "higher." These are relative classifications that have to be balanced against in-the-field judgment, experience, and real-world conditions. In general, the higher the extreme – too steep, too long, too much, too fast – the higher the risk of erosion. Tread grade is the single most important factor, with even a 2 percent grade being susceptible to eroding in some situations.

How To Use This Table: Preventing erosion starts with identifying the weakest link, which is the most erosion-prone aspect. This tends to set the erosion risk for any given tread watershed. Since tread grade is the single most important factor, a number of factors in the "higher risk" category will have little effect if tread grades are low. For example, while a high tread displacement rating for trail uses may be in a higher risk category, if the tread grade remains low and the tread length is short, high displacement may not pose much erosion risk.

Special Note: If tread grade is 5 percent or steeper and one or more factors in the "higher risk" category are not mitigated by other factors, erosion risk should be lowered by reducing the size of the tread watershed or adjusting other factors.

Risk factor	Lower risk	Moderate risk	Higher risk
For the trail tread itself			
Tread grade (tread climb)	< 5%	> 5%	> 10%
Tread grade as relates to fall line	Tread grade < 1/4 of fall-line	Tread grade 1/4 to 1/3 of fall-line	Tread grade > 1/3 of fall-line
Tread length in tread watershed	Short	Medium	Long
Tread width	Narrow	Medium	Wide
Stability of tread material	High	Moderate	Low stability
Compaction of tread material	High	Moderate	Little or none
Amount of trail usage	Low	Moderate	High
Trail use displacement rating*	Low	Moderate	High
Risk of crest breach†	Low	Moderate	High
Tree canopy over tread	Thick or continuous canopy	Intermittent canopy	No canopy
For the tread watershed above the tread			
Surface area of tread watershed	Small	Medium	Large
Vegetation on tread watershed	Thick forest w/ thick leaf litter	Grassland, shrubby, no leaf litter	Rocky, bare soil, thin vegetation
Soil type of tread watershed	Sandy, well-drained, uncompacted	Loamy, moderately well-drained	High rock content, clay, poorly drained, compacted or impervious
Chance of voluminous and/or rapid surface runoff	Low	Moderate	High

* Each type of trail use has a displacement rating that indicates the amount of displacement force it typically imparts.

† Likelihood that a tread crest will be breached and allow water to flow from one tread watershed to the next. On a trail that is climbing through two or more tread watersheds, a crest breach (like a failed waterbar) could create a domino effect that would overwhelm tread watersheds down the trail.

General Guideline for Trail-Building Process

The process for developing high-quality natural surface trails centers around two important considerations:

1. **Defining the user group(s).** Each type of user group brings with it trail development nuances that must be considered if the trail is to be sustainable with minimal maintenance.
2. **Planning a route that is sustainable and enjoyable.** An interesting, exciting, and rewarding route is critical to trail success and sustainability. If trails do not meet user expectations, the likelihood of bypassing and creating new routes increases. With higher impact uses, bored users are more likely to use the trail recklessly and cause additional impacts to surrounding vegetation.

Basic Step-By-Step Process for Developing Trails

The following outlines the basic step-by-step process for developing a natural surface trail. These steps complement the trail project planning guidelines in Section 1 – Framework for Planning Sustainable Trails, which should be referred to for more extensive checklists and standard requirements when developing a trail. IMBA's *Trail Solutions* is also a suggested reference, especially when laypersons are involved in building a trail with hand tools and require a basic understanding of the process. Typical trail-building steps include:

