



INTERNATIONAL MOUNTAIN
BICYCLING ASSOCIATION



Sustainable Trail Development

A Guide to Designing and Constructing Native-surface Trails



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Acknowledgement:

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Special thanks should also go to professional trail builder Tony Boone with Arrowhead Trails Inc., whose extensive 20-year knowledge of sustainable trail design and construction inspired the Town of Castle Rock to look at native surface trails in a new approach and in developing a world-class trail system.

Prepared By: Richard Havel, Trails Planner for Town of Castle Rock, Parks & Recreation Department ~ May 2009

Introduction:

What is a sustainable trail? Building a sustainable trail system takes into account many factors. Most importantly, a sustainable trail should have as little impact to the environment as possible; this is accomplished through proper trail planning, design, construction and maintenance. A properly built trail will last for generations to come with little maintenance needed and will blend into the natural surroundings. Native-surface trails, also known as soft-surface trails, use the existing site materials to construct the final trail; this defers from paved trails in which, in some circumstances, asphalt or concrete may be used as the trail material. Because of the nature of the material used to construct native-surface, the principles of sustainable trail development are vital to the longevity of the trail system as a whole. This guideline will focus on native-surface development guidelines to help insure the success of the final trail.

The National Park Service's Definition is as follows:

A Sustainable Trail:

- Supports current and future use with minimal impact to the area's natural systems.
- Produces negligible soil loss or movement while allowing vegetation to inhabit the area.
- Recognizes that pruning or removal of certain plants may be necessary for proper maintenance.
- Does not adversely affect the area's animal life.
- Accommodates existing use while allowing only appropriate future use.
- Requires little rerouting and minimal long-term maintenance.

~ From the National Park Service, Rocky Mountain Region, January 1991

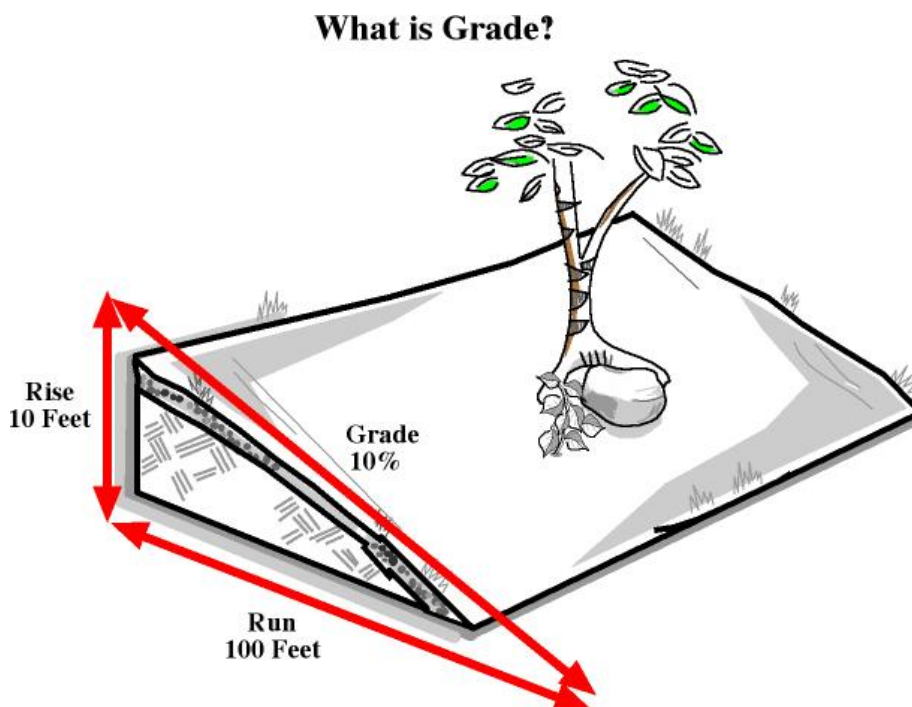
Well-constructed trails will withstand erosion and are more enjoyable to use. Poorly designed trails will create an unpleasant experience for riders and walkers as well as a financial and volunteer resource drain.

The following sections will help guide those who are planning to develop a native-surface trail system.

Part One: **Principles of Sustainable Trails**

Erosion is the key issue leading to trail failure. Left unchecked, erosion can devastate a trail and harm the surrounding environment. All trail users loosen soil, especially on steep grades. When water is introduced, the problem is multiplied by allowing water to channel down the trail gaining velocity and energy, washing soil away and cutting deeper into the trail tread.

A major oversight in trail building is creating a trail that is too steep. Percent of grade in trail building is very important in the prevention of soil erosion and understanding the concept of grading is vital; the illustration below shows this concept.



Percent of grade is determined by dividing the elevation distance (Rise) by the linear distance (Run) multiplied by 100. $10/100 \times 100 = 10\%$ Grade

The Five Essential Elements of Sustainable Trails

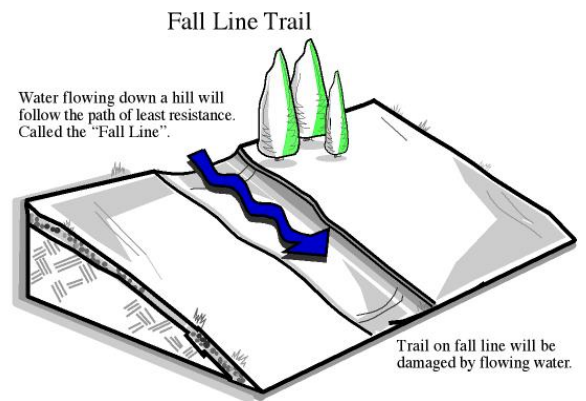
1. The Half Rule
2. The Ten Percent Average Grade
3. Maximum Sustainable Grade
4. Grade Reversals
5. Outslope

1. The Half Rule

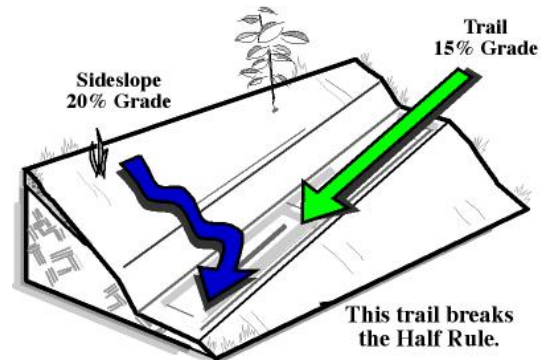
A trail's grade should not exceed half the grade of the sideslope the trail is traversing. If the trail's grade exceeds half the slope's grade, it's considered a fall-line trail. Water will be focused to travel the fall line, the path of least resistance, rather than flowing across it.

Using a tool Clinometer (**See Page 19**) to measure the sideslope percent of grade, keep the trail's tread grade below half of what was measured will ensure proper drainage. For example, with a sideslope of 20%, the trail's tread should not exceed 10%.

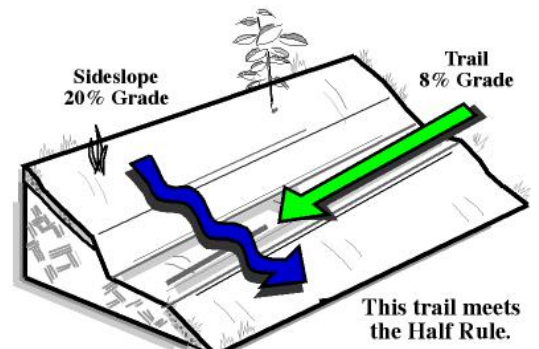
The half rule is especially important in areas of gentle slopes, erosion can still occur and the half rule still applies. For example, a trail traveling through an area with sideslopes of 6%, the trail's grade should be less than 3% to avoid the fall-line. Flat areas should be avoided, as trails built in these areas are more likely to collect and hold water.



Half Rule



Water will flow down trail.

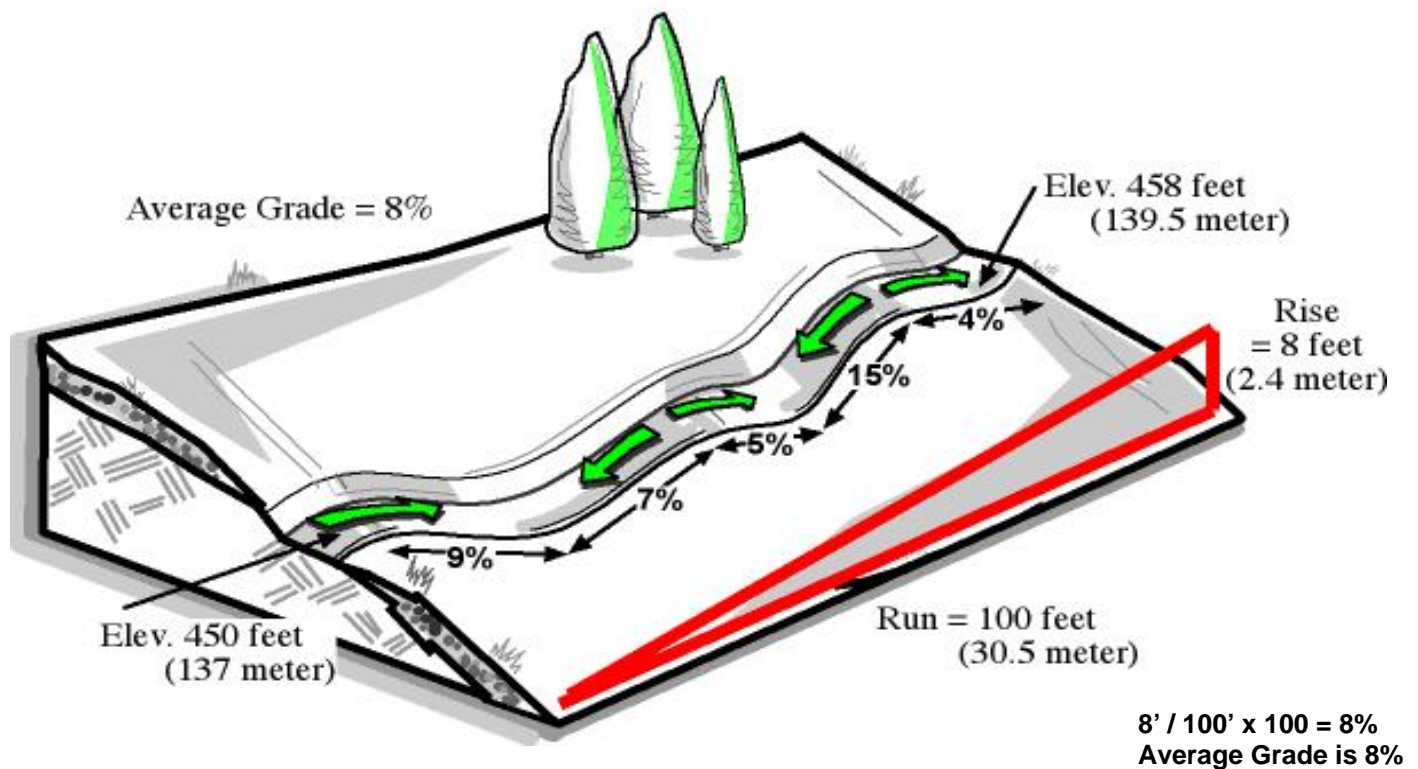


Water will sheet across trail.

2. The Ten Percent Average Guideline

Generally, a 10% average grade is the most sustainable. This does not mean that all trail grades should be kept under 10%. In many situations, the trail may undulate, creating areas that have short sections steeper than 10%. But overall, the trail's average grade should be maintained at a sustainable grade of 10% or less. Short sections can exceed 10% as long as the half rule is still used (15% trail grades can be used for short sections as long as the sideslope is greater than 30%).

Average or Overall Grade



3. Maximum Sustainable Trail Grades

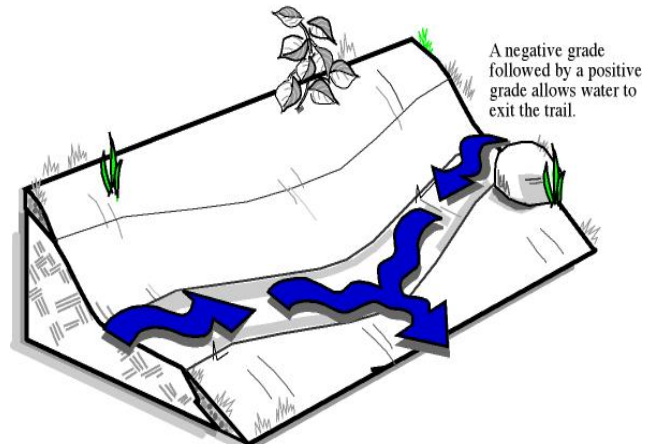
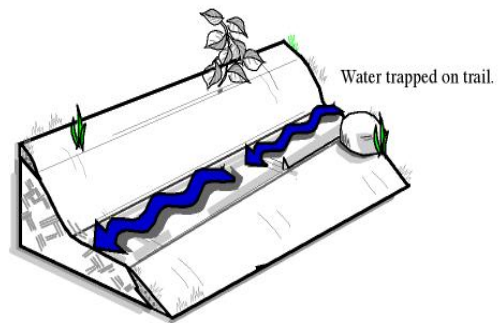
Maximum grade, usually around 15% to 20%, is the steepest allowable grade based on several site-specific factors, which include: **Half Rule** (the trail's grade is less than half the sideslope grade); **Soil Types** (some soils support steeper grades than others); **Rock** (solid rock or rock embedded slopes can be steeper); **Annual Rainfall** (heavy rainfall leads to water caused erosion, low rain leads to dry loose soils); **Grade Reversals** (a short dip followed by a rise forces the water to drain off the trail); **Types of Users** (low impact users, hiking and biking, can sustain a steep grade. While higher impact users, horses and motorized should have lower maximum grades); **Number of Users** (higher anticipated use leads to lower grades); **Difficulty Level** (trails with a higher degree of technical challenge tend to have steeper grades, grade reversals and armoring are necessary to ensure sustainability).

Grade Reversal

4. Grade Reversals

A grade reversal is a spot at which a climbing trail levels out for about 10 to 50 feet before rising again. This change in grade allows water to exit the trail tread at the low point of the grade reversal. Grade reversals are recommended every 20 to 50 feet. Grade reversals are also known as: grade dips, grade brakes, drainage dips and rolling dips.

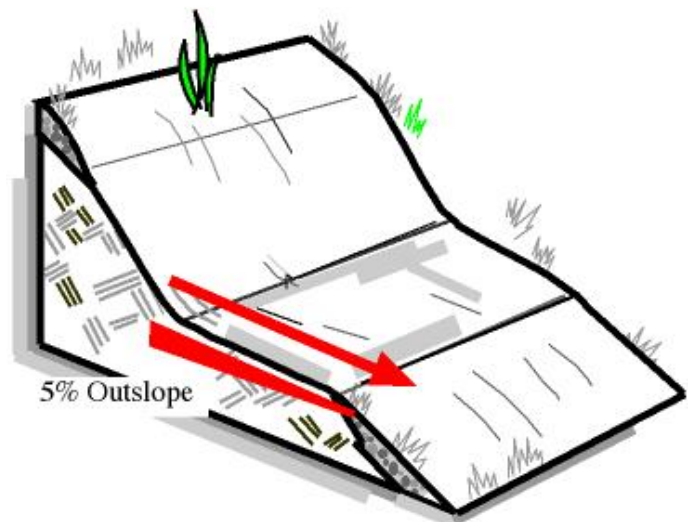
Grade reversals also make a trail more enjoyable. On long downhill sections, grade reversals slow bicycle speeds and add variety and challenge. On up hills, brief descents help users regain their momentum and catch their breath.



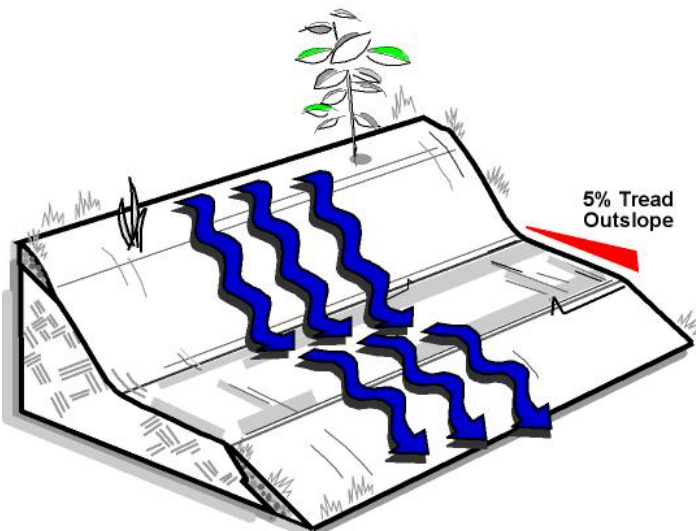
5. Outslope

As the trail contours across a hillside, the downhill, or outer edge of the trails tread should be slightly lower than hillside, or inside edge by 5 percent. Outslopes encourage water to sheet across the trail rather than traveling down the trails center. Outslopes can be difficult to maintain in loose soils. Constant impact from users tends to compact the center of the trail and push soils to the sides. Frequent grade reversals are essential in order to drain water from the trail in this situation.

Outslope



Sheet Flow



Trail Profile



Part Two: **Trail Design**

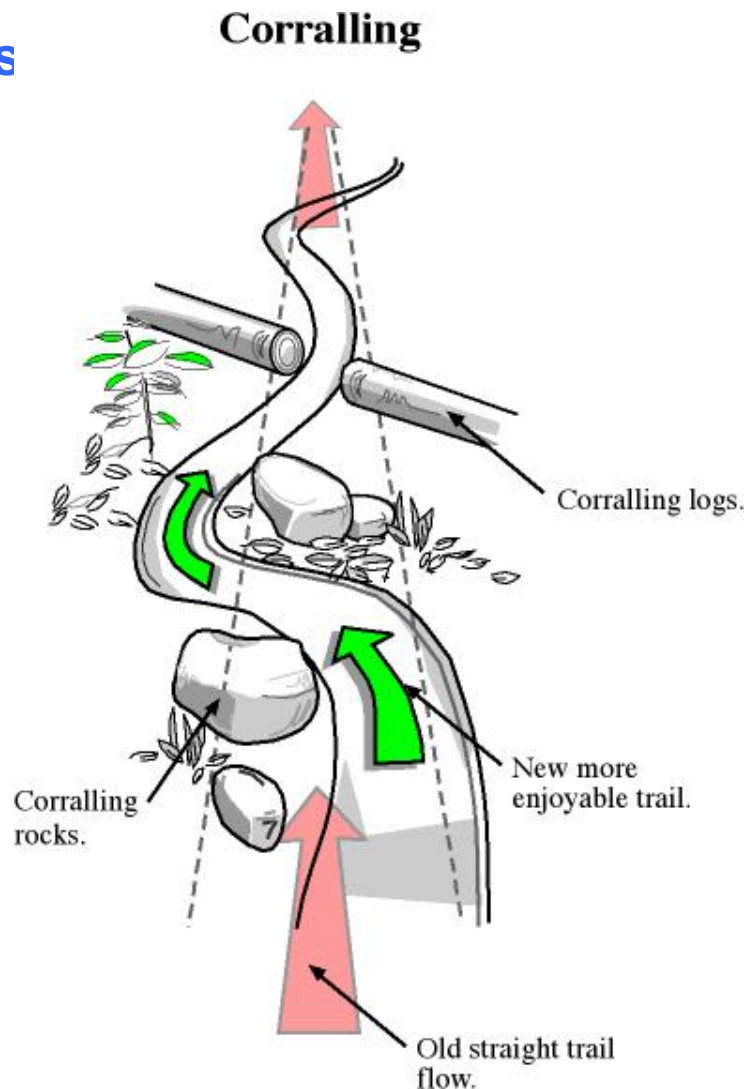
The speed mountain bikers' travel on a trail is controlled through proper trail design. Some trails attract inexperienced bikers who are still learning how to manage their speed and in some cases they travel too fast making other users uncomfortable. In other cases, they'll brake too suddenly when approaching a turn or obstacle and damage the trail. For these reasons, the designer, not the rider, best controls speed. The following are methods used to control speed:

Corralling, Chokes and Turns

Include objects to define the sides of the trail and emphasize turns. Also called **trail anchors**, these can be large rocks, logs, trees or other obstacles staggered on either side of the trail that serve as physical and visual barriers to keep users on the trail and slow riders.

Create a slight narrowing of the trail with rocks or plants to control speed. Also called **gateways**, these should be installed just prior to spots in the trail where users need to slow down, such as sharp turns and trail intersections. Chokes encourage riders to gradually apply their brakes well in advance of sensitive areas. Make sure the narrowing flows naturally with the trail. Otherwise, users could find it annoying and may create a new route around it.

You can also build a tight and twisty trail, with constant ups and downs, lefts and rights. Since trail users must stay focused on an always-changing trail, they feel like they are traveling faster than they actually are. A tight and twisty single-track gives the illusion of speed without allowing trail users to actually go very fast. Always create gradual transitions between changes to trail flow.



Eleven Steps to Designing a Great Trail

Most trail management problems, from erosion to user conflict, stem from poor design. Poorly designed trails, no matter how well built, will almost always fall apart and become a source of contention for managers and users. The following steps will help alleviate the most common trail building pitfalls.

1. Get Permission and Build a Partnership
2. Identify Property Boundaries
3. Determine Trail Users
4. Identify Control Points
5. Configure Loops
6. Plan a Contour Route
7. Determine Type of Flow Trail
8. Walk and Flag the Trail Corridor
9. Develop a Construction Plan
10. Conduct an Assessment Study
11. Flag the Final Alignment and Confirm Permission

Step 1: Get Permission and Build a Partnership

Always get permission before you begin building a trail. Forming a partnership with the landowner or land manager from the start will accomplish more and create a situation in which everyone benefits. Present a written proposal describing how and where you want to implement or improve the trail system.

Step 2: Identify Property Boundaries

Locate and mark the property boundaries on a topographical map. Consider whether the trails proximity to private property may tempt users to wander into restricted areas. In some cases, trails should direct users away from boundaries. Also, there may be off-limits areas within the property (sensitive habitat sites, for instance) that need to be protected.

Step 3: Determine Trail Users

Think about the people who will use the trail. Does the trail system accommodate their needs?

- What experiences do they want?
- What trail length will appeal to them?
- What level of fitness and ability do they have?
- How often will they use the trail?

Pedestrians

Walkers are usually interested in getting a little exercise. For the most part, they prefer short trails that provide a direct path from one natural feature to another.

Hikers tend to be familiar with the outdoors and enjoy a more strenuous and adventurous experience than walkers. They can handle difficult terrain and steep grades. They generally stay on the trails that are direct yet interesting.

Trail Runners enjoy connecting trail loops to add variety in their workouts. Most runners want several miles of rolling trail with occasional challenging sections.

Endurance Athletes, including runners, mountain bikers and equestrians, like to push their limits. These people seek trails that are as much as a hundred miles long. A large network is more appealing to these users than multiple laps of a short loop.

Rock Climbers use trails to reach climbing areas. Contour trails may be too indirect for them. They prefer short, direct access to the rocks.

Backpackers yearn for a backcountry experience and will travel many miles to reach it. Even though they have an intended destination, they are less apt to shortcut because they carry heavy loads that hinder maneuverability. Gentle trail grades linking natural features help keep long-distance foot travel interesting. Water sources should be regularly spaced and near suitable campsites.

Mountain Bikers

As is the case with trail runners and endurance athletes, trails are not only a source of recreation for mountain bikers but also a source of exercise. Keep this in mind when deciding how much trail to build.

Beginner Cross-Country Riders tend to like gentle, relatively short trails. As they become more skilled, they often seek longer, more difficult routes. Trails that are fun will discourage riders from traveling off the trail to find more exciting routes.

Avid Cross-Country Riders are more comfortable in the backcountry. Avid riders seek trails that let them cover 10 to 100 miles in search of solitude, nature and challenge. Desirable trails feature several miles of connecting loops with natural obstacles.

Downhillers are usually advanced riders who use sophisticated equipment specifically designed for descending steep and technical trails. The most sustainable trails for downhillers are rocky contours with many grade reversals. Since downhill bikes are heavy, it's helpful to have access to a road for a vehicle shuttle to the top.

Freeriders like challenges such as drop-offs, ledges, logs, elevated bridges, dirt jumps and teeter-totters. Some free riders prefer these technical features within cross-country rides, while others prefer them as stand-alone areas such as bike parks.

Disabled Trail Users

The Americans with Disabilities Act is a 1990 federal law that helps people with disabilities gain access to public facilities. Suitable trails have wide, smooth tread with gentle average grades of 5% and no staircases. Some small obstacles may be allowed as long as this is indicated by appropriate signage at the trail entrance.

Equestrians

Equestrian are the heaviest, widest and tallest non-motorized user. Their trails require a wider corridor and higher ceiling than those for pedestrian and bikers. Contour trails with a durable tread with frequent grade reversals are most sustainable.

Motorized Users

ATVs (all-terrain vehicles) require a 4 to 5 foot wide tread that is open and flowing.

Off-Road Motorcycles require more operator skill than ATVs and can be used on narrow trails. Riders prefer trails that are open and flowing.

Step 4: Identify Control Points

Control points are places that influence where the trail goes. The beginning and end of your trail are basic control points. Other control points may include parking areas, trailheads, structures, slopes for turns or switchbacks, road or water crossings, and other trails.

Control points can be a **positive control point; places where you want trail users to go to**. Positive control points include scenic overlooks, waterfalls, rock outcroppings, lakes, creek and other natural features. Design the trail to connect these places, keeping the route interesting along the way.

If you fail to include positive control points in your trail design, users will surely create their own unsustainable social trails to the waterfall or scenic overlook you should have included on the original route.

Control points can also be **negative control points; places you want trail users to avoid**. Examples are low-lying wet areas, flat ground that may hold water, extremely steep side slopes, fall lines, environmentally sensitive wildlife habitat or plant communities, certain water crossings, riparian areas, sensitive archeological sites, safety hazards and private property.

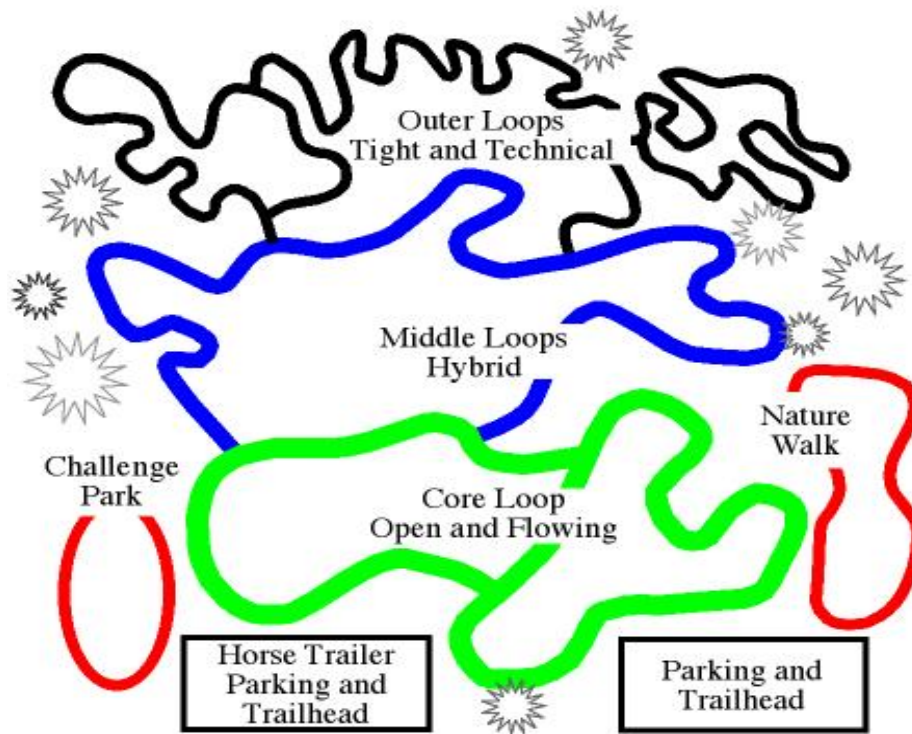
As free riding and technical trails become more popular, boulders and rock outcroppings are important positive control points to include in your trail design for their usefulness in creating highly challenging yet sustainable trails.

Step 5: Configure Loops

Trail systems with loops are appealing because they offer variety. Trail users seek the adventure of starting down one path and returning to the same point by way of a different trail. Loops let visitors enjoy trails of varying distance, difficulty and surroundings in the same outing.

Trail users can choose a small loop, a combination of loops, or a large outer loop. In a mountain terrain, a trail may climb one drainage to a summit and then descend another drainage. Staked loop trail systems make optimal use of available land.

Stacked Loop trail System



In high-use areas, the core trail leading from the trailhead or parking lot should be wide and smooth, appealing to a variety of users allowing them to travel side by side and socialize at the beginning. Loops that branch from the core trail may become longer, narrow and more challenging, as they get further away from the trailhead and core trail. Trail users who seek more challenging and remote experiences are usually willing to travel farther.

In some cases a stacked loop system may not work due to the space needed. In this case, considering the trail system as a whole, there may be a region in which you have several parks. In this case, it may be a good idea to create a different type of trail system for each site creating a large cooperative system of diverse trails.

Step 6: Plan a Contour Route

Once the control points have been identified, the next step is planning the trail route. Using a topographical map, begin by connecting the control points and laying out the trail along the map's contour lines remembering to keep the trail route at a sustainable 10% maximum grade. This is just the initial planning for the trail route. Final trail layout tightens in the field using survey flagging and a clinometer (**See Page 19**).

Step 7: Determine Type of Trail Flow

Trails designed for fast travel will have a different flow than those designed for slower travel. Understanding flow can reduce erosion and user conflict. It is also important to remember that trail flow can often be dictated by the landscape it travels through.

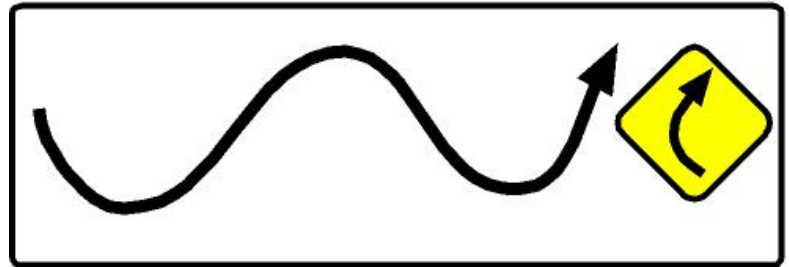
There are three basic types of trail flow:

Open and flowing trails are relatively gentle. They have long sightlines, gradual turns, every few technical features and appeal to less skilled cyclists as well as those who enjoy traveling fast. Because open and flowing trails do invite higher speeds, long sightlines are absolutely needed.

Tight and technical trails have sharp and twist turns, rougher surfaces, a narrow tread, natural obstacles and provide challenges for skilled riders while keeping speed down. Tight and technical trails may frustrate hikers or destination hikers, and shortcutting may result. To help prevent shortcutting, natural objects such as rocks and vegetation may be used.

Hybrid trails successfully blend open flowing with tight and technical. Hybrid trails are often a good choice for urban areas. Brush and obstacles close to the trail should be below eye level, allowing for longer sightlines to help reduce user conflicts. A slightly wider tread allows users to pass, while technical features reduce speeds and add variety. Transitions between open and flowing and tight and technical should be gradual to avoid riders braking hard causing erosion and user conflicts.

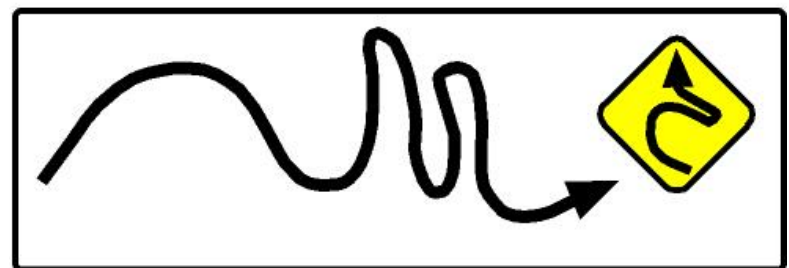
Trail Flow



Open and Flowing



Tight and Technical



Poor Flow - abrupt transitions from one type of flow to another.

Good trail flow is important. A flow of rhythm where one turn blends into the next, a descent leads to a rise, is not only enjoyable for riders, it also helps to reduce erosion and user conflicts. When designing a trail across a featureless hillside for example, surf the contour with smooth turns and ups and downs to create a more enjoyable trail and improve drainage.

Step 8: Walk and Flag the Trail Corridor

Using flagging tape and a clinometer (**See Page 19**) walk and mark the general trail alignment. Be sure to use the *Half Rule* and keep trail at a sustainable 10% or less grade.

To ensure your trail is built correctly, make your design clear to the construction crew by using plenty of flags. Yellow or orange flagging do not work well in fall foliage. Green flags will not stand out in forested areas during the summer. Pink flagging is a good choice in most situations.

Step 9: Develop a Construction Plan

This step should include trail users, land manager and work crew. Including key players in decisions gives everyone a sense of ownership in the project and pride in the trail they are creating.

It is important during this step to reach agreement on trail dimensions including tread width, corridor width and ceiling height. Also discuss how the trail will be built, how long it will take, how much it will cost and who will be providing the labor if volunteers are involved.

Step 10: Conduct an Assessment Study

Many land management agencies require studies prior to new trail construction. These studies may be biological, botanical, cultural, archeological or historical and usually cover a 50-foot wide corridor along the trails centerline. Studies can be time consuming and expensive, but sometimes a simple walkthrough by the area's naturalist may be sufficient.

Make sure the trail plan you are proposing is exactly where you want it, because changing it after the study has been done may require going through the entire process again.

Step 11: Flag the Final Alignment

Using pin flags to mark the trails exact alignment works best. Pins flags are reusable, lightweight and can be used anywhere. Identify the obstacles (rock outcroppings, for example) that will be left in the tread. Let the natural terrain features guide the trail design.

Walk the entire flag line in both directions, making adjustments to improve flow. Avoid long, straight lines. Use natural obstacles to accentuate curves and grade reversals. Be creative to produce an exciting pathway. A well-flagged trail corridor resembles a serpentine line with rounded curves, and optimal flow comes from consistency in the radius of the turns.

Pin flags can be placed on the inside edge (uphill), the centerline, or the outside edge (downhill) of the trail. The downhill edge is preferred because flags can remain in place during construction to help trails crews envision the trails flow and depth of tread. When building a *retaining wall* to raise the trail's downhill edge, place the pin flags in the center of the trail to indicate the tread's finished depth; this is important in maintaining the trails correct grade.

If construction is going to be performed using machinery, pin flags should be placed on the uphill edge. The flags will be easier for the operator to see and will not end up buried in the debris pile.

Part Three: **Hand Tools for Trail Building**

Tools are the most important part of trail construction. Using the right tool can make a difficult job much easier.

Tool Safety

When tools are handled improperly they can cause serious injury to yourself or those around you. Crew leaders should know the location of the closest medical facility and who will go for help. Create an emergency plan prior to your trail workday. Make sure everyone knows his or hers responsibility during an emergency. Start each workday with a reminder of tool safety and the emergency plan.

Safety Tips

Cover the following points with all your volunteers before beginning any trail work.

Safety begins with a good grip.

Do not underestimate the importance of quality gloves. Gloves can protect your hands from blisters and other injuries, and they will insure you maintain a safe grip on your tool. Wet or muddy gloves can cause a tool to slip from your hands, striking you or someone near you.

Make sure you have a clear area in which to swing.

Watch for overhead or side hazards. A hazard is anything that can interfere with the completed swing of your tool, knocking it from your hands or down onto any part your body. Keep your tool in front of you at all times; you rarely need to swing a tool over your head. If you need to swing over your head, stop and give your coworkers a “heads up” before you begin. If you are within a tool-lengths distance of another worker who is swinging a tool (**The Circle of Death**), you are in danger of being gravely injured. Always stay well outside the range of another worker, and be sure others stay outside your circle of death before swinging your own tool.

Be alert for hazardous footing.

Make sure you have a firm, balanced and comfortable stance before starting your work. Clear the area you are working of tree limbs, sticks, loose rocks and other debris from your footing area. Make sure your feet are well away from your target area, particularly when you are using a striking tool.

Choose the right tool for the right job.

The wrong tool can force you to work in an awkward position or exert more force than is necessary, wearing out your tools and you. Choose the right tool.

Make sure the tools are sharp.

Dull tools can be very dangerous, particularly if it bounces or glances off what it should be cutting and into something it shouldn't. Sharp tools will cut much faster, are less tiring to use and is safer

because they are more accurate. Sharpen tools at least once a week; some tools require daily attention.

Carry the tool properly.

Always carry tools with your hands and carry them down at your side. Do not carry more than one tool in each hand and if you are carrying one tool, hold it in the downhill hand. Keep the sharpest side of the tool facing the ground and use blade guards whenever possible. Hold the business end of the tool in front of you.

Travel safely.

All trail workers should stay at least 10 feet apart from each other in and out from the worksite when carrying tools. When moving along a trail that is under construction, always announce your presence (coming through) to workers with tools in their hands, and make eye contact before passing them.

Stay alert.

Stay alert for environmental hazards such as poison ivy and poison oak, stinging insects and venomous creatures. Also watch for symptoms of sunstroke, altitude sickness, dehydration and hypothermia in yourself and others.

The Ten Essential Trail Building Tools

1. Clinometer

The grade or steepness of a trail is one of the most important factors in determining whether a trail will last for many years or fall apart within months. A variety of tools can be used to measure grades. A clinometer (Figure 1.) is a good choice because it's accurate, user friendly, relatively inexpensive and fits nicely in your pocket. Clinometers are particularly important during the trail design stage.



Figure 1: Clinometer

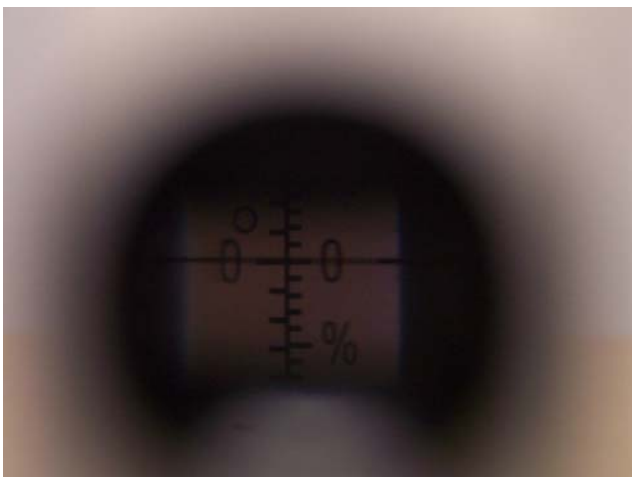


Figure 2: Clinometer Viewfinder



Figure 3: Clinometer in use

Using a Clinometer to Measure Grades:

To determine grades you will need to establish a visual target; another trail builder will serve this function perfectly. The following steps will explain how you, with a partner, can read grades with this useful tool.

Step 1: Getting familiar with your Clino.

Hold the Clinometer to your dominant eye (see tip below to determine your dominant eye). With your dominant eye open and your other eye closed, look into the clinometer's viewfinder. The first thing you will see is a rotating scale. There are numbers printed on both sides of the scale; one side is in degrees while the other side is in percent (see Figure 2.). For trail building as well as road and highway construction, percent is used. By rotating the clinometer toward the sky you will notice the numbers on the scale change.

Step 2: Locate the "Zero Point"

With your partner, preferable someone similar in height, stand about 10 feet apart on level ground (a floor in a building is ideal since most floors are perfectly level). Face your partner and hold the clino to your dominant eye with your opposite eye closed. Find the 0's and line them up with the horizontal line in the viewfinder (see Figure 2.). Now open your opposite eye. Binocular vision will superimpose the horizontal eye line across your partner's face; the point at which the line intersects your partner face is your target or "Zero Point". This is the spot you will be focusing on to determine grades.

If you are the same height as your partner, the zero point will fall across your partner eyes. If you are taller, the horizontal line will be above your partner's eyes. Don't forget where the zero point is and remember to always stand tall when reading grades. If you start to slouch throughout the day, the grades that you read will be inaccurate.

Don't make the mistake of guessing what the grade is. Some people believe they can judge the grade of a section of trail just by eyeballing it. They can't. Always use a clinometer or other tool to confirm grades.

Step 3: Practice

Ask your partner to stand on a chair, step, or a slope and then stand about 10 to 15 feet away facing your partner. Hold the clino up to your dominant eye and with both eyes open, put the horizontal line across your partner's zero point target. Now read the percent number on the scale in the viewfinder. You have just read the grade between you and your partner. If you move closer to your partner, the grade will increase. If you move further away, the grade will decrease. This is because the rise is constant while the run is changing in the equation ($\text{grade} = \text{rise}/\text{run}$ as described earlier).

Which Eye is Your Dominant Eye?

Using the thumb test, stick your thumb up at arm's length in front of you. With both eyes open, line up your thumb with any target in the background, such as a tree, a doorknob, etc. Close one eye while keeping the other eye open and then switch by opening the other eye and closing the opposite. Your thumb will appear to move. Determine which eye doesn't move your thumb, this is your dominant eye.