1. **Confirm property limits** – to ensure that the trail is being built on the right property.
2. **Confirm trail users** – to understand the exact trail requirements and the design parameters that must be applied. Refer to Section 4 - Trail Classifications and General Characteristics to determine the specific requirements and layout considerations for each type of use. This also includes defining the different type of users within each group. For example, trails within a designated OHV recreation site are often designed to a different standard than a designated OHV trail.
3. **Layout the trail** – including control points and desired places to visit and avoid. Loop configurations, trail flow, and rolling grade character are all important factors in creating an appealing trail. (Refer to Section 2 – Principles of Designing Quality Recreational Trails and Section 4 – Trail Classifications and General Characteristics for pertinent information on creating trails that will meet user expectations.)
4. **Flag the trail corridor** – incorporating all of the desired features and creating a sequence of events that will make the trail interesting and meet the desired level of challenge. Remember that trail quality is closely related to how well the trail builders pay attention to detail design issues.
5. **Prepare a construction plan** – which includes input of key participants and land managers to ensure that construction techniques and equipment used are well suited for the type of trail being built. Equipment selection is particularly important in that its size and maneuverability will be reflected in the final form of the trail. For example, an intimate hiking trail is often better built with hand tools then a mechanized dozer if keeping the trail narrow with limited disruption to the surrounding landscape is important.
6. **Construct the trail** – following the construction plan and making sure that each section of trail is stable and sustainable before moving on to the next section. Avoid exposing extensive sections of the trail to erosion during construction.
7. **Formalize a management and maintenance plan** – to ensure that ongoing maintenance is being considered at the point when the trail is being constructed. Routine inspections are especially important during the initial season or two that the trail is open to ensure that it is stable and sustainable. Problem areas should be immediately addressed before use patterns are established and realignments become more difficult.

Trail-Building Tools and Equipment – an Important Consideration

Choosing the right tools and equipment for building a rolling grade natural surface trail is a subject that is too broad to cover in detail in this manual. There are, however, a number of resources worth reviewing that cover various types of tools and equipment best suited for any trail-building situation. The following illustration provides an overview of trail-building tool and equipment selection, along with resource links for more in-depth information.

Resources for Selecting Tools and Equipment for Building Trails

Resources for Tool/ Equipment Selection

- IMBA's *Trail Solutions* handbook (www.imba.com/resources/trail_building/trail_solutions.html) offers a practical guide for building natural surface trails, with particular attention given to common hand tools and smaller walk-behind mechanized equipment.
- The Professional Trail Builders Association website (www.trailbuilders.org/suppliers.html) provides an extensive listing of trail building equipment and services that are available.
- The American Trails website (www.americantrails.org/resources/consultants/index) provides a listing of tools and supplies for trail-building and maintenance – including links to equipment manufacturers offering specialized equipment.
- *Forest Service Trails Reports 2004* is a collection of reports (www.fhwa.dot.gov/environment/rectrails/trailpub.htm) under the publication 0423-2C03-MTDC. This CD offers several publications that describe tools and equipment. Publications *8823-2601-MTDC Handtools for Trail Work* and *9823-2837-MTDC OHV Trail and Road Grading Equipment* have particular application.

Narrow Hiking or Mountain Biking Trail

For intimate trails, hand tools are most often used to keep the trail intimate and narrow, limit construction impact, and avoid moving heavier equipment into often remote areas with challenging terrain. This particular trail was built with hand tools by a group of volunteers.



Wider Hiking, Mountain Biking, Horseback Trail/ Narrower ATV Trail

As trails become wider, walk-behind and smaller ride-on mechanized equipment is commonly used to gain efficiency and the capacity to move more soil. As equipment size increases, trail intimacy decreases. Walk-behind mechanized equipment with a mounted front blade was exclusively used for developing this trail, along with select hand tools.



Wider OHV Trails

For wider OHV trails, ride-on mechanized equipment becomes more useful and necessary. Even then, however, the equipment used for trail building is often considerably smaller and more specialized than typical road-building equipment. A variety of specialized mechanized pieces of equipment were used to develop this trail segment where importing fill material was necessary.



Whereas most of the hand tools used for trail building have been in use for many years, the type and level of specialization of mechanized equipment continually evolves in response to new demands. This is especially the case with equipment for building OHV trails, where newer trails are often many miles long and require specialized equipment to cost-effectively develop and maintain them. The photos on the next page highlight a few of the pieces of equipment and attachments that are becoming more commonly used for building natural surface trails.