2. Flagging (Ribbon Tape/Pin Flag)

In the form of either a roll of nylon ribbon tape or wire pin flags, flagging is used to identify the trail alignment, construction and maintenance. Colors should be chosen so they can be easily identified in the field. Ribbon Flagging is best used in the identification of the trail corridor during the initial onsite trail layout and pin flags are best used to identify the trail tread in preparation for trail construction. All flagging material should be removed once trail work has been completed.



Tape



Flags

3. McLeod

The McLeod is the ultimate trail building tool. It has a flat, square-shaped blade with a cutting edge on one side and a rake with widely spaced tines on the other. The McLeod is useful for removing slough and forming the final trail tread as well as tamping and compacting soil. The McLeod can also be used to shape the trail's backslope. The tool is not designed to withstand serious pounding, so use it for shaping, not swinging.



Blade

Tines

4. Pulaski

Pulaskis have an axe blade on one side and a grub hoe or adze blade on the other. This tool is used for loosening soil, cutting roots, grubbing brush, sculpting and woodworking for timber projects. The Pulaski should not be used in rocky soils.

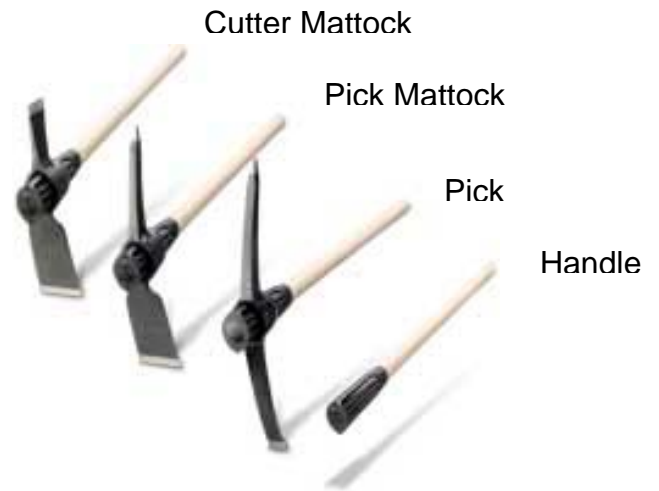


Adz Blade

Axe Blade

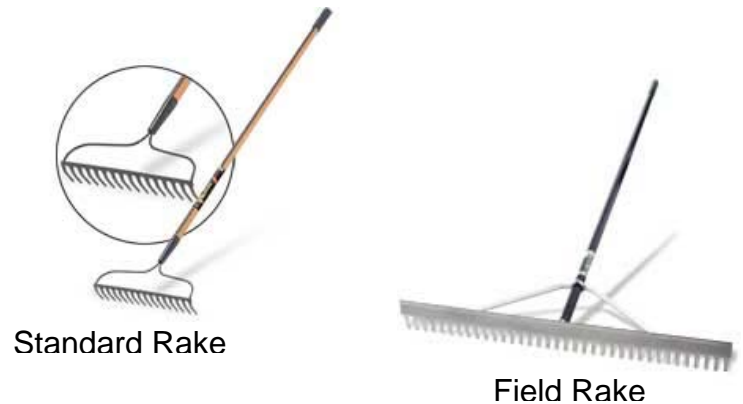
5. Pick Mattock

A pick mattock is a heavy grubbing tool with a hoe or adz blade one side and a pick or cutter (Cutter Mattock) on the other. The tool is used to dig or loosen hard rocky soil and for breaking small rocks. The head can be removed for ease in packing in and will tighten on the handle when swung.



6. Rake

Field rakes (36" wide head) and standard hard rakes (14" head) are ideal tools used for final tread grading and surface smoothing.



7. Rock Bar (Spud Bar, Digging Tamping Bar)

The ideal rock bar is 4 feet long, weighs about 18 pounds has a chisel or beveled end on one end of the bar and a round cap on the other. Rock bars can be used to leverage, pry, cutting through roots, breaking through rocks or frozen soils and tamping.



8. Tape Measure / Digital Level

Trail work requires accurate measurement. Tape measures are lightweight and compact. Durable models with highly visible color are a must for field use. Trails must be properly outsloped to shed water. A digital level is useful for both determining the correct degree of tread outslope, the construction of steps and rock walls.



Tape Measure



Digital Level

9. Hand Pruners / Loppers / Folding Saws

Hand pruners and lopper can be used to remove small branches (1"-2" diameter) encroaching on the trail corridor or for cutting roots protruding from the tread. Saws can be used to handle larger branches.



Hand Pruners



Loppers



Folding Saw

10. Shovel

Flat shovels are great for moving large quantities of dirt and for shaping tread and drainages. Round-point shovels are used to move loosened dirt, dig holes and trenches, remove weeds, cleaning grade dips and diversion structures.



Spade



Flat

11. Sledgehammer

The sledgehammer has a 6 to 8 pound head with a 36" handle. A sledge can be used to crush rock into gravel for trail repair and is helpful for setting stones into an armored section of trail or a retaining wall.



Other Useful Hand Tools

(These tools are not as commonly used, but may of use in some situations)

Clearing Tools

Weed Cutters (Grass Whip, Swizzle Stick, Swing Blade, Weed Whip)

Weed cutters are used to clear trail corridors of vegetation such as grass, light brush and tree seedlings. The *L-shape weed whip* is used for grasses and weeds and should not be used for larger plant growth. The *Triangular-frame weed whip* cuts woody stems up to a half-inch in diameter.



Machete

Machetes are best used to clear the way when surveying new trail routes through dense vegetation. A slightly angled (off-vertical) stoke of the machete is more effective than a low horizontal swing. Machetes should not be used to cut tree branches.



Swedish Safety Brush Axe (Sandvik)

The Sandvik is a machete-like tool with a short, replaceable blade. Because of the shorter blade and the longer handle (27" overall length), the Sandvik may be safer than a machete, and it is faster, easier to control and safer than an axe or brush hook.



Brush Hook (Ditch Blade or Ditch Blade Axe)

The brush hook is used for removal of brush too heavy for a weed whip or too light for an axe. Swung like an axe, the brush hook's 36" long handle and heavy head give it a powerful cut. The curved blade, however, poses a safety risk. Always maintain a firm grip with both hands. Cut with a slicing rather than a hacking motion and pull back on the handle at the end of the swing in order to utilize the 12" curved blade.



Sawing and Chopping Tools

Bow Saws

A bow saw with a 16" to 21" blade is used for cutting brush and trimming small branches. Larger bow saws (36" and larger) are unwieldy for brushing and are better suited for medium size log cutting. Blades cannot be resharpened and should be replaced when they become dull, rusty or bent.



Razor-Tooth Pruning Saw (Protooth Saw)

These saws have an extra thick, extra wide razor-tooth blade for rigidity and are used to cut limbs.



Pole Saw with Pole Pruner

Pole saws are used to cut limbs too high to reach from the trail. On some models the poles can be taken apart including removing the blade for easy packing. The built-in pruner can be operated from the ground with a rope. When cutting large branches it is best to use the two-step method: begin by cutting underneath the branch first then finish the cut from the top leaving a 4" to 6" stub; this prevent the bark from stripping from the trunk of the tree. Next, cut the stub flush with the trunk.



Axe

Axes can be used to chop deadfall from trails, shape stakes for turnpikes and waterbars and to cut notches for timber structures. Axes are usually recommended for trail work because they are safer and more efficient for average users. The axe is better suited for cutting jobs too thick for available saws.



Pounding and Hammering Tools

Engineer's Hammer

The engineer's hammer with a 3 to 4 pound head can be used with a star drill to punch holes in rock, to drive spikes and other jobs too demanding for a regular claw hammer but do not require the heavy blows of a sledge.



Star Drill

Star Drills are usually about 12" long and are used with an engineer's hammer to: punch holes in rock by rotating the drill after each blow; or it can be used to open a seam or crack in a rock.



Lifting and Hauling Tools

Timber Carrier (Log Carrier)

Timber Carriers are used for transporting heavy timbers and logs. The 5-foot long handles allow two people on each side of the carrier. Two or more can be used to aid in carrying larger timbers. A firm tap on the back of the hook will set the hook in place to avoid slippage during transport.



Peavey and Cant Hook (Cant Dog, Log Dog)

The Peavey and Cant hooks are used to roll and position logs and timbers. The peavey has a straight spike at the end whereas the cant hook has a blunt tip. The peavey's spike allows more control of the log but may cause more damage to the log surface.



Cant Hook



Peavey Hook

Cable Winch (GripHoist)

GripHoist is the brand name for a compact, lightweight-rigging tool. The machine consists of a metal body with a cable running through it. By cranking the lever, a set of cams clench the cable and pulls it a few inches at a time, moving heavy objects with ease.



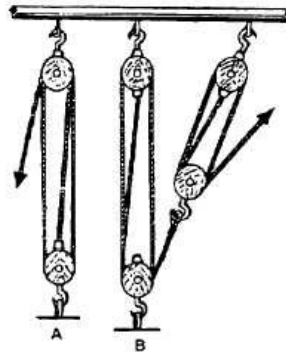
Come Along

The come along is a simple ratchet-and-pawl cable winch used for pulling, lifting or stretching. With a 25' cable length, hauling material over a considerable distance requires frequent reanchoring of the winch.



Rigging (Block and Tackle)

Rigging refers to a system of cables, pulleys and winches used to suspend or move heavy loads. The setup and use of rigging systems requires sophisticated training or prior experience and should not be attempted without this knowledge. Severe accidents can occur if a rigging system is used improperly.



Wheelbarrow

A wheelbarrow can be used to haul both materials and tools. A single pneumatic tire is recommended because the tire pressure can be adjusted to help roll over uneven terrain much easier.



B.O.B or YAK Trailer

The YAK trailer, also known as the Beast of Burden (BOB), is a cargo carrier that attaches to the rear hub of a mountain bike. It can be used to carry hand tools, chainsaws and day gear.



Canvas Bags, 5 Gallon Buckets

Great for portaging dirt, small rocks, tools or anything else you want to carry. Heavy-duty bags are lightweight and easier to pack than buckets and can carry up to 95 pounds.



Bark Peeling Tools

Spud (Bark Spud, Peeling Spud)

Bark spuds remove the bark from a green log that will be used for the trail project, slowing the decaying process and giving the wood a longer life span. Bark spuds have a 1 to 4 foot long handle and a dished blade with three cutting edges. The blade is run between the bark and the wood of the log. Spring is the best time of the year to debark wood.

Drawknife

A drawknife is used to strip the bark from small diameter green logs. Grasp the knife with both hands and pull the blade toward yourself. Drawknives are razor sharp, so use caution.

Adze (Carpenter Adze)

An Adze is basically an axe with a curved blade that points inward at a right angle to the handle. The adze is used to finish hew beams and logs to form a flat surface – such as the walking surface of a native log bridge. An adze should be kept very sharp and used only for hewing. The blade should never contact the ground and should be protected with a sheath when not in use.

Miscellaneous Tools

MAX Multi-Purpose Axe

This tool incorporates seven basic hand tools into one compact unit.

Files

A 10" to 12" flat mill or flat single cut bastard file is the simplest tool for shaping a bevel or giving a blade a quick edge. Use a file card to keep file clean.

Measuring Wheel

Measuring wheels can be used to measure distances for guidebooks, assessment notes or to pinpoint location of work to be done along the trail.



Mechanized Tools

Traditionally, trail construction has been done with the use of hand tools. However, with the recent advancements of new technology, machines have been developed specifically for trail construction. These specialized earthmovers with a three-person crew can build 5 to 10 times the trail as a crew using only hand tools. These new machines are powerful, versatile and leave a very light footprint on the trail and are capable of sculpting narrow paths in the most extreme terrain.

A skilled machine operator can build a more consistent trail tread than a group of laborers using hand tools, while leaving almost no trace of its passage. In the hands of a less-skilled machine operator, however, earthmovers can cause considerable damage, flattening vegetation and leaving obvious track marks that may be slow to heal. Machines do not entirely replace handwork; they just enable more efficient trail construction.

Types of Mechanized Tools:

There are three types of machines used for trail construction and maintenance: walk-behind earthmovers, ride-on earthmovers and excavators.

Walk-Behind Earthmovers

These earthmovers are basically a small skid-steer bulldozer that is operated while walking behind the machine. Toro, Ditch Witch and Bobcat produce the most popular models. All accept multiple attachments that allow the operator to perform a variety of construction and maintenance tasks. The most popular attachments are the blade (used mainly for new constructions) and the bucket (used for maintenance tasks).

Ride-On Earthmovers

Ride-ons, or mini dozers, are more powerful and can move dirt much faster than the walk-behind models. But, mini dozers are more expensive and require more skill to operate and maintain than walk-behinds. Some examples are:

- Sutter Equipment SWECO 480, specifically designed for trail construction, has numerous attachments that enable the machine to perform a variety of construction and maintenance tasks.
- All Season Vehicle's (ASV) Positrack is a compact, rubber-tracked machine, ride-on machine.
- The Italian-made Pentamoter Ibex features a fully articulating blade/bucket and a dumping payload.
- Ditch Witch also produces a mini dozer that includes an excavator on the back.

Excavators

Some trail builders prefer mini excavators to the mini dozer. Excavators move dirt by pulling material towards the machine in a bucket, scoop it up, and then swing the arm around to deposit the material. Mini dozer, by contrast, mainly pushes dirt to create trails. Manufacturers of mini dozers include Takeuchi, IHI, Bobcat and Ditch Witch.

Choosing the Right Machine

No single machine is best for trail building. Just like particular hand tools are better suited to certain trail building tasks, various situations require the use of different mechanized tools or combinations of machines. The following are factors to consider when choosing what machine to use for trail construction.

1. **Is hand labor available?** A dozer is faster than an excavator at roughing in a trail. However, an excavator with a skilled operator can work more precisely, minimizing the hand finishing that all machine-built trail require.
2. **How steep are the sideslopes?** Trail building along steep sideslopes require a large amount of material to be removed. Construction on steep sideslopes also results in tall backslopes, which can be better sculpted with the use of an excavator than a dozer. The use of both a dozer and an excavator works well in situations like this. The dozer can cut the bench, while the excavator can follow behind, blending the backslope and broadcasting the debris.
3. **How is the traction?** When traction is an issue in slippery conditions for example, a dozer may become stuck and damage the trail tread. Excavators, on the other hand, are able to pull themselves out when their tracks slip with the use of the machine's arm.
4. **What is the desired width of the tread?** The finished width of a machine-built trail largely depends on the operator's skill and hand-finishing work. However, machines can vary in width. Smaller machines can build narrower trails, but they are less stable and have less traction the larger models.
5. **Are there rocks and roots?** A proposed trail route with large rocks and vegetation may require a more powerful machine.
6. **Is there a deep organic layer?** If a proposed trail route has an organic layer deeper than 1 foot deep to be removed, an excavator is better suited to remove this material than a dozer

Tips for Using Mechanized Tools

1. **Learn from a pro.** Instruction from an experienced operator is essential to learning the techniques needed to build sustainable trails with minimal impact.
2. **Secure the machine during transport.** Use 2 chains and a ratchet binder to securely fasten the machine to the trailer or flatbed during transport. Make sure the chains will not come loose, even if the machine moves during transport.
3. **Check fluids.** Measure the fluids while the machine is warm and level.
4. **Maintain the machine.** In addition to checking fluids, keep moving parts well greased and regularly check the track tension, air filter and other key elements.
5. **Watch the fuel.** Do not run the machine dry and don't confuse diesel fuel, oil/gas mixtures and gasoline; store these fuels in different containers (yellow for diesel, red for gasoline). Keep fuels away from running equipment.
6. **Keep machine arms low.** A low center of gravity keeps the machine stable. Raising the arms or attachments makes the machine less stable the higher they are raised and may result in tipping the machine over; this is especially true when the bucket is full of material.
7. **Use protection.** Machine noise can damage hearing, use ear protection. A hardhat and eye/face protection is also recommended, especially in forested areas.
8. **Push small loads and make multiple passes.** Do not try to push too much material. If the tracks slip or the engine strains, you're pushing too much material. Back off and make smaller repeated passes.
9. **Float the blade.** Many dozers have a "float" setting that allows the blade to track along the ground. Dragging the blade backward in the float setting is a useful technique for minor grading of material removal without digging.
10. **Turn Carefully.** The tracks of machines have little impact when moving forward in a straight line. However, their tracks can dig and churn when turning.
11. **Spread debris.** Piles of debris along the trail can be a long-lasting eyesore as well as impede drainage. Use the machine to remove as much material as possible away from the trail, hiding as much debris as possible. Removing as much material with the machine will allow the hand-crews to focus on hand finishing.
12. **Decreasing trail width.** There are three ways to narrow a machine built trail: 1) cut a $\frac{3}{4}$ bench tread and then remove the cut material by hand or with a smaller machine, 2) the backslope can be blended into the trail tread, 3) material can be pulled back onto the trail tread once the machine has passed.

13. **Keep a winch handy.** Eventually the machine will get stuck. Having an appropriate sized winch or come along and similarly sized straps and shackles will enable you to retrieve or right the machine.

Other Useful Mechanized Tools

Motorized Carriers and Power Wheelbarrows

Motorized carriers are useful for heavy or frequent hauling needs. These come in different configurations and usually have a small engine with a dump body.

All Terrain Vehicles

ATV's can carry workers, tools and can haul small loads. ATV's can also pull a variety of trail grooming attachments such as harrows, which can rake the tread, loosen rocks and break clods.

Chainsaws

Chainsaws with a 16-inch bar is adequate for most trail work. Chain brakes, vibration-damped handles and high quality muffler are key. Leather gloves, eye and ear protection, a hardhat and saw chaps are required when using a chain saw. Chainsaws should only be used by those who are experienced and have been trained and certified in chainsaw use.

Brush Saw

These weed cutters have a 35cc to 80cc engine, bicycle-type handlebars and a saw-type or universal grass-brush blade (not a sting cutter).

Brush Mover

These sturdy movers can cut heavy grasses, weeds, briars and small saplings. 17 HP movers are recommended for trail work and can cut up to 2-inch saplings.

Stump Grinder

A gasoline-powered portable stump grinder can be handy if you have to remove many stumps.

Rock Drills/Breakers

The drills are used to bore holes in rock or concrete. The breakers can split rock, cut asphalt, drive pipe and signposts, and chip or shape rock. The drills and breakers can be run on gasoline, electricity or run off the hydraulics of the trail machinery.

Part Four: **Trail Construction**

A well-built trail using sustainable trail construction techniques will withstand the negative effects of time, weather, trail users and will require only minimal maintenance. A poorly built trail, on the other hand, can fall apart in months, requiring constant maintenance.

Clearing the Trail Corridor

The first step in trail construction is to clear the space, or corridor, in which the trail will pass through. This will require the removal of trees, downed trees, branches, shrubs and brush. Check with the local land manager regarding what vegetation can and cannot be removed.

The width and height of a trail corridor can really make or break the trail experience. A carefully trimmed corridor can accentuate turns, hide nearby trails, prevent trail widening, control speed and add to the overall character of the trail.

There are several factors to consider when determining corridor width and height:

Vegetation Type and Growth Rate

Some species are more visually appealing and can add to the character of the trail. However, there are some plants that grow very fast and should be removed or heavily cut back.

Type of Users

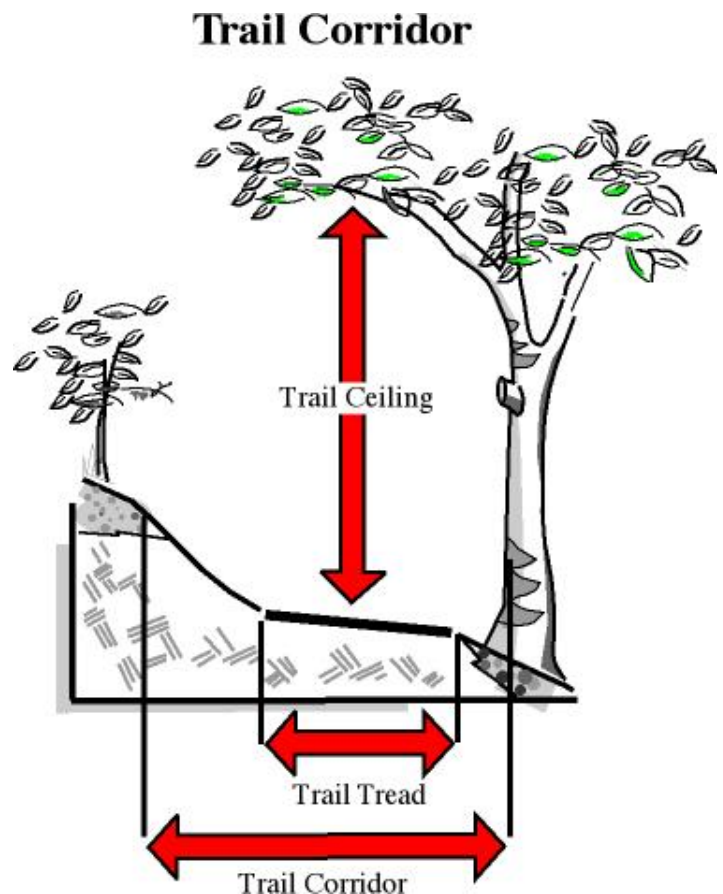
Consider the mix of trail users. Equestrians need a larger corridor (10' ceiling) than other users (8' ceiling).

Speed of Users

A tighter corridor will slow trail users. An open corridor may invite more speed.

Number of Users

Trails with a high traffic may need a wider corridor to allow passing and visibility.



Difficulty Level

Corridor size can greatly affect the technical challenge of a trail. Narrow openings between trees, low branches, thorny bushes or cactus next to the trail can create a tight tricky trail.

Trail Flow

Are you creating a twisty trail or an open flowing trail? Cut the corridor to match the trail.

Maintenance Frequency

If you know you will only be able to clear the corridor once a year, trim a bit more.

Sightline Needs

A heavily used trail calls for greater visibility. However, if the tread surface is smooth and the corridor is wide, mountain bikers may travel too fast. Creative corridor clearing can help. Keep some vegetation trimmed above the waist along the trail edge to control width and provide visibility.

Travel Direction

A one-way trail is trimmed differently than a two-way trail, as sightlines only need to be cleared in one direction of travel.

Aesthetics

A trail with a tight corridor will allow users to feel closer to nature. Your goal should always be to minimize your impact on the environment and leave the area looking as natural as possible.

Removing Trees and Brush

Do not leave trees or brush cut flush to the ground. Cut branch waist high to leave a handle to lever them loose. Remove entire roots then fill and compact the resulting hole.

Trimming Branches

The thickened section of bark just outside the spot where a branch joins its tree is called the “bark collar”. When trimming trees always cut to the outside of the bark collar; this will allow the trees to heal more quickly. When removing larger branches, make a partial cut underneath before cutting from the top. This way when the branch falls, it will not strip protective bark from the tree. Place branches at least 10 feet from the trail.

Recommended Tools for Clearing a Trail Corridor

- Loppers
- Brush Cutters
- Folding Saw
- Pole Saw
- Weed Cutters
- Chainsaw
- McLeod

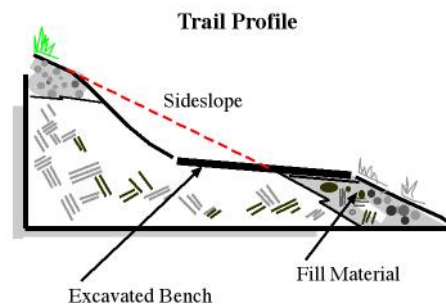
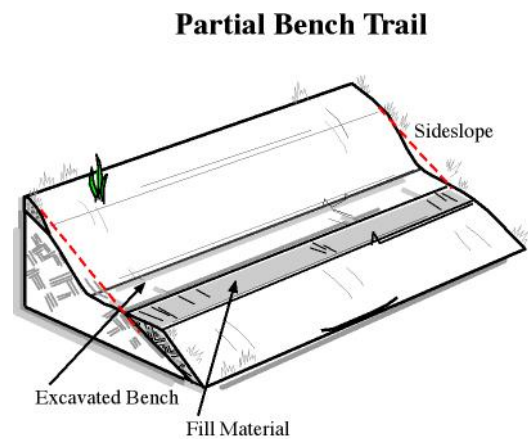
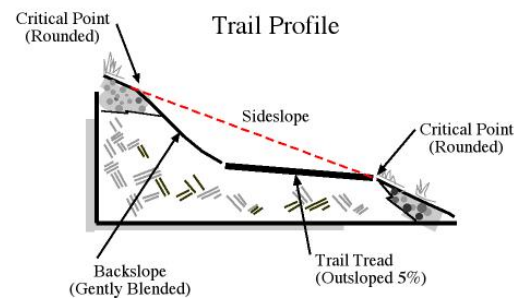
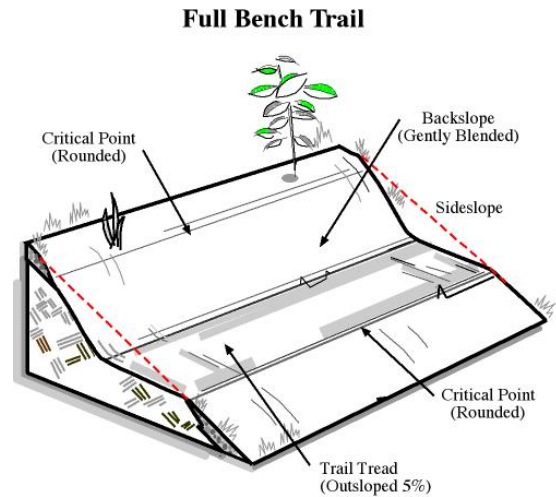
Bench Cut Trails

A bench is a section of trail that is cut across the side of a hill, or along the contour of the slope. A **full bench trail** is constructed by cutting the full width of the trail's tread into the hillside. The entire tread is dug down to the compacted mineral soil layer. This is the preferred method of constructing a bench cut trail that will last indefinitely with little maintenance required.

A **partial bench trail** cuts only a portion of the hillside. The soil that is removed is placed at the lower edge of the trail to create the desired tread width. There are disadvantages to a partial bench trail: the section of trail that is made from fill rarely compacts and gradually slides downhill; and partial bench trails are rarely sustainable and are not recommended.

There are a few situations in which the only option is to create a partial bench trail (one example, the crossslope is excessively steep and a full bench would remove too much material). In these situations, a rock retaining wall can be built on the downhill side of the tread to prevent the fill from sliding downhill. (It is important to keep the height of the wall lower than the trail's tread to allow water to sheet across and off the tread.)

The construction cost and time of a retaining wall reinforced tread is usually at least twice that of a standard full bench trail.



Building a Full Bench Trail with Hand Tools

1. Dig the tread.
2. Cut the backslope.
3. Outslope the tread.
4. Compact the tread.
5. Finish the tread.

Step 1: Dig the Tread

With the trail corridor cleared and the trail tread marked with a single row of pin flags, start by raking the loose material (leaves, small branches, etc.) on the ground uphill from the trail. Keep this material uphill, as it will be used later in the process.

With the line of pin flags clearly visible, it's time to mark the trail tread width. Stand below the pin flags and mark the width of the trail uphill from each the pin flags. For example, if your trail needs to be 24 inches in width, mark 24 inches uphill from each pin flag. Next, connect the dots by scratching a line from pin flag to pin flag and from the marks you made from each of the pin flags. This will be a visual marker for digging the tread of the trail.

Beginning on the downhill edge and using a grubbing tool (such as a Pulaski, Hoe, or Mattock), loosen the organic material and work your way down to mineral soil. A good way to tell the difference between organic and mineral soils: organic soil will burn, mineral soil will not. Remember, there is no need to remove rocks and roots if you are building a technical trail.

Broadcasting tools (shovels, rakes and McLeods) should follow the grubbing tools and distribute the excavated material as far downhill and away from the trail as possible.

Step 2: Cut the Backslope.

The uphill side of the tread, where it blends into the slope above the trail, is called the **backslope**. Once the trail tread has been cut the next step is to blend the backslope. Laying back the backslope to blend into the existing hillside will prevent the backslope from eroding onto the trail and provide a smooth surface for water to gently sheet across the tread of the trail.

Use grubbing tools to shape the backslope into the hillside and broadcast tools to remove excess material from the trail. Use the flat bottom plate of the McLeod to compact the soil of the backslope and to round and compact the *critical point* (the location where the backslope meets the existing hillside). If the critical point is not properly shaped and compacted, water flowing down the sideslope will cut into the backslope of the trail and material will slough onto the tread.

Step3: Outslope the Trail Tread.

The slightly downhill tilt of the trail tread is called the **outslope**. This is the most important part of the tread because it allows the water to gently sheet across the trail. Without it, water would channel along the trail and erode the tread surface.

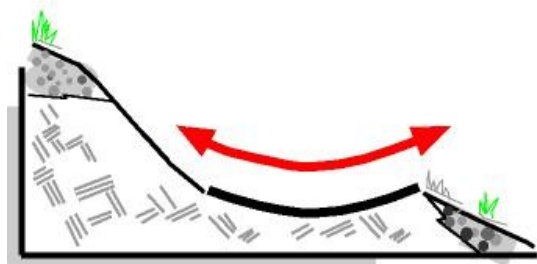
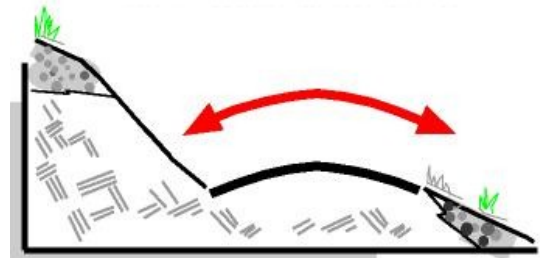
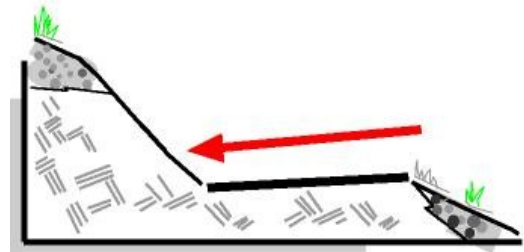
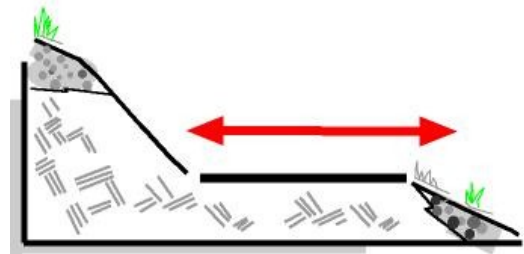
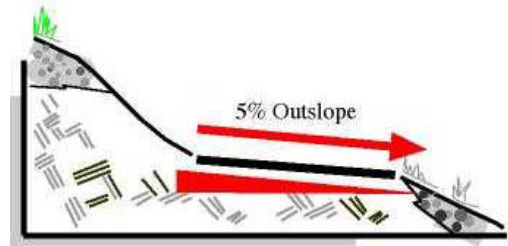
Use a McLeod to cut a 5% outslope on the trails tread. Standing below the trail, scrape the McLeod from the top to the bottom edge of the trail removing material and creating a 5% outslope. Broadcast the excess material down the hillside. You can roughly gage a 5% grade by standing a McLeod on the tread and eyeballing the angle, it should be leaning away from the upper hillside. You can measure the outslope more accurately by using a digital level or a clinometer.

While working on the outslope, remember to broadcast the excess material several feet downhill from the trail. Allowing material to settle too close to the tread will create a berm and will disrupt the sheet flow, causing water to collect and channel along the trail. The ground beyond the tread should slope away, if possible.

Step 4: Compact the Tread

Use the flat bottom of the McLeod to compact the trail tread. Don't leave this step to the trail users. Most trail users travel along the center of the trail, causing loose soil to sink and form a shallow trench or *cupped trail tread*. Water will become trapped in the trench and erode the tread.

Trail compaction may be difficult in loose soils conditions. In this case, it is best to avoid trail grades greater than 10%, increase the outslope during construction and include grade reversals.



Step 5: Finish the Tread

Finally, remove the pin flags and use the loose material that was piled on the topside of the trail to cover the loose soils that was broadcast down the hillside. This will help to stabilize the loose soils and make the trail look more natural. A properly constructed trail should look like it has been there forever.

The look of a finished trail tread will depend on who the trail's frequent users will be. If the trail will be utilized by advanced users, leave natural obstacles such as rocks and roots in the trails tread that are not safety hazards or will not create erosion problems later.

Rocks

On a bench cut trail, remove most of the rocks from the tread's inner edge next to the backslope. Leaving rocks along the inner edge will force users to the outside edge of the trail and cause the edge to break down in time. On the other hand, placing obstacles along the outer edge of the tread will keep users in the center of the trail. Avoid lining the outer edge with objects as this will trap water on the trail and cause erosion.

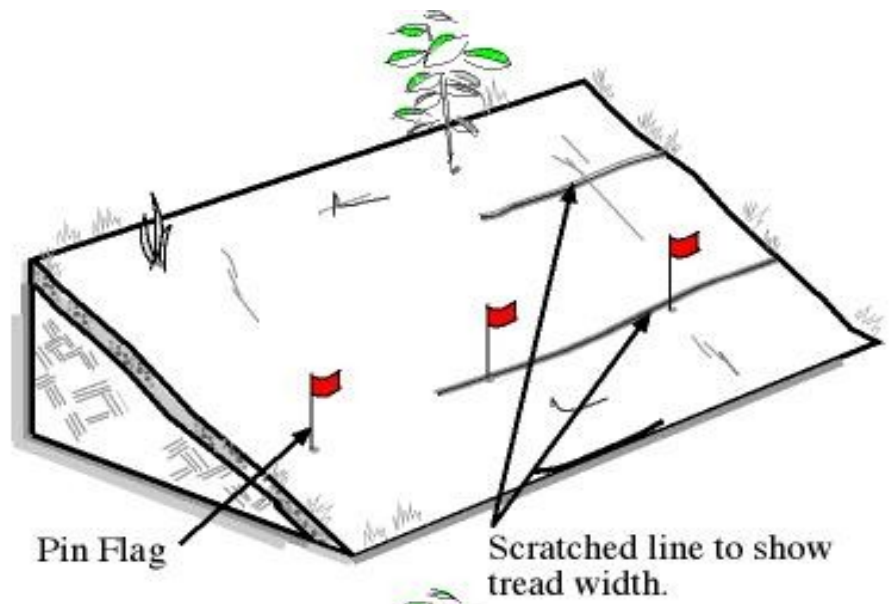
Large, stable, round rocks are a good choice for a tread surface as are square rectangular shape rocks. However, sharp pointed rocks tend to force users off the trail. Remove these types as well as loose rocks from the tread, fill and compact the hole left behind. If you kick a rock and it's loose, remove it.

Roots

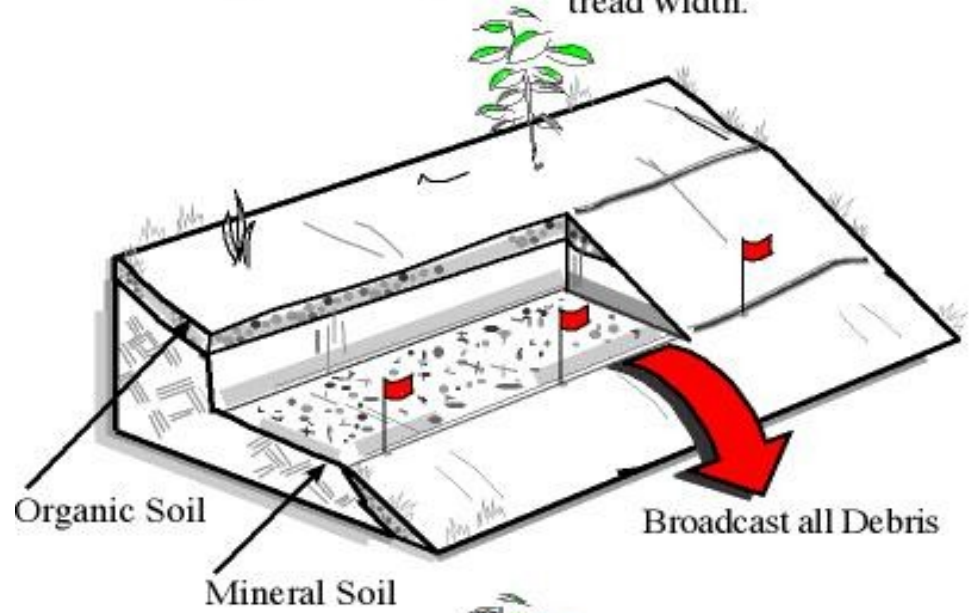
Remove most of the roots from the trail tread during construction. This is especially true from roots that run parallel with the trail which can channel water and force users off the trail. Sometimes large roots, which run perpendicular to the tread, can add a technical challenge. Unfortunately, they may also force users off the trail causing widening of the trail of "tread creep". Consider the style of trail you are building and determine whether leaving the roots exposed will cause significant damage to the trail or to the tree itself. Cutting large feeder roots near the downhill side of the tree might kill the tree. Sometimes it is best to build a retaining wall and fill over the large roots instead of removing them.



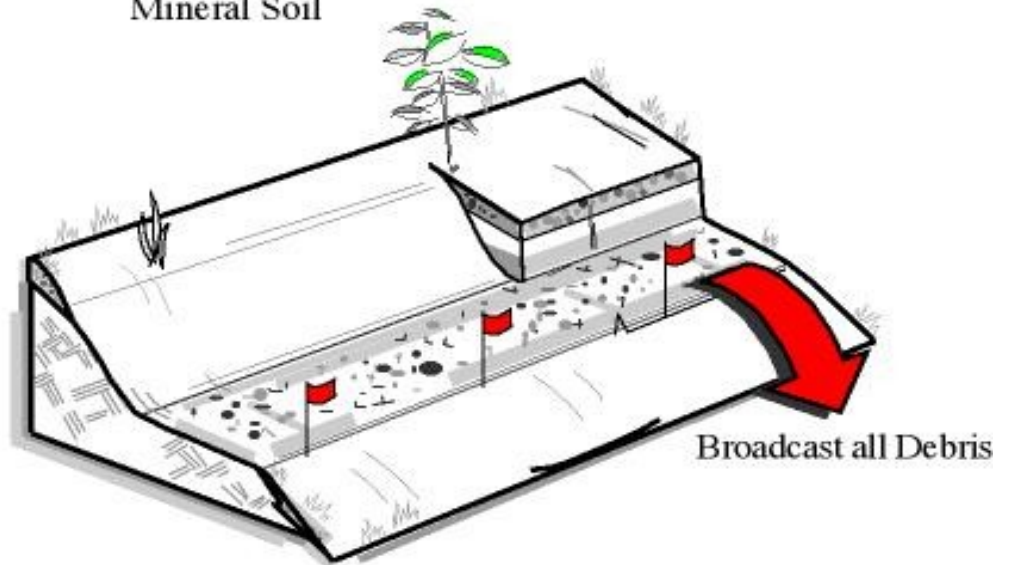
Before



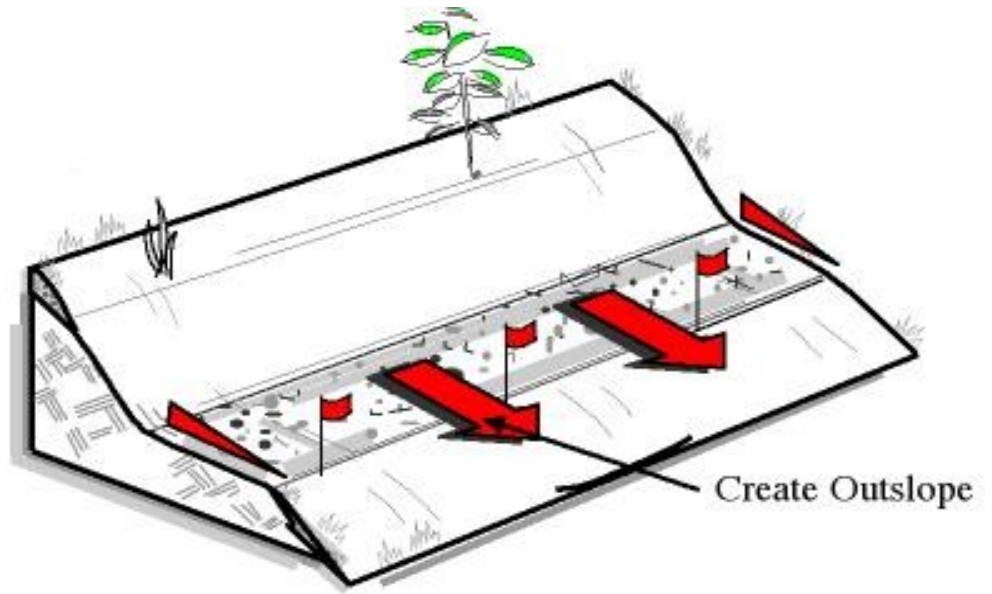
Step 1: Dig the tread



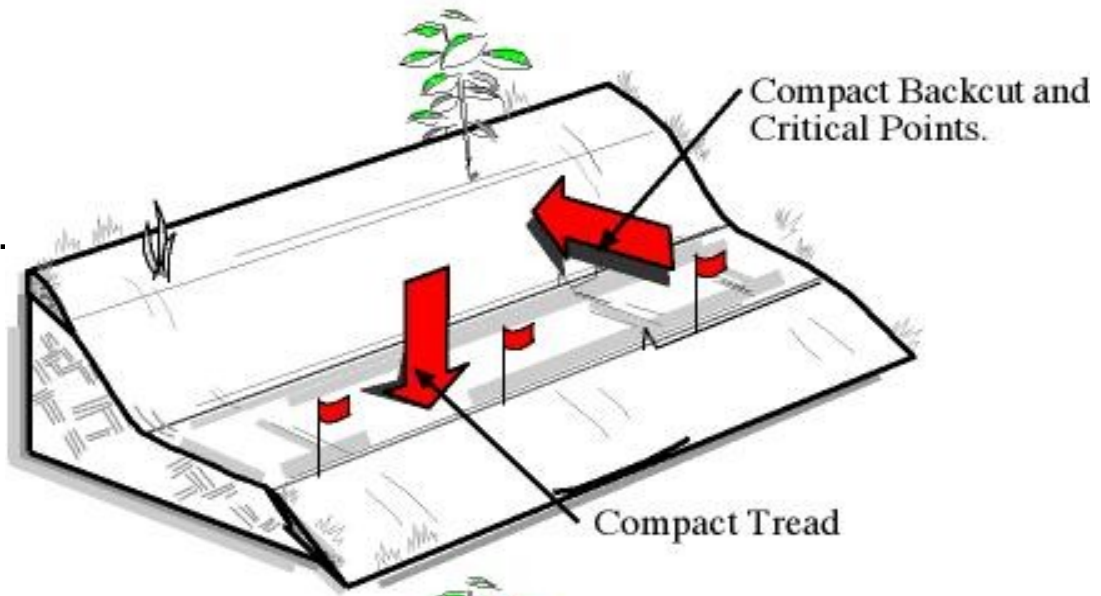
Step 2: Cut the backslope.