(Left) Walk-behind or small ride-on pieces of equipment remain the workhorses for building natural surfaced trails of all types.

(Right) The correct equipment for trail maintenance is also critical. This attachment first tills or scarifies a rough trail surface, then blades it smooth in one efficient operation.





(Left) This mid-sized excavator is extremely useful in building OHV trails where efficient earth moving is necessary.

(Right) A tiller/box blade mounted on a ride-on tracked implement carrier effectively reconditions a heavily used ATV trail.





(Left) This small ride-on tracked transporter is an essential piece of equipment for larger-scale trail projects.

(Right) New models of transporters dump in multiple directions and accommodate a variety of attachments using a universal hitching assembly.





A variety of new implement carriers enter the market each year, each with an extensive array of implement attachments that can till, scarify, blade, level, cultivate, condition, and compact trail surfaces.

Rolling Grade Trail-Building Techniques

Tread crests, dips, climbs, drainage crossings, and edge buffers give form to the rolling grade design pattern. IMBA's *Trail Solutions* provides an introduction to building these elements into natural surface trails and is a suggested reference to complement this manual. The following takes trail building to the next level by expanding on basic rolling grade techniques to give the trail planner or builder a more extensive understanding of how natural surface trails can be constructed to remain sustainable even after years of hard use.

Tread Crests

Tread crests divide the trail into individual watersheds. Each crest is a local high point in the trail and must be sufficiently long, high, and durable to permanently remain as a high point even as tread compaction, displacement, and erosion occur. The larger and longer a crest is, the less likely it will be to be breached by displacement. In some cases, it may also be necessary to harden an entire crest to keep it in place. As trail grade increases, basic physics also make tread crests increasingly difficult to form and sustain.



Displacement and compaction. *This small former crest has lost its top to displacement and compaction. It was simply too small. A larger, longer crest would have lasted much longer.*



Sedimentation. *This flexible waterbar is no longer functional because of sedimentation, which allows water to now flow over the top of it.*



Visitor bypass. *Some hikers perceive these rough stone waterbars as obstacles and bypass them. Note how new treads are forming on both sides of the waterbars.*

Tread Crests

Tread crests divide the trail into individual tread watersheds. A combination of tread crests and dips are used to manage the flow of stormwater runoff to prevent erosion.



Tread crests are vulnerable to breaching when runoff from one watershed flows through an adjoining crest into the next. The three main causes of crest breach are:

1. **Displacement and compaction.** Displacement from trail use can quickly grind the tops off small, steep, pointy, or soft crests. High-displacement uses can wear the tops off of even larger crests, especially on steep tread grades. Compaction can also lower the top. Using a combination of design techniques and carefully selecting crest locations to withstand displacement can help prevent breaches.
2. **Sedimentation.** When a crest is on a climbing trail grade, sediment from erosion and dry displacement can pile up on the uphill side of the crest, eventually reaching the top and enabling water to flow over. Although this is a problem more associated with a tread dip, appropriate construction can help prevent it. Regular trail maintenance can also help prevent and remove sediment accumulation.
3. **Visitor bypass.** If a crest is not comfortable or convenient – too high, too sharp, too rough, perceived as obstacle – some visitors will attempt to go around it, which defeats the purpose. If smaller crests are placed along a climbing trail grade, bypassing them can carve new channels for water to flow around a crest and continue down the trail. Carefully using site anchors and integrating crests into the site will reduce the tendency to create crest bypasses.

The effective volume of a tread crest (the portion that actually holds back water) is also an important factor in whether it will breach. As trail grade increases, less of the entire crest serves as the actual "dam" for water on the uphill side. The greater the effective volume, the more likely the crest will withstand displacement and compaction, as the following graphic illustrates.