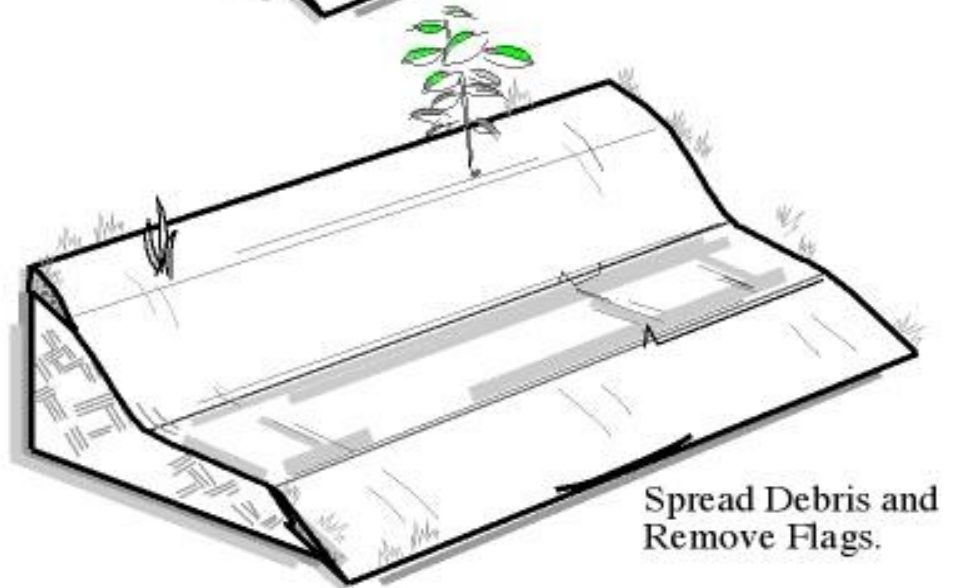
Step 3: Outslope the Trail tread.



Step 4: Compact the tread.



Step 5: Finish the tread.



Climbing Turns, Switchbacks and Inslope Turns

Some trails can gain the needed elevation by staying at a consistent sustainable grade using the *half rule* and the *10 percent guideline*, which were discussed earlier. However, most contour trails will require a directional change, or turn to help gain the needed elevation.

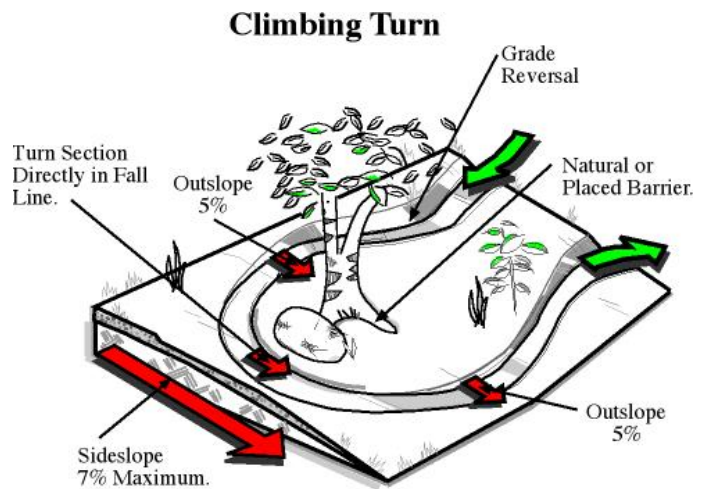
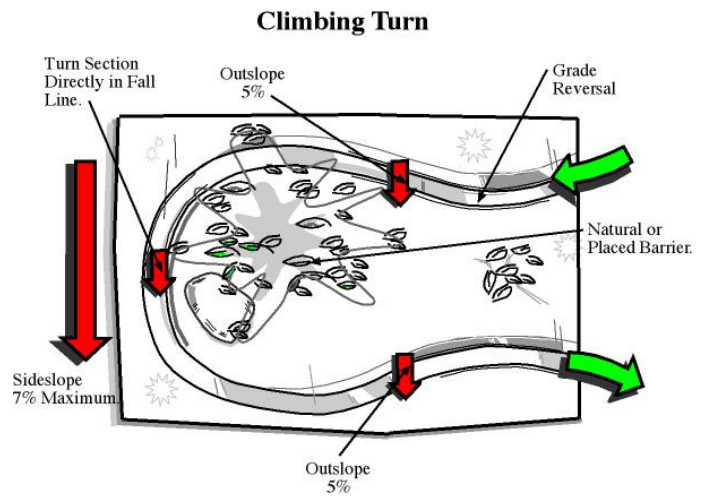
Building Climbing Turns

Climbing turns should be built on shallow slopes of 7 percent or less. Climbing turns should be flowing and gentle to control cyclists' speed and prevent skidding. Turns should be as wide as possible at 20-foot radius or more.

A common mistake in trail building is trying to construct a climbing turn on sideslopes that are too steep. Trail users descending through the turn are forced into the steep fall line. The braking action of feet and tires loosen the soil. Gravity and water removes the loosened soil and create a rutted damaged tread. This, in turn, causes trail users to avoid the damaged section of trail and may lead to trail widening or shortcutting.

It is important to locate grade reversal just above the turn. The grade reversal diverts the water off the trail before it reaches the fall line section of the turn. To reduce user-caused erosion, consider armoring the fall line section of the turn and adding a choke point prior to the turn to slow riders down before they approach the turn.

Remember, if you want your climbing turn to endure the test of time, make sure the sideslopes are 7 percent or less. If the side slopes are steeper than 7 percent, it's time to build a switchback instead.



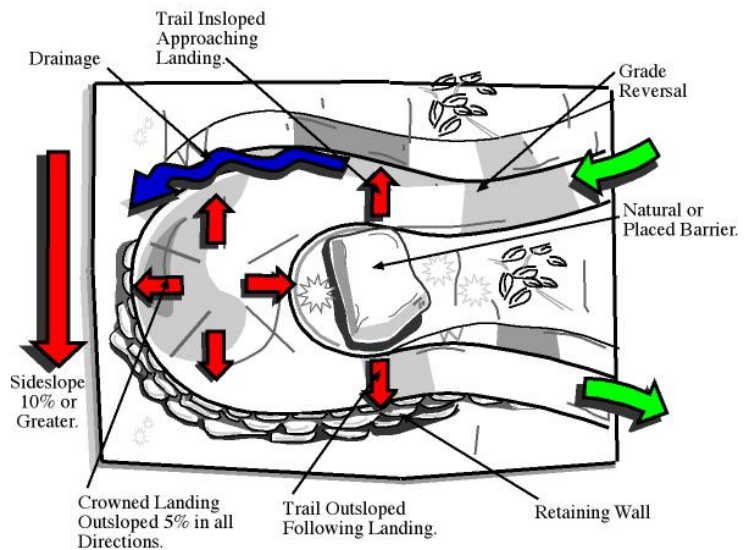
Building Switchbacks

A *Switchback* reverses trails direction on a reasonably level built landing. Switchbacks are more difficult to build, but are more sustainable on steep sideslopes than climbing turns. On a switchback, users are not forced to turn direction on a fall line. Instead, they can turn on a level platform. It is recommended to use a version called a **Rolling Crown Switchback**. It is carefully engineered for proper drainage.

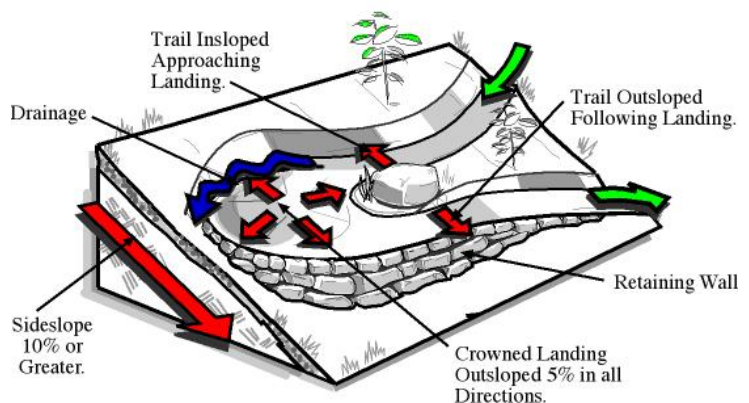
Key Features of a Rolling Crown Switchback

- Consider switchback locations as control points.
- Water drains from all sides of the turn.
- Turns occur on near-level platforms that are slightly crowned.
- The trail stays on the contour on both approaches.
- Bench cuts and retaining walls are used as needed.
- Material excavated from the top approach is used to fill the bottom approach behind a retaining wall.
- Retaining walls are carefully built to ensure stability.
- The upper approach is insloped to help drain water before the turn.
- The lower approach is outloped.
- Approaches should be designed to control user speed prior to entering turn.
- Grade reversals should be used prior to approaches to help divert water.
- Switchbacks should **not** be built directly above one another. They should be staggered on the hillside to prevent shortcutting and water accumulation.

Rolling Crown Switchback



Rolling Crown Switchback



Four Steps to Building a Switchback

Building a switchback is one of the largest trail construction activities you can undertake. Switchbacks require a small degree of engineering, precise placement, significant hauling of material and a lot of labor. Building a rolling crown switchback require about 10 people and at least one day to complete.

Step 1: Choose the Location

The best location for a switchback is the flattest area you can find along the desired route of the trail. The steeper the slope, the larger the retaining wall will need to be on the downhill side of the structure. Ridges and sun-facing slopes are ideal locations. Whenever possible, always wrap the switchback around an obstacle, like a tree, low-lying bush or a large rock, this will discourage users from shortcutting the switchback. Keep sightlines open to avoid user conflicts. Once the location for the switchback is found, layout the turn and mark the lower and upper approaches using pin flags.

Step 2: Build the Turning Platform and Retaining Wall

The first things you'll need to build are the retaining wall and turning platform. The turning platform on a shared-use trail should have a radius of at least 6-feet.

Typically, for a 10 percent sideslope, you will need a 1-foot retaining wall. Thus a 40 percent sideslope will need a 4-foot retaining wall. Constructing the retaining wall is the most difficult part of building a switchback.

Retaining walls can be built from wood or rock. Large rocks are the preferred material since they will not rot and the weight of the rock provides greater strength for the wall. If rock is used, select the largest and flattest rock you can find and make sure it is staked so that the wall leans into the slope. *(For more information of retaining walls, see page 47)* If wood has to be used, select commercially-treated lumber.

After each layer of rock is added to the retaining wall, add a layer of fill behind it and compact the fill completely before adding another layer of rock to the wall. Place the fill in layers (about 6-inches) and compact as you fill. It is essential to have proper compaction of the fill to prevent settling of the turning platform over time.

Step 3: Build the Upper Approach

Excavate the upper approach and upper section of the turning platform. Completely remove all organic material and scatter, do not use this for fill material as it will rot and settle in time leaving an unstable trail. Once you have reached the mineral layer, use the excavated mineral soil to fill the lower section behind the retaining wall. The upper approach should have a 5 percent inslope extending about 30-feet beyond the switchback with a grade dip at the beginning of the inslope.

Step 4: Complete the Lower Approach

Complete the switchback by extending the retaining wall along the lower approach. As you extend the wall further way from the switchback, taper the wall so it blends into the trail beyond the turn. The lower approach should have a 5 percent outsloped for proper drainage.

Building Insloped Turns

A well-built inslope turn is sustainable, improves trail flow and adds an element of excitement for cyclists. A rolling crown switchback drains water very well but they tend to make negotiating turns awkward. While this is not an issue for those who travel slow (hikers and horseback riders), it may be an issue for those who travel faster (cyclists and runners) who prefer to maintain their speed and flow through turns. This can be accomplished by building an inslope turn, creating a banked or bermed turn.

By improving flow, inslope turns can reduce skidding, trail widening and lateral soil displacement that sometimes occur on flat or outsloped turns. Inslope turns are most appropriate when the trail users are causing, or predicted to cause lateral displacement of tread material. Things to ask yourself are: will the trail flow and user speed cause the rider or runner to drift outward while negotiating the turn? Will users be required to drastically slow down to negotiate the turn smoothly? If so, an inslope turn should be considered. If higher speeds are predicted, good sightlines and/or choke points should be used to reduce user conflicts.

Four Steps to Building an Inslope Turn

Step 1: Chose the Location

As with climbing turns and switchbacks, correct placement of an inslope turn is critical. There are several things to consider.

Sideslopes

Gentle sideslopes are best with grades of 25 percent or less. On steeper sideslopes, you may need to build a turning platform similar to that of a switchback along with a retaining wall to lessen the grade of the turn.

Approach

Similar to that of a climbing turn, the upper and lower approach should follow the contour, with the trail turning quickly and evenly through the fall line. Grade reversals should be used on both the upper and lower sections just before the turn to allow water to drain from the tread.

Turn Radius

The radius of an inslope turn should be between 10 to 15 feet. Tighter turns will require the users to slow down to navigate the turn, thus the turn will not require a bank or berm. Wider turns are less sustainable and can lead to higher travel speeds.

Natural Obstacles

As with other turns, position the trail around a tree, bush, or a large rock. Not having an obstacle, know as a *naked turn*, will encourage users to shortcut the turn. Since inslope turns force users to lean into the corner, avoid placing the turns too close to large obstacles, such as trees, where one might hit their head or shoulder. Also, remember to keep sightlines well open. Since the potential for speed is greater than other turns, make sure users can see what, or who is around the bend.

Step 2: Build a Turning Platform and Retaining Walls

On steep sideslopes you may need to build a turning platform to lessen the grade of the turn. On slopes steeper than 25 percent, consider raising the lower section of the turning platform. For example, every 10 percent of sideslope steeper than 25 percent raise the lower side of the turning platform 1 foot.

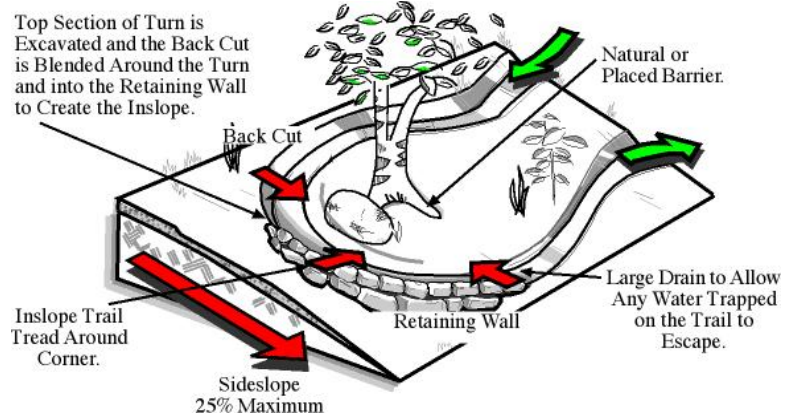
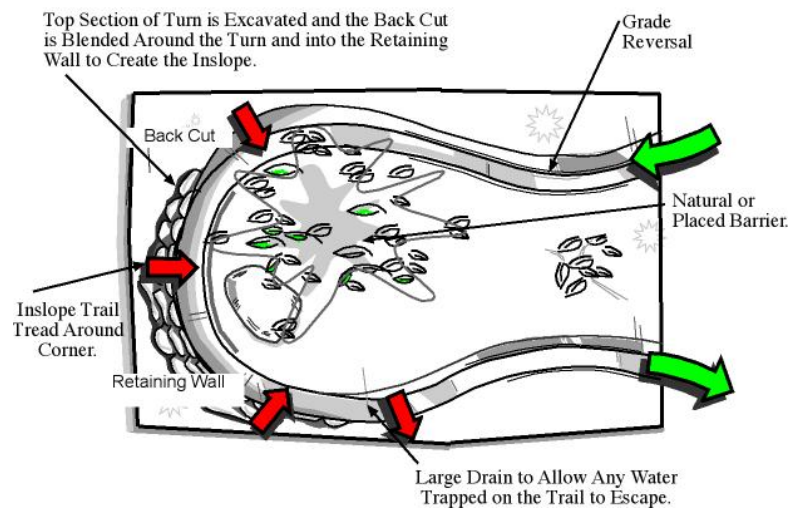
If you need to raise the lower section of the turning platform, it should be reinforced with a retaining wall. A retaining wall may also be needed to support the berm to withstand the forces the riders apply as they push their bikes through the turn. See pg. 47 for tips on building retaining walls.

Step 3: Build the Insloped Turning Area

The steeper the sideslope, the higher and steeper you will want the berm to be. There are no standard height or recommended inslope angle to a berm. Very little inslope is required to make your turn flow smoothly, and as little as a 7 percent tilt towards the inside of the turn will make a difference in the feel of the turn. When building the berm, create a consistent slope from top to bottom.

Construct the berm with small rocks and mineral soil only. Add a small amount of material at a time and compact each layer as they are added. The top layer should be mineral soil only. Use soils that are cohesive and compact well; sand or organic soils will not work. In areas where the clay content is minimal, imported clay fill will need to be mixed with existing soil. If the berm is short, it can stand on its own, but taller berms will need to be built against a retaining wall.

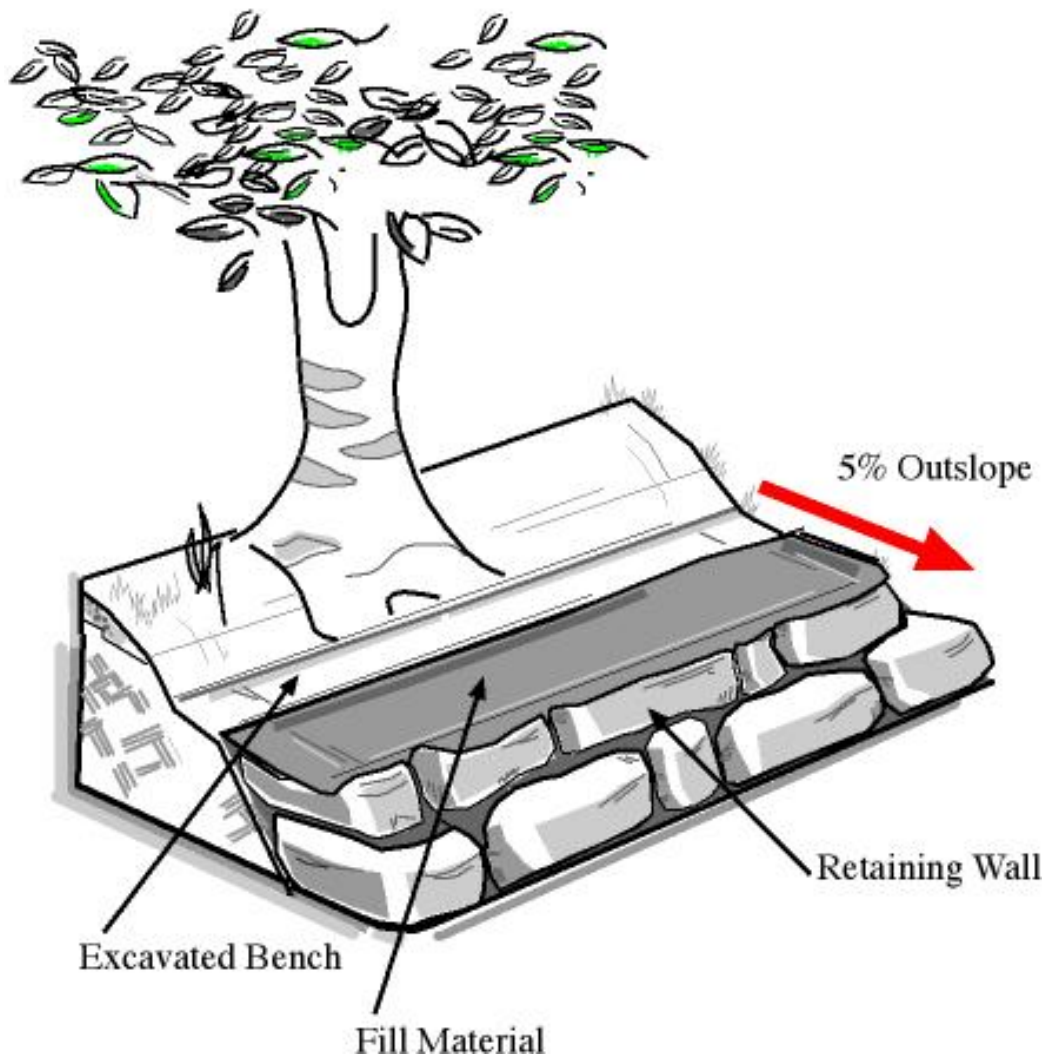
Insloped Turn



Building Retaining Walls

Retaining walls are frequently used in trail building. They are used to support turning platforms on switchbacks, shore up trails on rough terrain, or used to reinforce an outer edge of a partial benched trail. Building large retaining walls is a difficult job, so enlist those who have experience in building them.

Partial Bench Trail with Retaining Wall



Nine Steps to Building a Retaining Wall

Step 1: Choose Rock or Wood

Large rocks are the preferred material for building retaining walls since they do not rot and the weight alone creates a stronger structure. If wood must be used, construction of a **crib wall** is usually necessary to achieve the strength and stability required. The same keys apply regardless of what building material is used.

Step 2: Used Appropriate Rocks

If possible, use angular rocks that have flat sides and square edges, round rocks are difficult to work with and are not as stable as square rock when staked. It is better to use rocks that are at least 50 pounds, preferably 150 pounds. If you can lift the rock yourself, it's most likely too small. Try to use local stone to make the wall look more natural. Importing stones may spread invasive plants to the area.

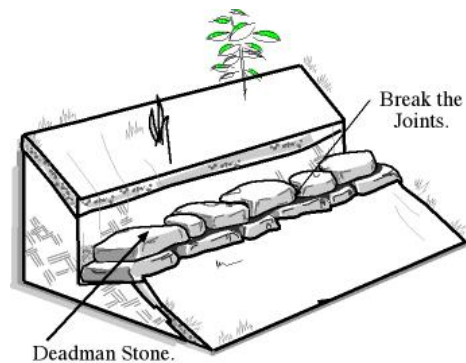
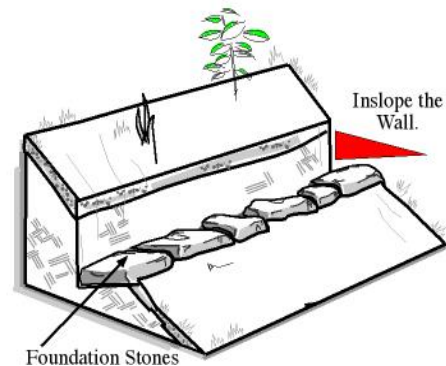
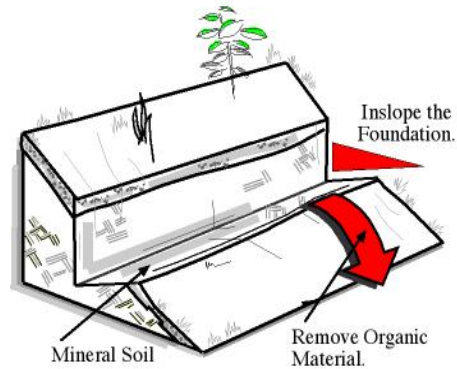
Step 3: Lay the Foundation

Excavate the footing, then place large, well-anchored rocks to form the base layer. The first rocks in the retaining wall are crucial in anchoring the wall in place; these rocks must be immobile once they are set in place to form a solid foundation.

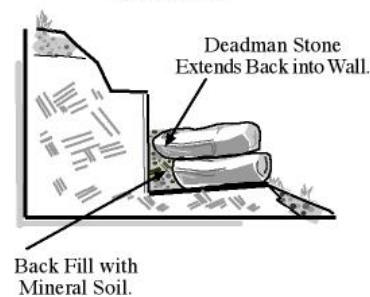
Step 4: Build the Wall

Once you have a solid foundation, place more rocks in tiers to form a wall. Ensure that all rocks touch one another and everything is locked in place. You will need to move rocks around to get the best fit. If a rock wobbles under foot, reposition it. Use smaller angular rocks as wedges to fill gaps. Without mortar, friction and gravity must hold the wall together.

Rock Retaining Wall



Wall Profile



Step 5: Break the Joints

Place each rock so that it spans the gap of the rocks beneath it (known as a running bond). Just like building a brick wall, avoid aligning joint because this will weaken the structure.

Step 6: Use Deadmen

Every 4 to 6 feet, try to place a **deadmen** or **header** – a piece of timber or a large rock used as an anchor that extends into the bank behind the wall. This helps to lock everything together.

Step 7: Inslope the Wall

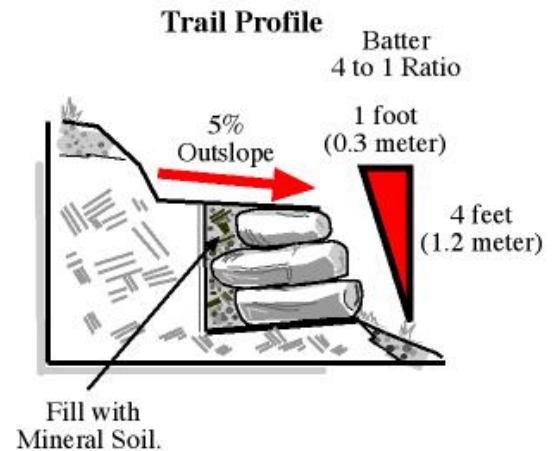
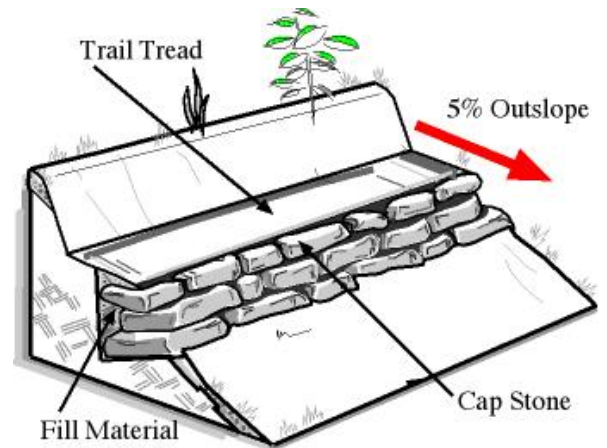
The wall should tilt towards the backslope. This angle is known as the wall's **batter**. A **batter** should not be shallower than a 4:1 slope (every 4 feet in height, the wall will tilt towards the backslope 1 foot). A batter of 2:1 is preferred.

Step 8: Back Fill

Back fill must be placed and compacted behind the wall as each layer of rock is placed building the wall. Use small rocks and moist mineral soil, not organic soil as fill material.

Step 9: Place Capstones

Use large flat rocks for the top layer of the wall. The weight and size of the **capstones** are used to hold everything together. When finished, the top of the retaining wall should be slightly lower than the surface of the trail's tread to allow proper drainage.



Wooden Retaining Walls

A retaining wall built with logs, known as a **crib wall**, also use deadmen that are buried into the hillside behind them. The deadmen are connected to the face of the wall using notched log-cabin construction and are sometimes reinforced with spikes or pins. Be sure to use large rot-resistant logs or timbers or commercially-treated wood.

Armoring ~ Using Rock to Harden Trails

Armoring is a method of using large rocks to pave a trail to prevent erosion. Armoring is useful to elevate a trail above soft or wet soils where there are no other available routes to take. Also, armoring is helpful in hardening a trail to prevent user caused erosion.

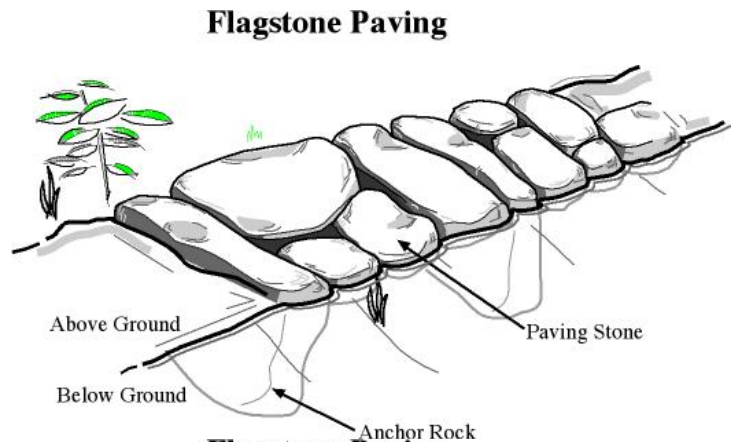
It is important to know the difference between user and water caused erosion. It would be wasteful to spend the time to armor a trail if water drainage issues have not been addressed. Water will destroy armoring if it is allowed to flow under the rocks; this will undermine the armoring or frost heave the structure out of position.

Armoring can benefit a trail by: hardening a surface in extremely rainy climates, stabilizing steep trail grades of 20 to 45 percent, reinforcing stream crossings, crossing a low-lying muddy or sandy area when a reroute isn't possible, hardening landing areas following jumps or drop-offs, hardening trail surfaces on high-traffic areas to withstand user-caused erosion.

Five Ways to Armor with Rock

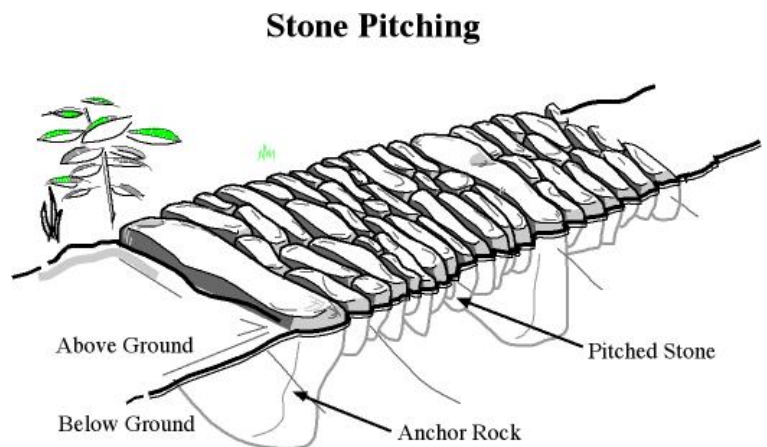
1: Flagstone Paving

Large, flat-faced stones are placed directly on a mineral soil base or an aggregate base (a mixture of sand, gravel, pebbles and small rocks, with no organic material within or beneath base). Each stones largest and smoothest face is placed up and at grade to form the tread. This is the most common and simple armoring technique.



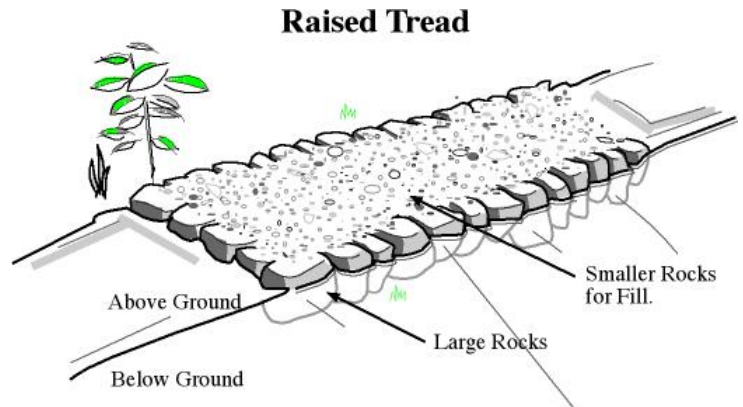
2: Stone Pitching

This is an ancient road building technique where medium-sized rocks are set on edge, or **pitched** up on their side. The stones are hand-fitted tightly together with aggregate packed into the gaps to tighten the structure. It may seem like a tough job, but stone pitching can often be more efficient than flagstone paving, depending on the stone selection.



3: Raised Tread Construction

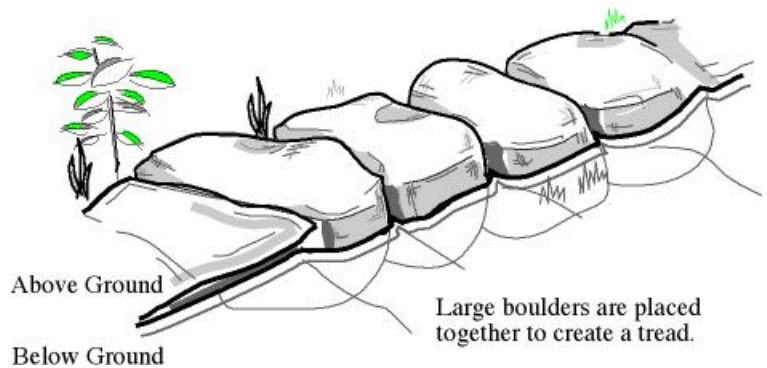
Also known as a **rock turnpike**, the foundation consists of large rocks embedded into the tread. Medium rocks follow and are locked into place. Finally, the tread is capped with aggregate, or crushed stone. Make sure the tread is crowned to shed water and does not form a dam, raising the water level on the sides of your trail.



4: Boulder Causeway

A **boulder causeway** is basically the same as flagstone paving technique where giant boulders and large rock slabs are used to raise the tread.

Boulder Causeway



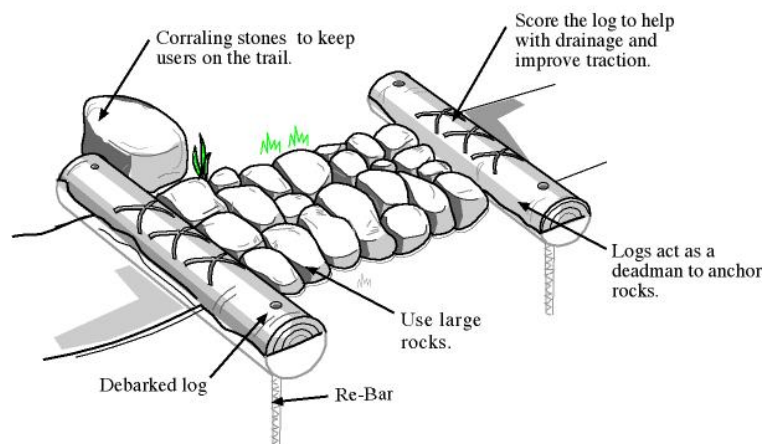
5: Natural Rock Outcroppings

Routing a trail over and through existing, exposed rocks is an excellent way to create a highly challenging freeride trail. The exposed rock can support fall-line trail sections very well.

Appalachian Armoring

Appalachian armoring is a technique of armoring that blends broken concrete with rot-resistant logs. The logs serve as deadmen which are partially buried and rebar is driven through the ends to keep the log in place. On steeper sections, deadmen should be placed every 4 feet, otherwise, every 5 to 6 feet. Once the logs are in place, concrete can be positioned using the flagstone paving technique. If stone is available, use it.

Appalachian Armoring



Ten Tips for Rock Armoring

1: Remove Organic Matter First

As with all trail construction, it is important to excavate down to mineral soil if practical. You want to set your rocks on a firm foundation, so remove the organic material from the tread before placing the stones.

2: Start at the Bottom

If you're on a slope, start at the bottom and work upslope. The weight of the stones will hold the structure together.

3: Drop the Anchor

The first **keystone** in an armored trail plays a crucial role in anchoring the entire structure together. The anchor rock must be large and immobile once it's in place and at least two-thirds buried. Large angular rocks work best for anchors rather than round rocks. Anchors should be placed every couple of yards.

4: Lay the Tread

Once the anchor rock has been placed, follow by positioning more stones to form the tread. Ensure that all stones touch each other and everything is locked in place. You'll need to move rocks around to find the best fit. If a rock wobbles under foot, reposition it. Use smaller angular rocks as wedges to fill the gaps. Remember, without mortar, gravity and friction holds everything together.

5: Break the Joints

Place each stone so that it spans the gap between the adjacent stones, this is known as a **running bond**. Like building a brick wall, you must avoid directly aligning the joints or they will weaken the structure. Also avoid joints running parallel to the trail as these gaps might catch a bicycle wheel.

7: Fill the Gaps

It's important to fill the gaps between large rocks with small rocks, stone dust, gravel or sand. Pack the fill material tightly, using hand tools. **Crusher fines**, also known as quarry waste, is the best fill material because it contains binders from the parent stone.

8: Compact the Tread

It is best to compact any surfacing material in layers, or lifts (minimum of 6" lifts) while the material is slightly wet. A mechanical compactor works best for this important step.

9: Corral the Trail

Include something to define the sides of the armoring. Large ominous rocks, logs, trees or other obstacles staggered on either side of the trail serve as physical and visual barriers to keep riders on the armored section of the trail. Make sure the barriers are visually interesting and flow naturally with the trail; otherwise, users may find them annoying and create new routes around them.

10: Consider trail Flow

Smooth flow is vital on trails used by cyclists. Mountain bikers love the rhythm of a trail where one turn blends into the next, and a trail surface is somewhat predictable. A trail with good flow helps to minimize erosion, user conflict and safety concerns. Strive for a subtle transition into the armored section.

When Armoring, Always...

Be Safe

- A hardhat, eye protection, gloves and steel-toed boots are necessities.
- Don't hurry.
- Learn the mechanics of lifting without injury.
- Communicate with people around you.
- Keep hands away from any rock being shifted by pry bars or other means.
- Skid a rock in a controlled manner rather than rolling it. Rolling rocks rarely stop where you want them.

Use Proper Tools

- At least three heavy-duty rock bars, or pry bars are needed to move rocks.
- Pick mattocks and pulaskis are useful for digging, positioning rocks and light prying.
- A heavy sledgehammer will help to break rocks and final tight fit positioning.
- Rock hammers and chisels are useful in shaping stones.

Be Considerate When Locating Material

- It's best to use local stone, when available, so your work will look natural. Importing stone may spread invasive plant matter.
- Try to use rocks that are out of site and uphill from of the trail corridor.
- Don't move rocks that will damage vegetation or sensitive areas.
- Restore any significant disruption caused by rock quarrying.

Choose the Right Shape and Size

- If possible, select angular rocks with flat sides and square edges. Round rocks are difficult to work with.
- The exact size and shape will depend on the armoring being done.

Even though you are using rocks to armor a trail against erosion, all the principles of sustainable trail construction still apply. It is essential to follow the half rule and incorporate grade reversals because the key to long-lasting stone armoring is to prevent water from flowing down or under the structure you just built. Well-built stonework can withstand many years of traffic, but it can fail rapidly if attacked by gravity-powered water.

Man-Made Soil Hardener

There are basically three groups of man-made soil hardeners: chemical binders, physical binders and geosynthetics. Man-made soil hardeners are typically more costly than the natural hardeners and won't stand the test of time on grades greater than 5 percent. Soil hardeners are used to hold the trail's tread together in such areas as: sandy or wet soils, or excessive grades (hardeners should only be used if a reroute is not possible).

Chemical Binders

There are several liquid stabilizers on the market that, when mixed with water and soil, help increase the moisture resistance, density and weight-bearing strength of otherwise unstable soils. Although this concept seems to be good, these products have mixed reviews when applied to trails. Some products failed to firm up the soil, while others made the soil's surface extremely slick and potentially hazardous to users. Others can be harmful to the environment. Always consult with the land manager before using chemical binders on a trail.

Physical Binders

When building a trail, you want to avoid soils that are either extremely fine or coarse. Finely textured soils such as silt or clay drain poorly while coarse soils such as sand do not bind well and are easily displaced by heavy traffic. It is best to avoid these areas altogether, but sometimes this is not possible and you are forced to build in these less than ideal conditions. There is a wide array of physical binders used, everything from clay-based kitty litter to oyster shells to high-tech soil additives. In some cases, physical binders can be quite effective. It's all a question of finding the right additive for your particular type of unstable soil.

Geosynthetics

Geosynthetics are man-made sheets, nets and grids designed to stabilize soil. When used with high-quality fill material, Geosynthetics can help improve trails that cross soft, water-saturated soils.

- **Geotextile Sheets** are commonly used to separate and support fill material. For example, in a boggy section, if you were to place crusher-fines on top of the existing soils without first placing the geotextile fabric, the crusher-fines would mix with the existing wet soils and you will end up with a much worse soil condition. The fabric prevents the materials from mixing together. Geotextile fabric also allows water to drain through to insure the trail stays high and dry. Geotextile fabric will last indefinitely if kept out of the sun; otherwise the fabric will rapidly degrade if exposed to UV light.
- **Geonets** are geotextile sheets with a polyethylene core. Since they have a bit more bulk and structure to them, they tend to provide better support to the trail than a single sheet.
- **Geocells** are honeycombed grids that help to hold fill soil in place over saturated soils. Some trail builders will typically cover the soggy ground with a geotextile sheet and then place the geocell on top of that. Each cell in the grid is packed with fill soil. Finally, the entire geocell is capped with an additional 2 inches of fill soil. Geocells results are mixed. The cap soil tends to erode away, particularly on steep slopes, which, in turn, expose the geocells and poses a hazard to trail users.

Wetlands and Water Crossings

Water crossings can be a challenge to design, labor-intensive to build and maintain, and most important, they can be devastating to aquatic ecosystems. Trail builders need a basic knowledge of wetland ecosystems, stream dynamics and aquatic habitat to construct a sustainable crossing that minimizes impact on these important ecosystems.

Stream Corridor Function and Dynamics

Stream corridors, which consist of the channel, adjacent floodplain and riparian vegetation, perform a number of critical watershed functions. They serve as conduits for water, sediment, organic material and aquatic organisms. They moderate flood flows, augment summer flows and filter runoff. They provide shade, cover and food to the stream ecosystem. Watershed health depends upon maintenance of the ecological connectivity provided by streams and their associated corridors. Trails crossings, when done poorly, can disrupt this connectivity and impair the stream corridor functions.

Stream channels are highly variable in shape and are naturally dynamic. Properly functioning streams will adjust their shape to accommodate small changes in flow and sediment transport. For example, a meandering stream will typically migrate across its floodplain, changing its location incrementally while maintaining the same cross section and slope. After a significant event, streams will undergo a series of changes to reestablish stability, sometimes at a different base elevation and channel slope. These changes will spread upstream and downstream to maintain stability. Anchoring streams with a stationary trail crossing can disrupt this evolutionary process with cascading consequences.

The U.S. Forest Service's Stream System Technology Center in Fort Collins, CO, can provide more information on this subject at: www.stream.fs.fed.us

Water crossings should be avoided whenever possible. However, when you have no alternative to crossing a drainage, your priorities should be:

1. Minimize the impact to the stream channel
2. Minimize the impact to the streamside environment
3. Create a safe and sustainable passage for trail users
4. Minimize the number of crossings

Five General Guidelines for Water Crossings

1: Consult with Land Managers

The land management agency should have data on stream corridors, including seasonal flow rates, frequency of flood events, fish habitat and water quality records. This information may help in determining the location and type of crossing required to minimize impacts. Depending on the type of crossing used, a Federal Army Corp of Engineers permit may be required; the local land management agency may be of assistance.

2: Identify Water Crossings a Control Points

A water crossing is an important control point, which is identified during the design phase. Certain terrain and stream features dictate where crossings should occur. Stream crossings should be located at riffle (low depth and straight flowing) sections instead of locations where the stream meanders or pools, as riffles are relatively stable, have the coarsest base and can best accommodate a crossing.

3: Carefully Design Crossing Approaches

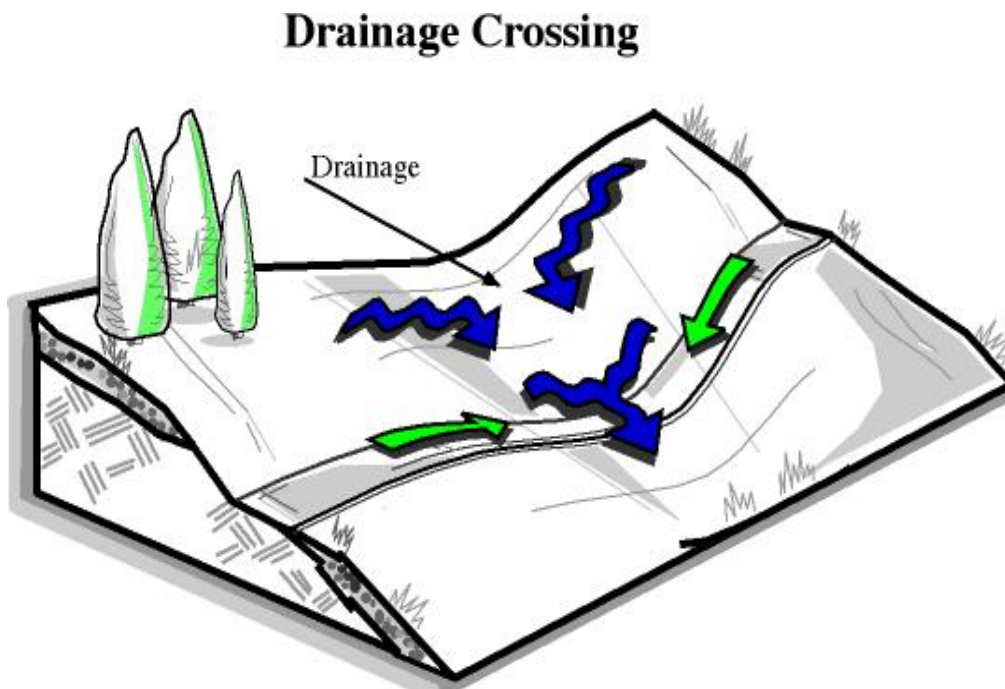
The trail should descend into and climb out of the stream crossing, preventing water from flowing down the trail, even during a storm event. Be careful, however, to keep the crossing on a gentle grade of 8 percent or less. The trail entering the stream crossing should avoid the fall line of the slope to prevent dumping water and debris into the stream.

4: Include Grade Reversals

Grade reversals should be used on both side of the approach; this will prevent large amounts of water and sediment from flowing down the trail and into the stream.

5: Mimic the Stream

The crossing should maintain the streams cross slope, slope, alignment and substrate (stream bottom), thereby mitigating issues to the aquatic life. Habitat fragmentation is incremental and cumulative; even a small crossing, when poorly done, contributes to loss of ecologic function. Mimic the stream by giving your crossing a natural bottom and maintaining the slopes and width of the waterway.



Types of Water Crossings

There are three basic types of water crossings to consider: armored, culverts and bridged crossings. Again, crossings should be avoided whenever possible and the number of crossings should be limited.

Armored Crossings

Armored crossings, or fords, are a simple and inexpensive way to allow trail users the means to cross a stream while minimizing sedimentation. You should only consider building a ford in a stream with slow water velocities and depth less than 3 feet during high flow events. Fords should be constructed in shallow riffle sections of the stream. Low banks are important to minimize excavation on the approaches. Be sure to select a section with stable bed and banks.

Armoring a stream crossing is much like armoring a wet section of trail (see page 49). Stones are sunk into the ground at grade to make the approaches and bed more durable. It is essential to armor the entry and exit of the crossing at least 6 feet in length to prevent sedimentation from being carried into the stream.

Stone pitched armoring is the most durable technique to use. Be sure to use large stones that won't become dislodged by flood events. In clay, silt or sand bedded streams, it may be necessary to underlay larger stones with gravel, cobble, or geotextile to prevent excessive settling. Construct the ford with the same cross section as the existing adjacent channel. Mimic the stream to avoid potential undercutting and sedimentation. Although armored fords are one of the least invasive means of crossing a stream, it is important to contact the local land manager before disturbing any creek or streambed.

Culverts

A culvert, usually a metal or plastic pipe, allows water to flow beneath the trail. Culverts are ideal for crossing small drainages with minimal flows and predictable flood peaks. However, culverts used on larger streams are frequently a problem.

Of the three crossings, culverts have the highest potential for damaging streams. They are often undersized, installed incorrectly (too high or too low in relation to the stream flow), installed with an incorrect slope (too steep or too shallow), or have an incorrect alignment in relationship to the channel. Improper installation most often results in flow constriction, headcutting, upstream sedimentation, downstream scouring, debris blockage and excessive velocities within the culvert. These effects create barriers to aquatic life, destroys stream habitat by channel abandonment, gullyng and inundation of streambeds with silt.

Even properly built culvert crossings can have negative impacts by reducing the amount or quality of habitat and forcing flood events through a small area, rather than spread across the floodplain where silt and debris can settle. Culverts also require regular maintenance in order to keep them free from debris.

Culverts should be sized to handle the largest flood event expected. Work with the land manager to determine the flood frequency and elevation. If no data is available, make field evaluations by examining the stream banks. Indicators include, breaks or sloughing of the stream bank (known as undermining), a change in the size of sediment particles on the bank, water stains on boulders, changes in vegetation or vegetation lying flat in the direction of flood flows and flood debris. Look for these signs of high flows and size the culvert accordingly.

Culverts should be invisible to the stream, with no change to the channel width, slope or stream substrate. The length of the culvert should be at least the width of the stream and a minimum of 24" in diameter. Align the culvert so there are no sharp bends as the flow enters and exits. Sink the culvert into the streambed to allow a natural bed surface to form inside the pipe.

It is important to size the pipe to insure flows stay with acceptable limits of velocity and depth. This will allow the target species and age class of fish within the stream to pass through the culvert unharmed. Resting pools may be needed at either end of the culvert if the pipe is particularly long. Professional help from a hydrologist, engineer or biologist will likely be needed to properly design a culvert crossing, again, check with the land manager.

Given the frequency in culvert failure, *plan for failure* by anticipating what will happen if the culvert is inundated by a large flood event, sedimentation buildup or debris jams. Build the crossing so that large flows can overtop the crossing without damage or diversion of the stream channel. Locate the culvert in a low spot of the channel with the trail rising on both approaches. Minimize fill used and use coarse material, as it is more resistant to erosion. Armor both the inlet and outlet of the culvert to protect from erosion. Cover the culvert with at least 12 inches of soil. Plastic culverts are lighter and easier to cut than metal culvert, making them more manageable for projects that are a long distance from the trailhead. Think about maintenance before you install a culvert. The longer the culvert, the more likely it will clog with silt, branches or other debris. Longer culverts are also more difficult to clear once they are clogged.

Bridges

Building a bridge is one of the most challenging tasks in trail building. It requires a strong understanding of engineering and hydrological principles. Bridges are labor intensive and expensive to build. However, if the stream being crossed is large or has particularly variable hydrology during large flood events, a bridge is the best means of crossing. By putting the trail above the water, you will minimize the impact each has on the other. There are wide ranges of bridge designs, from a simple single log with a handrail to expensive prefabricated steel structures. Again, check with the land manager, they may have standards for bridges structures on their lands.

Tips for Successful Bridge Construction

- Make the bridge high enough so that the approach is on a gentle, if not level, grade. Build the bridge with the 100-year flood elevation in mind. Bridges should be built at the riffle section of the stream.
- Extend approach ramps well onto the trail.

- Bridges and their approaches should not have sharp turns. Turns on the deck of an icy or wet bridge can be very dangerous.
- Design the bridge so that users on either side can see each other and slow down to yield before meeting abruptly in the middle of the structure.
- Design bridges with users in mind. For example, an equestrian bridge may have specific requirements for railing and deck requirements.
- For wooden bridges, use bolts and screws instead of nails.
- Avoid allowing the stringers to touch the ground, as this will cause rotting and collapse of the structure. Stringers should be placed on rock abutments or replaceable rot resistant lumber.
- Use only naturally rot-resistant woods such as cedar, cypress, hemlock, locust, redwood or tamarack. Not commercially-treated lumber.
- Bark must be stripped from the logs or the wood will rot and suffer insect damage.
- Before beginning work, consult with an experienced bridge builder or at least check with the land manager for its construction guidelines.

This is just a guideline in the bridge construction. For more detailed information, there are several sources to reference. Here are a couple resources to look at.

The U.S. Forest Service's *Trail Bridge Catalog*, available at:
www.fhwa.dot.gov/environment/fspubs

The Federal Highway Administration's *Recreational Trails Program*, available at:
www.fhwa.dot.gov/environment/rectrails/index.htm

Wetlands

Wetlands are the most vital and fragile ecosystems on the planet. They come in many forms from lowland swamps and marshes to high alpine bogs fed by springs and snowmelt. Wetlands perform important functions such as, regulating water flow, retaining runoff and purifying water. Wetlands also host diverse and often rare species of both plants and animals. For all these reasons, it is vital to tread lightly through wetlands or avoid routing trail through them whenever possible.

The general guidelines for water crossings also apply to wetland crossings: they should first be avoided and users should be directed away from them. However, if there are no other routes to

take the trail and the wetland must to be crossed, contact the land manager for permission and to help determine the best route for least amount of impact to the wetland.

Structures used to cross wetlands can be grouped into two categories, raised treads and boardwalks. **Raised Treads** are constructed directly on the ground and include, turn pike, causeway, raised camber and some types of armoring. **Boardwalks** are raised above the ground and include: puncheons, bog bridges, ladder bridges and gadburys.

Constructing wetland crossing requires careful planning and execution. The U.S. Forest Service publication, *Wetland Trail Design and Construction*, is available at:
www.fhwa.dot.gov/environment/fspubs

Part Five: **Trail Maintenance**

Trail maintenance is an important and often overlooked component of trail management. The following section offers solutions for maintaining the perfect tread to identifying problem areas on your trail system.

Assessing the Conditions of the Trail

Step 1: Trail Assessment and Repair Sheet

Creating a trail assessment sheet may seem like overkill. But, using one can save a lot of time and headache when it comes to a workday and you need to explain the where, what and why of trail repairs. Trail assessment sheets give trail crews the means of: identifying the maintenance problem; the project location; the nature of the problem; the approach to solving the problem, tools needed; number of crews needed for the particular issue; and identifying specific crew leaders needed to tackle certain problem areas.

A trail assessment sheet takes the ambiguity out of trail maintenance and will prevent a lot of confusion.

See Appendix A: Trail Assessment and Repair Sheet

Step 2: Walk or Ride the Trail

With the newly created assessment sheet and a measuring device, (such as a measuring wheel, GPS unit, cyclometer (if on a bike) or equivalent, begin recording your mileage the moment you leave the trailhead. Include the name and location of the trailhead on the assessment sheet.

While traveling the route, look for areas of concern or problem spots; once found, pull out your assessment sheet, record the mileage traveled from the trailhead, briefly explain what the problem is and provide any other important information. It is important to prioritize the problem areas, because, depending on the amount of work that needs to be done as well as the amount of crews you have on hand for repairs, you may need to focus your efforts on areas which may be dangerous to users first, and if time allows, move to other problem spots.

Step 3: Confer with Land Manager

Meet with the land manager, if applicable, and discuss the trail project well in advance of scheduling a workday event. Using your completed assessment sheet will help to explain to the manager the trail problems and how you plan to fix them. Keep a copy of the assessment sheet for your own records; this will help to develop a track record of what has been done on the trail as well as providing a group's stewardship credentials.

Step 4: Assign Work Crews

Assign a certified crew leader and a work crew of two to five people for each trail maintenance project. With an assessment sheet the group should be able to answer the following questions:

- Who's on the crew and who's the crew leader?
- Where's the work site located (what trail and how far from the trailhead)?
- What's the problem?
- What tools are needed?
- How should the problem area be repaired?

Basic Trail Corridor Maintenance

Brush, trees and branches will eventually find their way into the trail corridor. Thus, the first task should be to make sure the trail corridor is passable and that sight lines are acceptable. Look for vegetation that has grown into the trail corridor, trees that have fallen and blocked the trail, loose rocks on the tread and exposed roots that could be a hazard to users. Follow the four steps below to repair these basic trail corridor maintenance issues.

Step 1: Trail Vegetation

Maintaining the vegetation along the trail corridor helps to keep trail users on the center of the tread. Most forested areas require a least two corridor-clearing projects per year. Early spring is a good time to remove downed trees, while fall is a good time to remove over growth.

Be creative while trimming along curvy trail section and alternate cutting from one side of the trail to the other to accentuate the curves of the trail. Do not trim more that what is necessary. Over trimming will make the trail section too straight and invite higher speeds. Match the trail corridor height and width to the desired trail style, and maintain a high ceiling, 10 feet for equestrian use.

Grasses and light brush can be removed with a weed whip. Loppers can be used to remove woody brush and branches. Be sure to cut branches outside the bark collar. Completely remove stumps from the tread that are hazardous to trail users. See *page 33* for corridor clearing procedures.

Step 2: Cut and Remove Downed Trees

A downed tree should be removed from the corridor if it forces trail users off the tread or if water is being trapped or redirected causing erosion. However, on advanced trails, a log can be a desirable obstacle to experienced riders by proving a challenge and helping to reduce travel speeds. The log can be placed on the trail to allow novice riders to pass by safely while more experienced riders can ride over the log.

Step 3: Remove Loose Rocks

Trails which feature deeply embedded rocks are considered technical features to experienced riders on an advanced trail. However, on beginner and intermediate trails, loose rocks can be hazardous. Rocks that are torn from the tread will leave a hole, which can become a trip hazard. Such holes should be filled and compacted with moist fill soil.

Step 4: Examine Exposed Roots

Some users enjoy the challenge of riding over roots, but masses of exposed roots often indicate a serious erosion problem, requiring attention. If a root poses to be a safety hazard, for example if you can catch your foot beneath the root, it should be removed. Roots that run perpendicular to the trail are usually less hazardous than those which run parallel with the trail.

Identifying Tread Problems

Both users and water will cause some impact to the trail's tread. Below are listed some of the most common causes of erosion and solution for each.

User-caused Erosion Problems and How to Solve Them

Boot, Hoof and Tires

Problem: The trail is too steep and exceeds a maximum sustainable grade and is causing feet and tires to skid and erode the tread.

Solution: Maximum sustainable grades are site specific and are based on soils types, types of users and length of trail section (See page 8). Your first option should be to reroute the trail to a sustainable grade. If reroute is not possible and it is a short section, you can armor against user-caused erosion.

Problem: The trail is in a wet location

Solution: If the trail is on low-lying terrain and not on a slope, reroute the trail onto a sloped hillside. If your trail is built on a hillside and is still holding water, it is likely the trail does not have adequate outslope; in this case, build a knick to enhance drainage or retrofit grade dips into the trail. In rainy environments, even a well-built trail can stay wet; in this case, a raised trail tread may be your only solution (See page 49, Armoring)

Trail Widening, Trail Braiding and Trail Creep

Problem: Obstacles are forcing users off the trail's tread.

Solution: If the trail is built in flat open landscape, nothing can stop users from choosing their own adventure. Sideslopes are the best way to keep users on the trail. If users are going around an obstacle, remove it or corral users to keep them on the trail. Trimming vegetation can also help keep users on the center of the tread.

Problem: The trail is always wet and muddy.

Solution: Sitting water on a trail is a problem and it becomes worse when users travel around it. See *Boots, Hoofs and Tires* above.

Problem: The trail section is not well defined.

Solution: Install chokes at either end of the intersection to keep users on the trail. Installing chokes will slow users down to a safer speed while negotiating an intersection and will keep them center on the tread. If possible, it is always better to have users climb to an intersection.

Washboard and Brake Bumps

Problem: An abrupt flow transition or sharp turn is forcing users to brake excessively in one spot, causing washboard.

Solution: Slow users down before sharp turns and flow transitions. If your trail varies from open and flowing to tight and technical, add some challenge and choke points to create a transition between the two.

The Development of Social Trails

Problem: The trail bypasses a point of interest (positive control point) and users have created an unsustainable route to it.

Solution: Reroute the trail to include the positive control point, or create a new sustainable trail to the scenic overlook, rock outcropping or other point of interest.

Problem: The trail comes into view of a negative control point.

Solution: Reroute the trail to eliminate the sightline of the trash dump, ecological/archeological site or other places that are out of bounds to help prevent users tempted to investigate.

Water-Caused Erosion Problems and How to Solve Them

Eroded Trail

Gullies, ruts and washed-out tread are good indications of a drainage problem. Water is not sheeting off the trail. Instead water is traveling down the trail and is carving out the trail's tread. The longer the water is allowed to travel down the trail, the greater the amount of erosive force it produces.

Problem: The trail is on the fall line (remember the half rule and max. grade?).

Solution: A fall-line trail is a maintenance nightmare and water will always win. The best option is to reroute the trail to a sustainable, full bench cut, rolling contour trail. If this is not possible (i.e. endangered species on both sides), you may need to use some armoring techniques.

Problem: The trail lacks outslope and water is not sheeting off the trail gently.

Solution: Restore the outslope of the trail. A slight tilt of the tread will promote water to sheet off the trail instead of funneling down the center. Its common for trails to lose its outslope over time. In addition to restoring outslope of the tread, make sure the trail also incorporates grade dips as a defense against water.

Problem: The trail lacks grade dips.

Solution: Retrofit grades dips into the trail if possible; if this is not possible, several water diversion techniques are discussed below.

Drainage Solutions

Deberming and Maintaining the Outslope

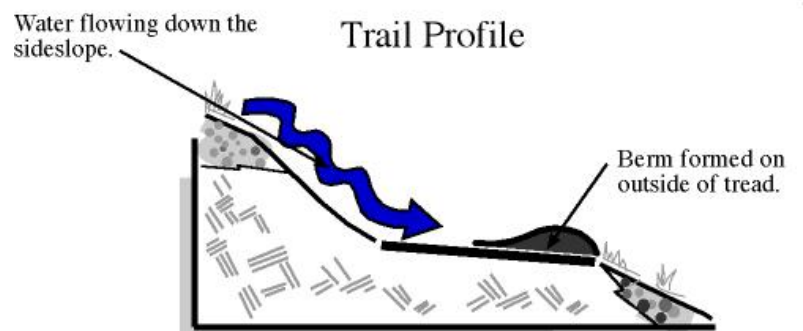
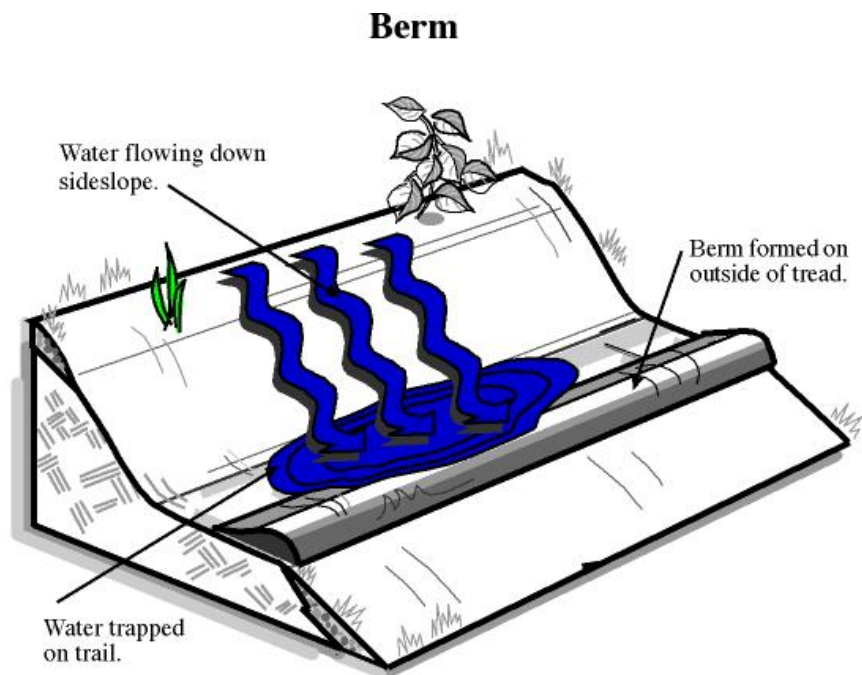
Even a well-built trail with proper outslope can lose their tilt over time and begin to trap water and funnel it down the trail.

There are two reasons for this:

1. The center of the trail becomes compacted in the center with use, resulting in a U-shaped tread, which traps water.
2. Loose material can collect on the outer edge of the tread, forming a berm which traps water.

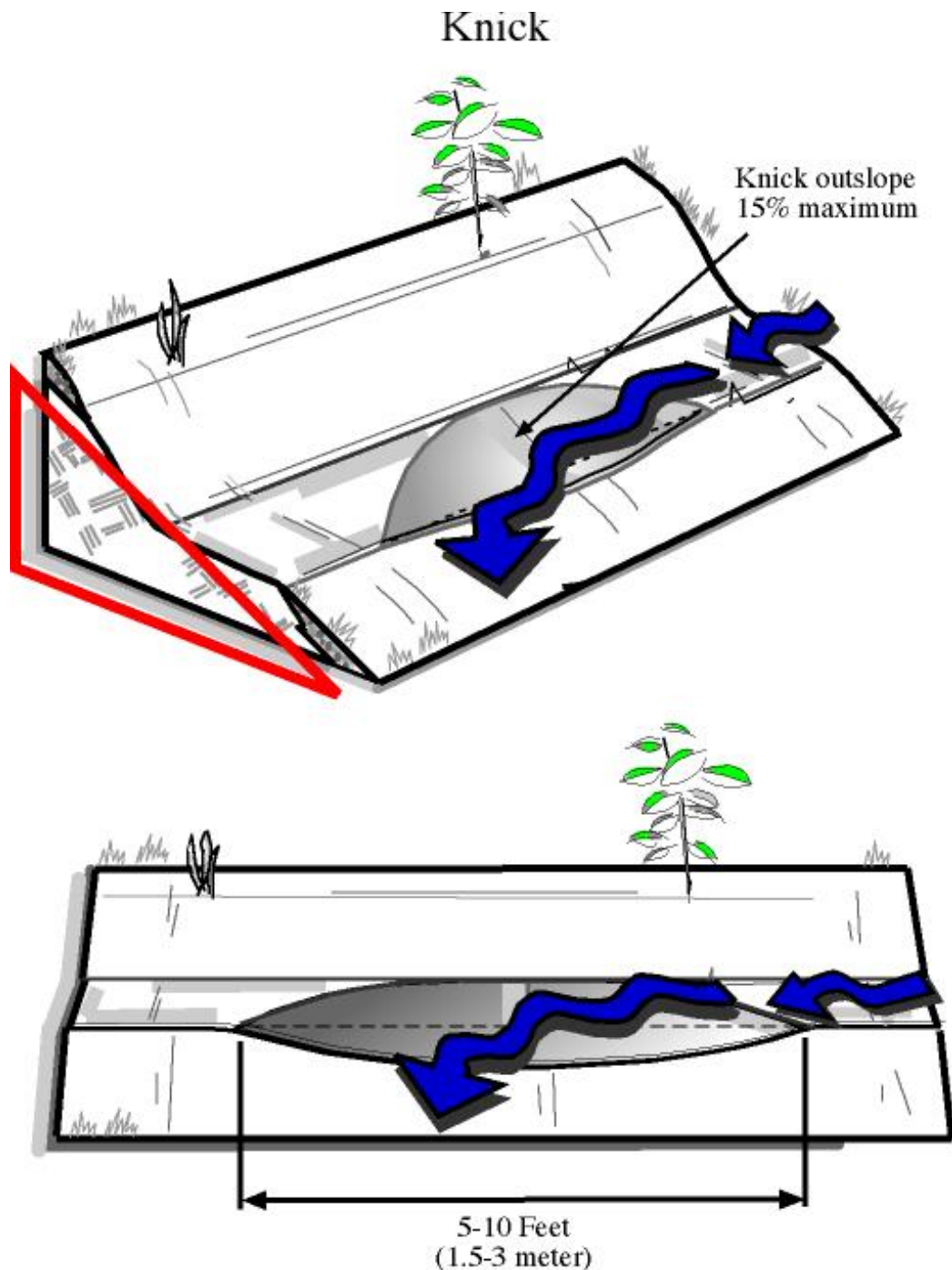
This is a fairly straightforward repair. Deberm the trail by scraping the mounded dirt from the edge and using it to reestablish a 5-percent outslope. This is a frequent maintenance job on most trails.

Note: Outslopes are hard to maintain in loose soils conditions. Grade dips are essential to insure proper drainage in these situations.



Knicks

A knick is a semi-circular, shaved down section of trail, about 10 feet wide, that is tilted to the outslope. A knick is smooth, subtle and many users won't even notice its presence. The center of the knick is outsloped at about 15 percent to allow water to drain off the trail. For a knick to be effective, there must be lower ground adjacent to the trail so that water has a place to drain.



Rolling Grade Dips

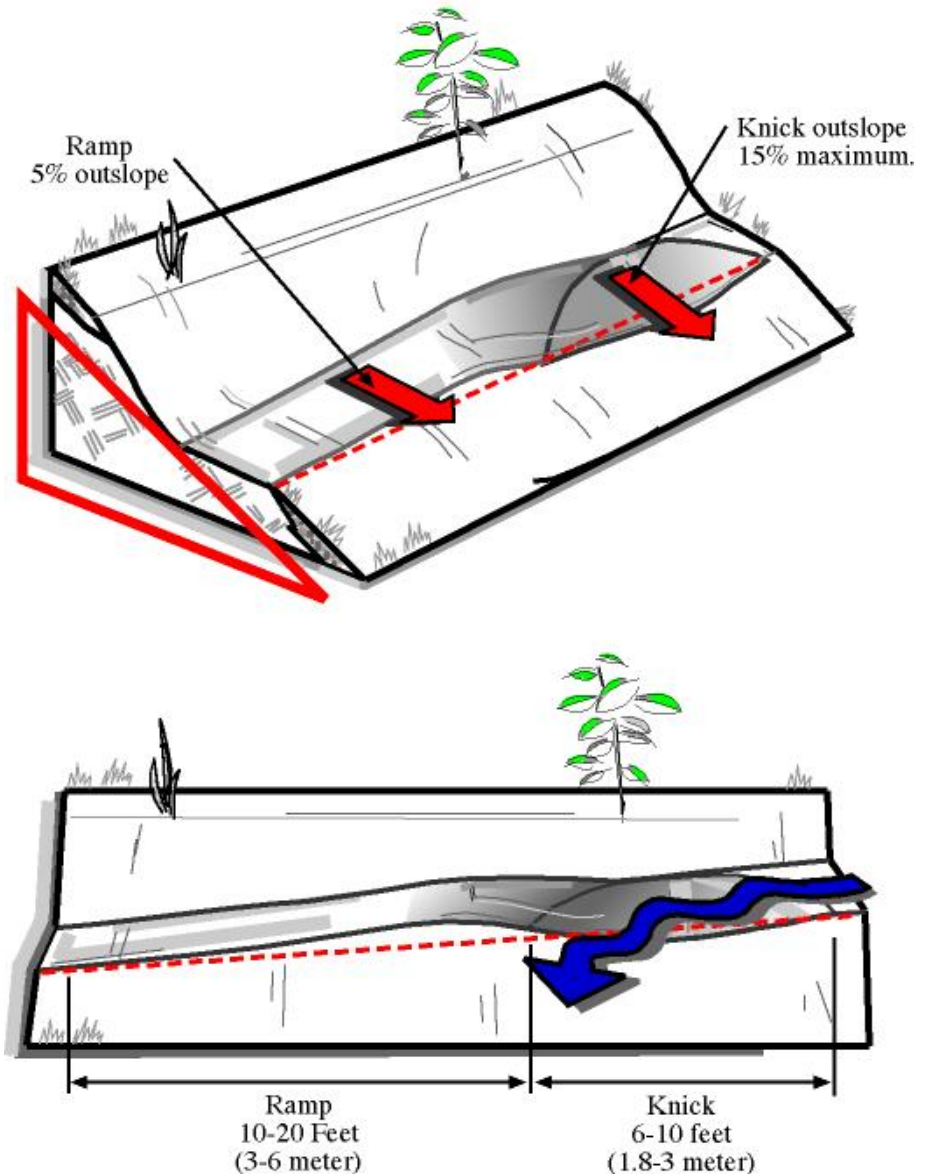
A rolling grade dip is an expansion of a knick drainage structure. It features a similar outsloped depression in the tread, followed by a long, gentle dirt ramp. The dip, or knick, portion should be 6 to 10 feet in length. The excavating material from the dip is used to form the ramp that follows the dip. The ramp should be 10 to 20 feet in length, depending on the steepness of the tread, the steeper the tread the longer the ramp.

Proper placement of a rolling grade dip is crucial. Look for areas that already naturally form the feature and accentuate it. On steep trails, several rolling grade dips will need to be used. Rolling grade dips most likely will not alleviate the issue of erosion on fall-line trails; a reroute is the only fix. Do not place rolling grade dips in turns.

Certain soil types, such as decomposed granite or sand, do not bond well and will not form a ramp. Remove and disperse all excavated material and carve the rolling grade dip out of the tread.

Properly built rolling grade dips require very little maintenance. Seasonally all that is needed is to remove the occasional leaves or silt from the dips.

Rolling Grade Dip



Waterbars: Good Intentions, Bad Results

Waterbars are the most popular and least effective drainage structures used. By installing rock, rubber or wood structures across a trail in the attempt to divert water, they tend to require frequent maintenance, clog easily, heavy water flows tend to flow over the top, they become undermined and users will go around the waterbars causing widening of the tread. Because of the problems

involved with waterbars, grade reversals such as grade dips, knicks or rolling grade dips are recommended to help shed water and prevent erosion (*see page 9*).

Armoring

Preferably, trails do best when built on loamy soils. But not all soils are the same. Soils that tend to drain poorly, pack when wet, or falls apart under traffic would be best handled by a reroute. If a reroute is not an option and the trail is designed and built properly, you may benefit with hardening the trail's tread. There are two ways to armor a trail: you can use natural rock or manmade materials such as soils binders or Geosynthetics (*see page 49*).

Special Conditions: Wet, Flat and Sandy

Whenever possible, trails should **not** be built in flat areas, wetlands, or extremely sandy soils. But, sometimes you may have no other choice: you must work on trails that have been built in such conditions. The following are guidelines for maintaining trails in challenging conditions.

Wet Areas

Trails that cross marshes, swamps or other wet areas, are a challenge to maintain and users will continually leave ruts in the tread and widening the trail when the tread is consistently wet. The following are tips for dealing with wet terrain.

Find the High Spot

Just a few feet in elevation gain can make a big difference between a wet muddy tread and a dry flowing sustainable trail. Find the high points in the surrounding area using a clinometer to find an appropriate reroute.

No High Spot? Build One.

If the area will not allow a reroute to higher ground, use rock to raise the tread above a spring or seasonal wet areas, build a turnpike to cross a wet meadow, or construct a wooden deck over moving or perennial water (*see page 49*). Just keep in mind you do not want to block the natural flow of the water you are crossing.

Flat Areas

Flat areas may seem to be an easy landscape to build trails on. However, trails built on flat terrain are difficult, if not impossible, to drain water from. Often what happens in these areas is the trail's tread becomes the areas drainage. As a result, trail widening, rutting and erosion occurs. In areas where the trail leads to a decent, the water is carried through a narrow stretch in which water accelerates causing massive erosion issues.

In truth, flat terrain is oftentimes the most difficult topography to build sustainable trails on. The following tips will help in these tricky conditions.

Work the Bumps

Small bumps and rises are useful on trails built in flat areas. An elevation gain of a foot or two to build a small bench with an outsloped tread will allow water to shed from the trail. As with all trail building, the goal is to get water off the tread as quickly as possible.

Build Smooth Turns and Build Them High

Proper trail flow is important to the health of all trails, this is even more important in flat terrain. Fast straight sections with tight turns cause riders to hit the brakes and erode the tread. Design trails that have smooth turns that can be navigated at a consistent speed. Chokes can also be used to slow riders before entering a turn.

The location of turns is also important. Turns should not be built in the lowest area where water can collect. Instead and whenever possible, build turns located on the highest spots within the area.

Sandy Areas

Deep sand can be a trail manager's nightmare. Users will avoid the areas by skirting them causing trail widening, while others will churn through them with extra power causing a 10 foot sand section to turn into a 100 foot long sand trap. Sand does not have a binder in which to hold the particles together to form a firm trail bed.

Shallow Grades with Sweeping Turns

Keep the grades below 5 to 7 percent and turns broad and flowing, not tight and twisty.

Make it Sticky

Binders can be added to the sand to help make it stick together. Clay-based soil binders can be used to help hold the soil together (*see page 53*). Organic material gathered nearby by or imported mulch can also help when mixed and compacted into the tread.

Inside Turns Vs. Outside Turns

Inside turns are concave and form a berm in which the rider is held into the turn. An outside turn is convex and more difficult to ride and forces the rider outside and way from the turn. Create inside turns in sandy areas rather than outside turns so that the force of riders pushes sand into the bermed turn rather than off of it. To maintain the turn over time, add organic material to the trail bed to help solidify the tread.

Armoring

As with wet areas, sandy soils can also benefit from armoring. Remember to use large rocks, especially in sandy conditions where it is difficult to hold the rocks in place. Stone pitching can also be useful in these tricky soils.

Rerouting and Reclaiming Damaged Trails

Too often trails are hastily designed and become maintenance nightmares. Sometimes the best solution for a problem trail isn't aggressive maintenance, but simply to a sustainable reroute. Designing and building a trail reroute may seem time-consuming, but having to return every few months to repair a fundamentally flawed trail? Now, that's definitely a waste of time.

You Know its Time to Reroute When the Trail...

- Is consistently wet despite being properly outsloped.
- Is eroded and grades exceed 15 percent.
- Isn't draining properly and is located in marshes, meadows or flatlands.
- Is damaging the surrounding natural resources.
- The trail flow is poorly designed causing user conflicts and or user erosion.
- Contains sections that are bypassed by users because of ruts, mud or damaged conditions.

Ten Tips for Rerouting and Reclaiming a Trail

1. Talk Before Rerouting

Get permission from the land manager to reroute a section of trail. Plant removal or habitat may be of concern. The land manager will be able to help.

2. Educate Trail Users

Most conflicts can be avoided by informing trail users the what, where, when and why a route is being closed. Post signs to let people know what changes are taking place. Ask for public feedback and recruit volunteers for trail workdays. Once completed, post maps showing the reroute and explaining why the old trail was closed. Be positive and focus on the benefits of the reroute.

3. Design a More Enjoyable Trail

A trail that seems to be an eroded nightmare to one person may be another's most favorite challenge. Look for features that make the reroute challenging and more appealing than the one it is replacing. The best way to ensure a closed trail remains closed is to create a more attractive replacement.

4. Design a Smooth Intersection

Create a natural, seamless transition into the new section. Trail users should not be able to notice where the new section begins and ends.

5. Break Up the Old Tread

The old compacted tread should be tilled or ripped so new plants and grasses can take root and grow. This is a key step, tilling should be at least 2 inches deep. A Pulaski, pick mattocks, or rototiller can be used in this important step.

6. Control the Erosion on the Closed Trail

It is essential to stop water from flowing down the old trail so the erosion does not continue and re-vegetation can take place. If the old route was steep, you may need to use check dams to hold sediment and minimize erosion. **Check dams** are typically made of logs, rocks, or straw bales fixed across the trail to trap soil. Be sure the check dams are tall enough to trap the soils and well secured so they won't wash away. If the trail being closed is rocky and hard to dig in the check dams, try using burlap bags filled with local soils for check dams. You can also cut an "X" on the top of the burlap bag and transplant a local shrub.

7. Transplant Vegetation

Starting local plants on the old trail is the best way to restore the landscape. Allowing the soils to remain open, void of vegetation, will introduce invasive plant species. Use plant material taken from your new route and use proper transplanting techniques to reduce plant shock.

8. Disguise the Corridor

A good way to keep people off a closed trail is to make it look like it was never there. Drag branches and logs across the old tread. "Plant" deadfall trees in the ground vertically to block the corridor at eye level. Finally, rake leaves and other organic material over the tread to disguise and encourage new plant growth.

9. Redirect Trail Users

Be sure to adjust signage and maps so that it no longer directs users onto the closed trail. Signs and maps should direct users onto the new trail.

10. Your Last Resort: Block the Corridor

As a last resort you can block the trail on both ends with fencing and signage; this will look out of place and could draw attention to the closure. The signage should explain why the trail has been closed. When the trail has been closed for a while and vegetation has been reclaimed, the fencing and signage can be removed.

Appendix A: Trail Assessment and Repair Sheet

Trail Assessment and Repair Sheet

Site Number:

Location:

Priority:

Crew Leader:

Problem:

Suggested Repair:

Sketch Existing Condition:

Sketch Suggested Repair:

Crew Needed:

Tools Needed: