Chapter Four
Engineering and the Natural Environment

Plan Your Ride, Ride Your Plan

Providing for the riders' needs is one of the key elements for success discussed in Chapter 1. Those needs were examined in Chapter 2 and incorporated into the trail concept plan in Chapter 3. The link between getting those needs on the ground and designing for sustainability is covered in this chapter on engineering.

The Tools for Success

- Provide for the riders' needs
- Design for sustainability
- Develop an effective O&M program

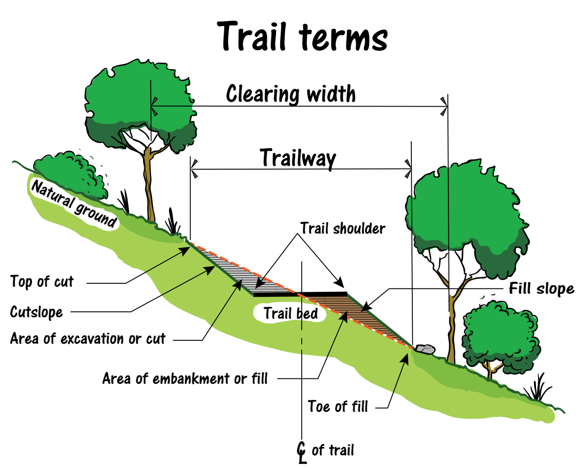
Engineering isn't just circles and squares or tangents and curves; it's understanding the natural environment and applying scientific knowledge to address or solve practical problems in that environment. Engineering is used to solve or mitigate trail issues or concerns. For example, what will happen to a particular soil when the forces of an OHV tire are applied to it? If the soil displaces, how will it be mitigated? The more engineering knowledge and experience that the designers have, the more tools they have to design a fun and sustainable trail under a variety of circumstances and conditions. Having creative vision is one thing, but being able to put that vision on the ground is another. In otrder to put a trail on the ground and keep it there, designers need to understand the physical properties of that piece of ground and the physical forces that will be applied to it.

Vision without Action is a Daydream
Action without Vision is a Nightmare
but Vision and Action without Engineering Ensures Disaster

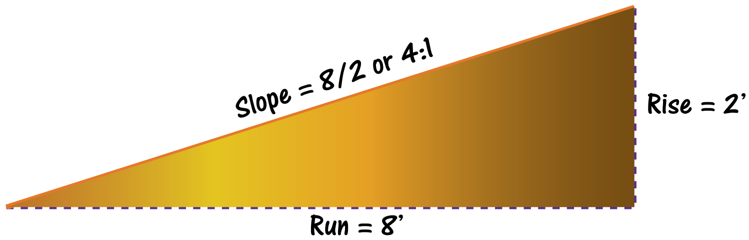
Section 1: Trail and Engineering Terms

Understanding Trail Terms

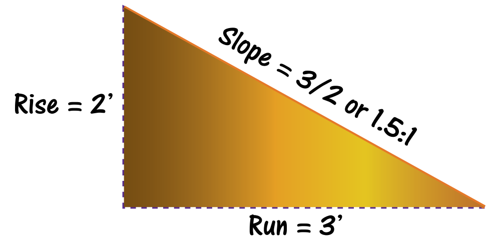
The three trail types are terra firma or land, water, and over-snow. For the purposes of this book, terra firma trails are discussed. The winter use of summer trails and the summer use of winter trails (snowmobile trails used for OHV trails) are discussed later in this book.



Horizontal run is the distance a slope runs along the ground. The vertical rise is the distance the elevation of the slope is increased. The angle of the cut slope and fill slope is normally expressed as a ratio of the horizontal run over the vertical rise. If a run is 1 foot and the rise is 1 foot, the slope is 1/1 or 1:1. If a run is 2 feet and the rise is 1 foot, the slope is 2/1 or 2:1. If a run is 1 foot and the rise is 2 feet, the slope is 1/2 or .5:1.

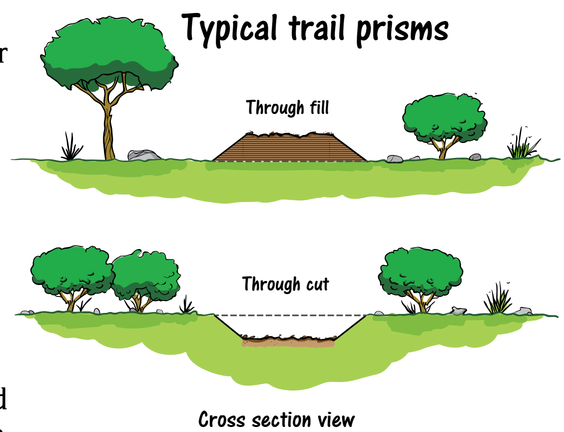


For this example there is 4' of run for every 1' of rise.



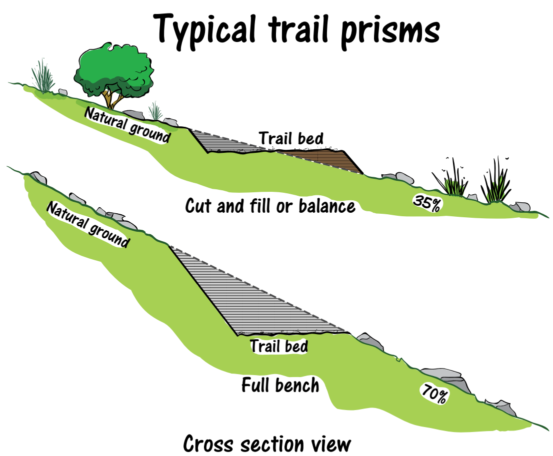
Here, there is 1.5' of run for every 1' of rise.

Backslopes are commonly 1:1 or steeper (.5:1) and fill slopes are commonly 1.5:1 or flatter (3:1). The soil type dictates the slopes that will be most stable for that particular type of soil. (More on that later.)



The trailway is the area from the top of the cut to the toe of the fill. By tracing a line down from the top of the cut to the inside trail shoulder, across the trailbed to the outside shoulder, and down the fill slope to the toe of the fill, a trail prism is created.

On flat ground with a sideslope of 0 to 10%, the entire trail prism is either going to be above the natural ground, called a through fill; or below the natural ground, called a through cut.

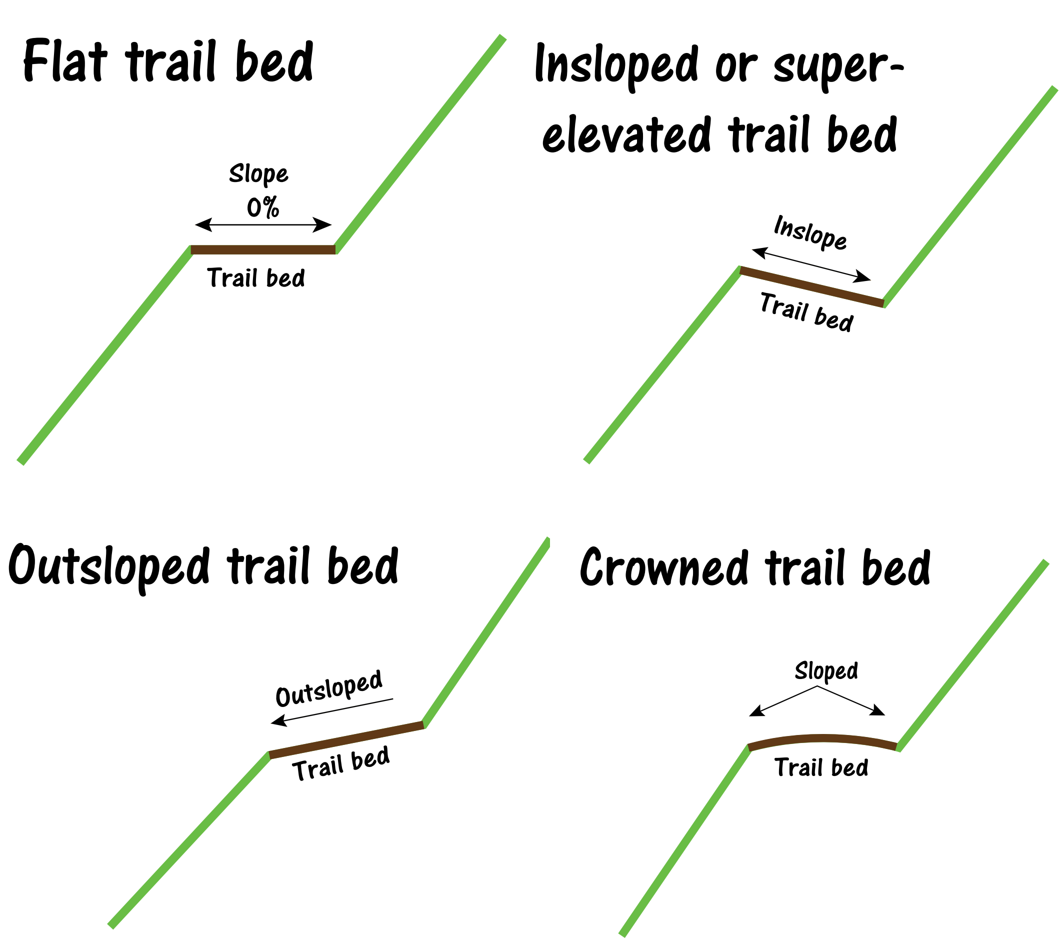


As the slope of the natural ground steepens to around 35%, the trail prism lies on the ground as a cut and fill or balanced section, which means that the amount of material excavated or cut will compact into the amount of embankment or fill needed.

On sideslopes of 70% or steeper, the ground is too steep for a stable fill to be constructed so the entire trail prism is excavated. This is called a full bench section. The material excavated is usually wasted over the side, but with the proper equipment and sufficient funding, it can be hauled back to be utilized for fills elsewhere on the project. This is called end haul and it may be required in sensitive areas that do not allow the wasting of material.

Why is the trail prism important? The prism can be dictated by the slope of the topography, but that isn't always the case. Trail design is all about options and making informed decisions after weighing the advantages and disadvantages of each option. If the trail is in a wet area or in an area subject to heavy rainfall, a through fill prism raises the trailbed above the natural ground so it will stay drier. In the through cut scenario, water will become channeled and collect on the trailbed making it more difficult to drain the water off the trailbed. When fills become saturated with water, they can fail. Whereas trails constructed as full bench prisms will have the least risk of failure. Given the soil, climate, and storm patterns, designers may choose to build an entire trail as a full bench or a through fill prism, or they may choose to use all four prisms and apply rock hardening in areas of through cut or cut and fill. Is one wrong and one right? No. What is important is recognizing the thought process and evaluating options.

The trailbed is normally configured into one of four shapes: flat, insloped, outsloped, and crowned. While flat is the most common for OHV trails, insloped, outsloped, and crowned trailbeds can be used to control and direct the flow of water.



An insloped trailbed sheets the water to the inside so the inside shoulder essentially becomes a ditch unless a ditch is actually constructed as part of the trail prism.

When inslope is constructed on curves, it is generally used to superelevate the curve. This holds riders into the curve and allows riders to carry more speed through the curve, which increases flow and can decrease tread impacts.

An outsloped trail is intended to sheet water evenly off the outside shoulder of the trail.

Continuously outsloped trails are awkward, if not difficult, to ride on an OHV. This is especially true in wet slippery soils and on curves where the outslope acts as a reverse superelevated turn that tends to slide riders off the curve, rather than hold them on it.

A short section of outslope is usually used in grade reversals, grade breaks, or rolling dips to help force the water off the trail.

The crowned trailbed is intended to sheet the water in both directions. Most roads are constructed with a crown, but it is far more difficult to build a crown and maintain it on a narrow, natural surface trail. Crown can work well on wider trails that are hardened to hold their shape.

For any prism other than flat, the key to have it effectively sheet water is regular maintenance. If the team doesn't have the budget, personnel, skillset, or equipment to routinely perform this maintenance, do not rely on a shaped trail prism for water control.

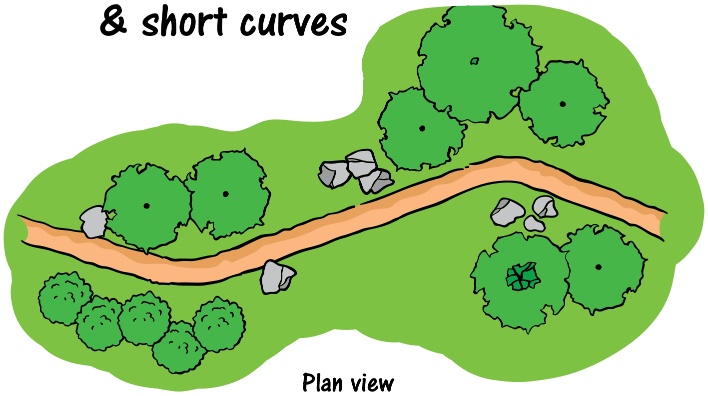
Design and Management Implications of the Trail Prism

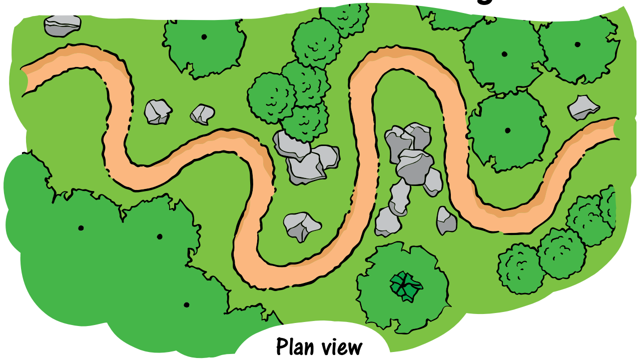
The configuration of the trail prism can affect the stability of the trail.

- A full bench prism will always be more stable than a cut and fill prism.
- Mechanical compaction during construction will improve the stability of the trail and the durability of the trail tread.
- The shape of the trailbed can affect water flow, trail flow, trail difficulty, rider experience, and rider safety.
- An outsloped trailbed should not be used in fine-grained soils that become slippery when wet.
- Any trail prism other than flat will require increased maintenance to keep the shape functional. Relying on maintenance and the shape of the trail prism to control the flow of water can be a trap.

Understanding Engineering Terms

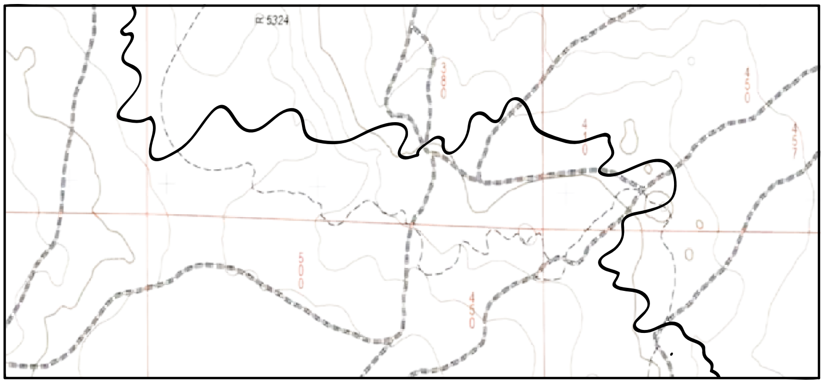
Engineers see the world in a three-dimensional view that allows them to take any point along a trail and view it on paper or on the computer in 3-D. The three views are the plan view, the profile view, and the cross-section view. The plan view is from the top looking down on the horizontal alignment of the trail. The horizontal alignment is comprised of a series of tangents (straight lines) and curves (arcs). The shorter the tangents, the more serpentine or curvilinear the trail becomes. A curvilinear trail provides more flow, and a linear or straight trail provides less horizontal flow. While the linear trail appears to be fast and boring, it does have its place in the realm of OHV trail design.





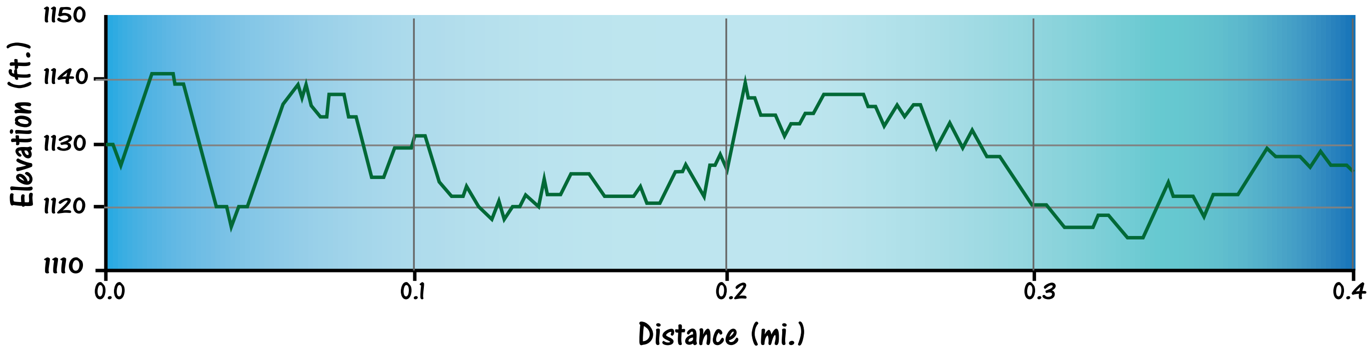
The plan view shows the trail route. What it does not show is the smoothness of the trail surface: smooth equals fast, rough equals slow. The plan view also does not show the character of the vertical alignment. For that, the profile view is needed.

The profile view is from the side. It shows the vertical alignment of the trail. The vertical alignment is also a series of tangents and curves that represent the elevation or grade changes from one point to another along the trail. Horizontally, a trail should constantly move from side to side, and vertically, the trail should constantly move up and down. Both of these are essential for sustainability and quality rider experiences.



This is the plan view or aerial view of a trail segment

Trail grade is one of the most critical elements and often the most abused element in OHV trail design. As grade increases, so can rider experience, but water velocity also increases, which potentially decreases trail tread stability and sustainability. This is a major dilemma in design: how to create a fun trail without excessive grades. (More on this later.)



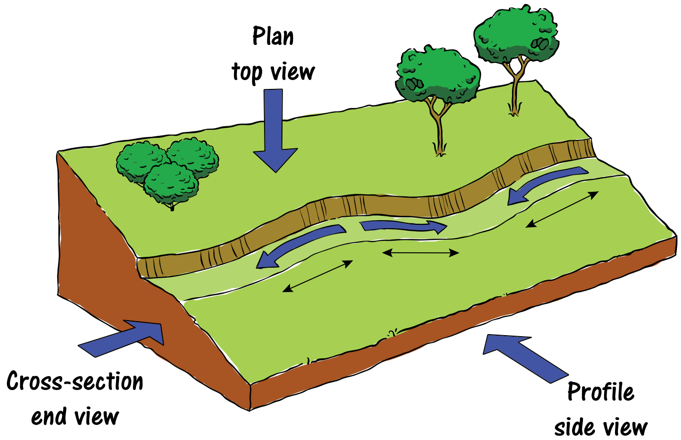
Above is the profile view of the same trail segment shown in the plan view. A rolling grade has recurring grade reversals, which means that the grade goes up and then it goes down. Grade reversals are 100% effective at stopping water flow down the trail. The shorter the interval between grade reversals, the less water volume, velocity, and potential erosion and sedimentation.

The third engineering view is the cross-section view, which is a cutaway view of the trail's transect, slicing into the ground and then viewing it from the end.

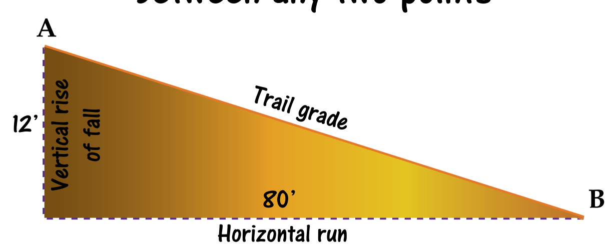
The schematic below summarizes the three views. Note the frequent grade reversals.

Tangents and curves comprise the horizontal alignment of the trail. Any two points make a line or tangent and any three points can make an arc or curve.

3D view of ground



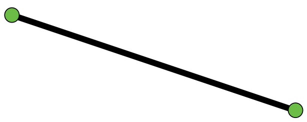
How to calculate trail grade between any two points



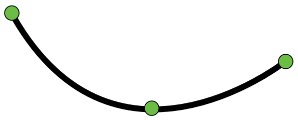
Rise / Run x 100 = Grade

12/80= 0.15 x 100 = 15%

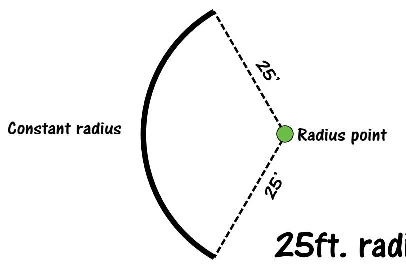
Any two points make a line or tangent



Any three points make an arc or curve



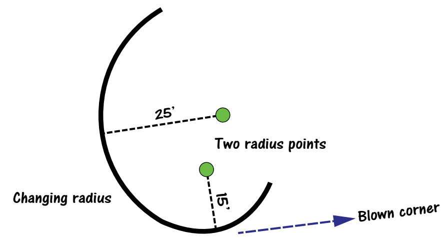
Circular curves are measured in degrees or in radius. This is a simple curve



25ft. radius curve

There are two types of curves: circular and non-circular. Circular curves have a constant radius as in a circle, and non-circular curves have no radius as in a spiral or parabolic shape. Circular curves have three main configurations: simple, compound, and broken back. Simple curves have a constant radius and are easy to ride in either direction. The smaller the radius, the sharper the curve.

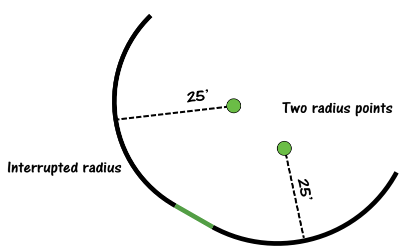
Compound curves are two simple curves of different radii connected together



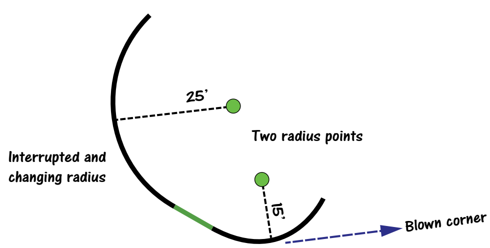
Compound curves start with one radius and end with another. In this example to the right, the curve is rideable in a clockwise direction, but not easily rideable in a counterclockwise direction. Why? Riders will adjust their speed accordingly to negotiate the larger radius curve, but as the curve tightens, they will be carrying too much speed, which often results in blown corners. Riders cannot easily stay on the trail unless they brake suddenly to lose speed. This results in skidding and excessive tread displacement. From an experience standpoint, compound curves increase difficulty when riding in the direction of decreasing radius.

Broken back curves are two simple curves connected in the middle by a short tangent. If both curves have the same radius, they can be rideable from either direction.

Broken back curves are two simple curves connected together by a short tangent

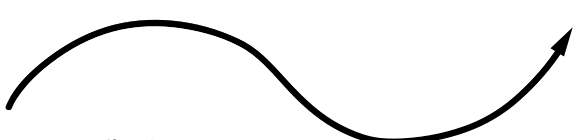


Broken back curve with curves of different radii



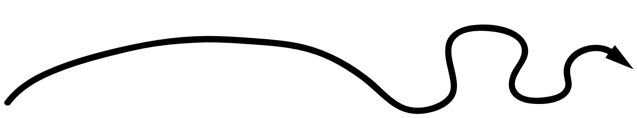
If the two curves have a different radius, then they are similar to the compound curve. In this example, it will be rideable in a clockwise direction, and not easily rideable in a counterclockwise direction, which again can result in tread impacts and blown corners. Like a compound curve, a broken back curve with tightening radius increases difficulty in that direction.

It is human nature to accelerate as the sight line increases. As the length of a tangent increases, the speed increases accordingly. Having a chance to increase speed improves the rider experience by adding variety, but it also decreases seat time. Designers and managers need to recognize that most riders will ride a trail as fast as they can within their skill level. This is part of the desired challenge of providing for the riders' needs. Most riders challenge themselves. This means that speed and any resulting impacts are always factors on any trail.



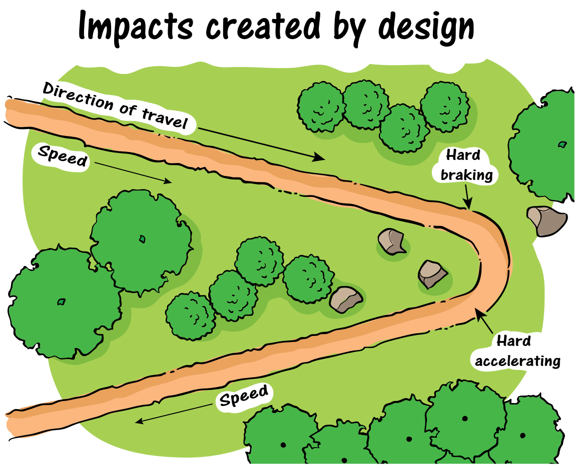
Open and flowing

Tight and technical



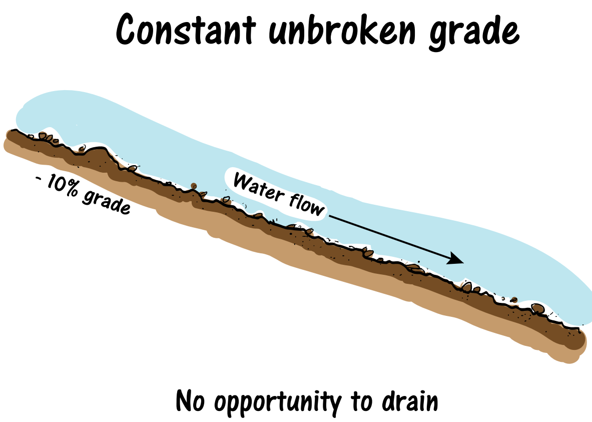
Poor flow - abrupt transitions from one type of flow to another

Whether a trail is linear or curvilinear, the tangent lengths, curve radii, and the sequencing of those tangents and curves can affect the trail flow, difficulty level, rider experience, and potential tread impacts.



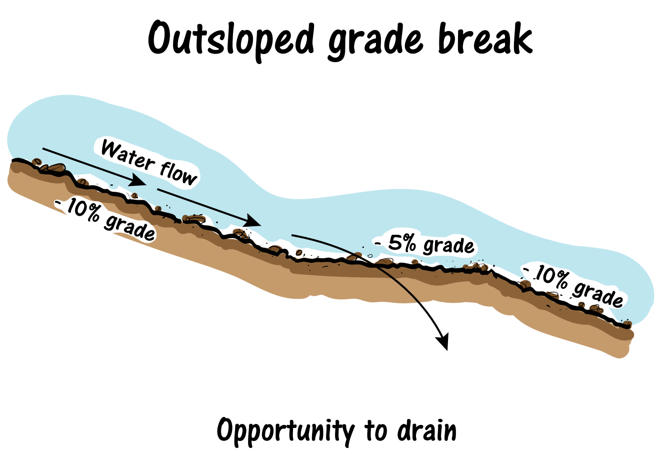
Speed increases with the length of the tangent, but what happens when the tangent ends in a curve? If there is a long tangent and then a short-radius curve (poor flow), riders will have to brake hard to negotiate the curve. Coming out of the curve, the riders eye the next tangent and start rolling on the throttle. These two actions result in increased forces being applied to the trail tread creating potentially severe tread impacts called brake chop and acceleration dishing. These two impacts can be reduced by: a) shortening the tangents, b) increasing the radius of the connecting curve so it can be negotiated at a greater speed, c) superelevating the curve so riders can carry more speed through the turn, or d) a combination of the above.

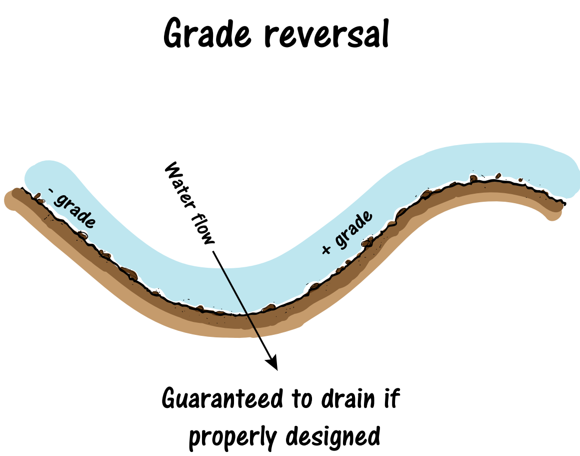
Tangents and curves play a similar role in the vertical alignment of the trail. A long tangent in this case means a long grade up or down, which again can result in an increase in rider speed. It also means that any water on the trail is going to increase in volume and velocity, which will increase erosion. Both of these actions can create significant tread impacts. Short or no tangents between curves increases the rider flow in the horizontal alignment. It also increases rider flow in the vertical alignment and decreases water flow.



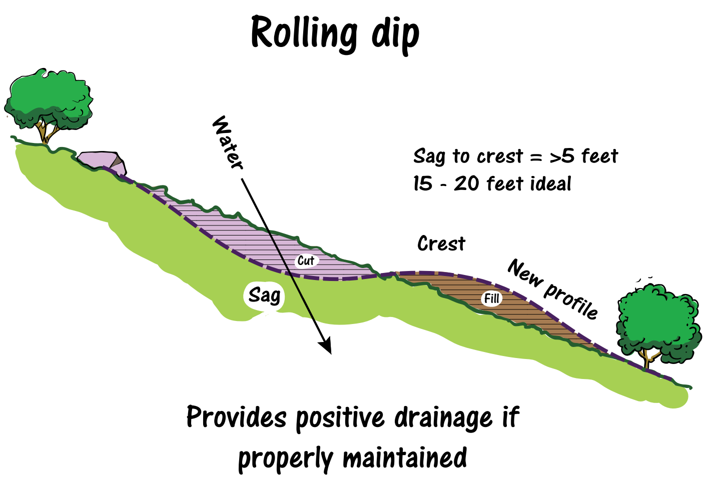
Water collects on the trail and then starts flowing down grade. The longer it flows or runs, the more velocity it gains and the harder it becomes to turn the water so it will drain off the trail. On a constant or unbroken grade, it is very difficult to effectively get water to drain off the trail. Four main profile shapes are utilized to get water off the trail: grade break, grade reversal, rolling dip, and waterbar.

A grade break is a place where the prevailing grade flattens off for a while without changing from negative to positive. As soon as water hits the flatter section of grade, its velocity reduces significantly and it will start to drop its load of sediment. If the trailbed is outsloped here, there is a good opportunity to turn the water and drain it off the trail. The flatter and longer the grade break, the more effectively it will drain.



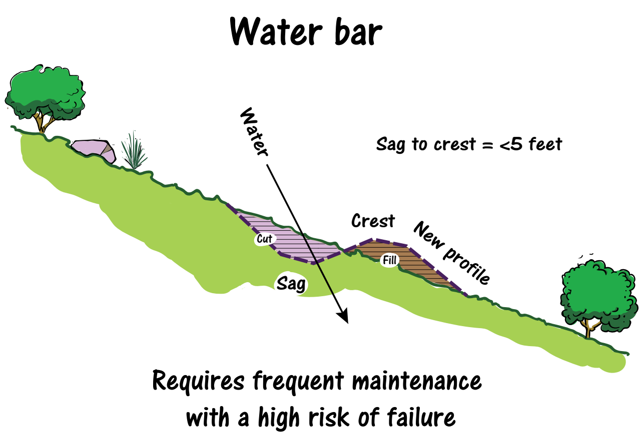


As discussed with the profile view, rolling the grade by changing from negative to positive is 100% effective in stopping water flow down the trail. This is called a grade reversal and it is flagged into the trail location on new trails or the relocation of existing trails; therefore, it is a natural feature and not a manmade structure. The longer the grade reversal and the greater the elevation difference from the bottom to the crest where the grade rolls down again, the more rideable and effective it will be. Ideally, the grade is reversed for 50 feet or more, but the minimum is three times the design vehicle length unless terrain features are incorporated. There should always be a minimum of two feet of elevation difference or gain, otherwise the forces of tires, rutting, and erosion may cause them to fail. If properly designed, a grade reversal will not fail to function due to weather, amount of use, or lack of maintenance (though ponding may occur). Because of this, a grade reversal is always the preferred method to provide drainage.



A rolling dip is usually installed on a long section of constant grade to provide drainage where there was previously none. Many refer to these as grade reversals and technically they are, but they are a manmade structure, not a natural terrain structure like the grade reversal. Rolling dips are often installed as a maintenance or reconstruction action on roads, road to trail conversions, and user-created trails. They do work, but they require regular maintenance to stay effective. The longer the distance from the sag to the crest of the dip, the more rideable and more effective the dip will be. About 15 to 20 feet is ideal. The shorter the distance, the more the dip functions like a waterbar. On steeper grades, a rolling dip acts like a ski jump. In doing so, forces are applied to the crest, which will increase the need and frequency for maintenance. Also on steeper existing grades, the over-steepened slopes going into the sag and out of the crest may exceed the maximum grade for durability for a given soil type.

Waterbars, the last category, are also used on existing trails but are not effective on OHV trails. They are short rolling dips with only 2 to 5 feet from the sag to the crest. These create an abrupt hump in the trail and the force of the tires against this hump will cause rapid deterioration and failure of the structure. On ATVs, ROVs, and 4WDs, waterbars are uncomfortable to negotiate and typically there is hard braking going into them and acceleration coming out of them, which results in lack of flow and further tread impacts. Waterbars require the most maintenance and are the least effective method to drain water off the trail. Rolling dips roll and flow, waterbars don't.



Design Implications of Horizontal and Vertical Alignments

- The configuration of horizontal and vertical alignments affect rider experience, rider speed, and rider flow, and have some effect on the velocity and volume of water.
- Trail flow is a constant series of serpentine horizontal and vertical curves. Flow does not necessarily equal speed.
- Less flow potentially has more tread impacts. High flow equals a high fun factor.
- Water creates issues and it only flows downhill. A grade reversal blocks that downhill flow and if provided regularly, reduces the velocity and volume of water.

Guidelines and Rules

It is human nature to want hard numbers: what is right and what is wrong? Many people will ask, "How steep is too steep?" As is often the case, the answer is, "It depends." The next question people ask is, "Then what is a range or a guideline?" This is a trap not only because of site variables but also because guidelines tend to become rules.

One such rule is that all trails should be outsloped at 5%. In principle, there is nothing wrong with outslope. Every opportunity to get water off the trail is a benefit. The tread shape, however, will change over time from the shape it had right after construction through the forces of compaction, displacement, and erosion. Unless the tread is regularly maintained or is hardened to maintain its shape, the outslope will likely fail, especially with OHV trails. It's a trap for designers to assume that outslope will work. On curves, outsloped trails can be awkward to ride in a motorized vehicle. On tangents, riders will tend to hug the upslope edge and potentially widen out the trail. In areas with slippery soils and steeper terrain, an outsloped trail can increase the difficulty level by increasing the exposure or risk of the vehicles and riders sliding off the trail.

Another rule is called the half rule. It states that a trail grade should not exceed 50% of the grade of the sideslope, so on a sideslope of 30%, the trail grade shouldn't exceed 15%. The theory is that if the tread is outsloped, overland water will sheet across the trail if the grade is less than 50% of the sideslope, but will be intercepted by and run down the tread if the grade is more than 50% of the sideslope. This is a trap. On motorized trails, the outslope will likely fail; the tread will become a trench; and water will be intercepted by and run down the trail. While flatter grades are a definite benefit, designers of a motorized trail should always assume that any water intercepted by the trail will run down the trail. The key point for the designers is to recognize that the steeper the grade, the more velocity the water will have, so the length of the grade needs to be shorter to reduce the potential for scouring and sedimentation.

One final rule is called the 10% average grade rule. While increasing grade increases the risk of erosion, designers also need to recognize that increasing grade enhances rider experience. The problem with this rule is that most people don't understand what it means or how to apply it. This so-called 10% Rule often gets misinterpreted to mean that the maximum grade for a trail should not exceed 10%. This is not correct. It means that the average grade on a given section of trail should not exceed 10%. In the example above, there are plus and minus grades with some up to 29%, but the average grade from Point A to Point B is 8.2% over a distance of 1.5 miles. (6875 – 6225 = 650' rise, 1.5 X 5280 = 7920' run).

What if the grade was a straight line from one end to the other? The grade would still be 8.2%, but would it be sustainable? No. So the length of the trail segment has a significant bearing on the outcome of the average grade. What length should be chosen? There are too many variables for this rule to be useful. Instead of rules, field personnel need to understand the physical forces that will be applied to the trail and make informed choices.

Section 2: Physical Forces Affecting the Trail

Things that make OHV trails unique from a design and sustainability standpoint are the vehicles themselves which have a motor, weigh more than most other trail modalities, and have torque of a wheel under power. These all create forces that are applied to the ground. Designing for sustainability requires understanding how the forces of compaction, displacement, and erosion impact the trail.

Compaction, Displacement, Erosion

Compaction is the downward force of the vehicle onto the ground. The amount of this force is influenced by the weight of the vehicle, occupants and gear, the number of tires, and the size and inflation pressure of the tires. Compaction is measured as pounds per square inch (PSI). As the contact area of the ground increases, the PSI of contact decreases. A 500-pound vehicle with four tires has more contact area, thus less PSI, than the same vehicle with two tires. In snow, sand, and mud, riders typically decrease the air pressure in their tires. This gives them more grip because their tires have more contact area.

Displacement is the physical movement of the trailbed surface particles as a result of the ground contact and torque of the vehicle. The softer and less cohesive the trailbed surface is, the higher the potential for displacement. Displacement is a force caused from human and animal interaction with nature, such as from tires, horse or other animals, a person walking, etc. A tire with high air pressure will generally cause more displacement than the same tire with lower pressure.

Erosion is the movement of the tread surface particcles due to natural causes like water and wind. Again, the softer and less cohesive the trailbed surface is, the higher the potential for erosion. If displacement has also occurred, the potential for erosion increases since soil particles have already been loosened and ruts have been created to channel the water and thus increase its velocity and potential for scour.

A basic theorem of physics 101 is that for every action, there is an equal and opposite reaction. If the OHV applies 100 PSI of downward force to the tread surface, the tread surface will react with 100 PSI of upward force. The amount of upward force will always equal the amount of downward force. If the trailbed surface is inflexible, as in solid rock or pavement, the physical forces are depicted by the diagram below. The downward and upward forces represented by the size of the arrows are equal and directly opposite.

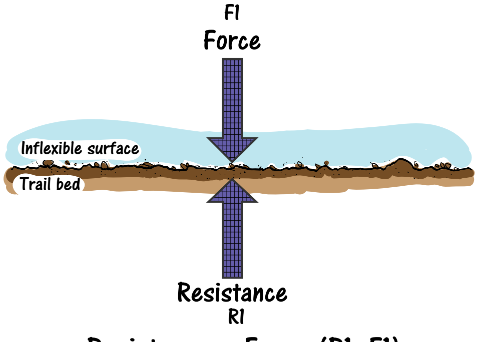
A Provoking Thought...

For every action, there is a reaction

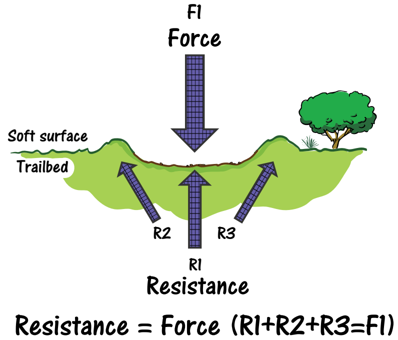
You cannot touch something without it touching you

You cannot touch someone without being touched

As the hardness of the trailbed decreases, the tread surface cannot support the downward force so the tread deflects and the upward forces are sent in different directions. Here, the downward and upward forces represented by the sizes of the arrows are equal but indirectly opposite. This is how ruts and berms are created in the trailbed. The softer the tread surface, the deeper the rut and the higher the berm. This action is mitigated in one of four ways: a) harden the tread surface so the forces become more equal and directly opposite; b) decrease the amount of force applied by having more tires or more ground contact area, which equates to less PSI; c) decrease tire pressure; or d) a combination of any or all of the above.



Resistance = Force (R1=F1)

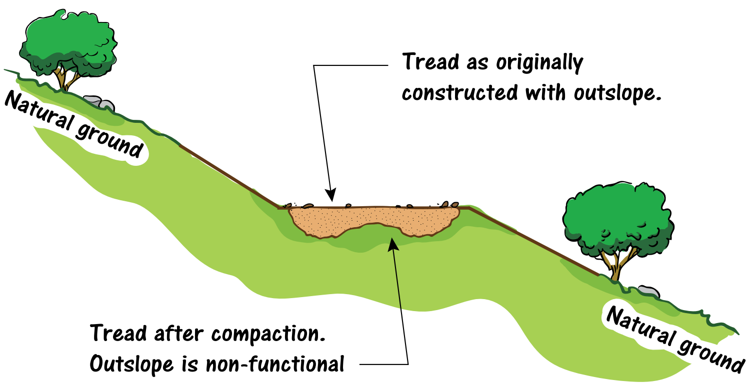


Resistance = Force (R1+R2+R3=F1)

The Interaction of Compaction and Displacement

When OHV tires are put on a newly constructed trail, compaction will start almost immediately and will cause the trail tread to compress. Naturally, the compaction will occur the most wherever the tires have had the most passes over any one place on the surface. For a single-track OHM trail, the compaction will be mostly in the center of the trail, but on an ATV, ROV, and 4WD trail, the compaction will create two ruts on either side of the center. Over time, the entire compacted tread will be lower than the untrafficked tread and potentially lower than the surrounding ground.

The effects of compaction



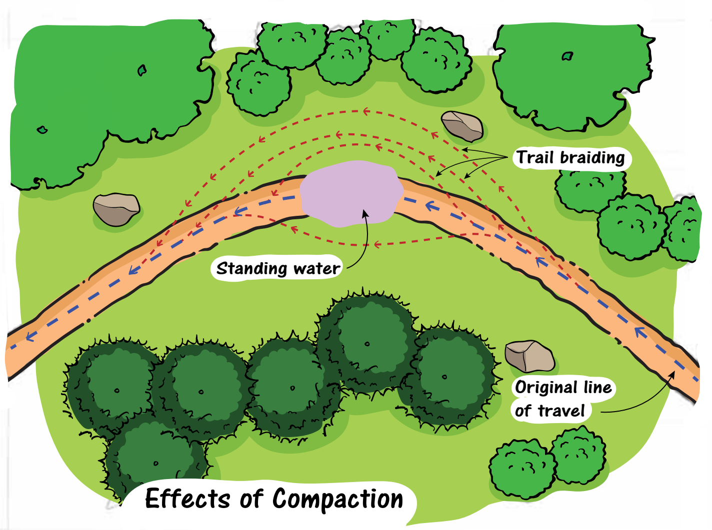
Why is this important to know? If the tread was constructed with outslope, water will no longer come down the slope and sheet across the trail as originally designed. The water will now be trapped in the ruts of the trail and will either collect on the trail or run down the trail.

As compaction occurs, the soil particles in the tread become packed together tighter as voids become filled with finer material. This makes the tread surface less porous, so now water is less likely to be absorbed into the tread. Instead, water will either pond on the surface or accumulate and run down the trail. There will be more water since it is not soaking in. As the grade increases, the velocity of the water will increase, which will increase the likelihood of scour or erosion.

The designers must recognize that these actions will occur and plan to force the water off at regular intervals through knicks, rolling dips, or best of all, grade reversals.

On flat ground, the compaction will cause water to pond up in low areas. If the trail is not confined by vegetation or topography, riders will tend to go around these ponds thus widening out the trail tread or make alternative routes that results in trail braiding.

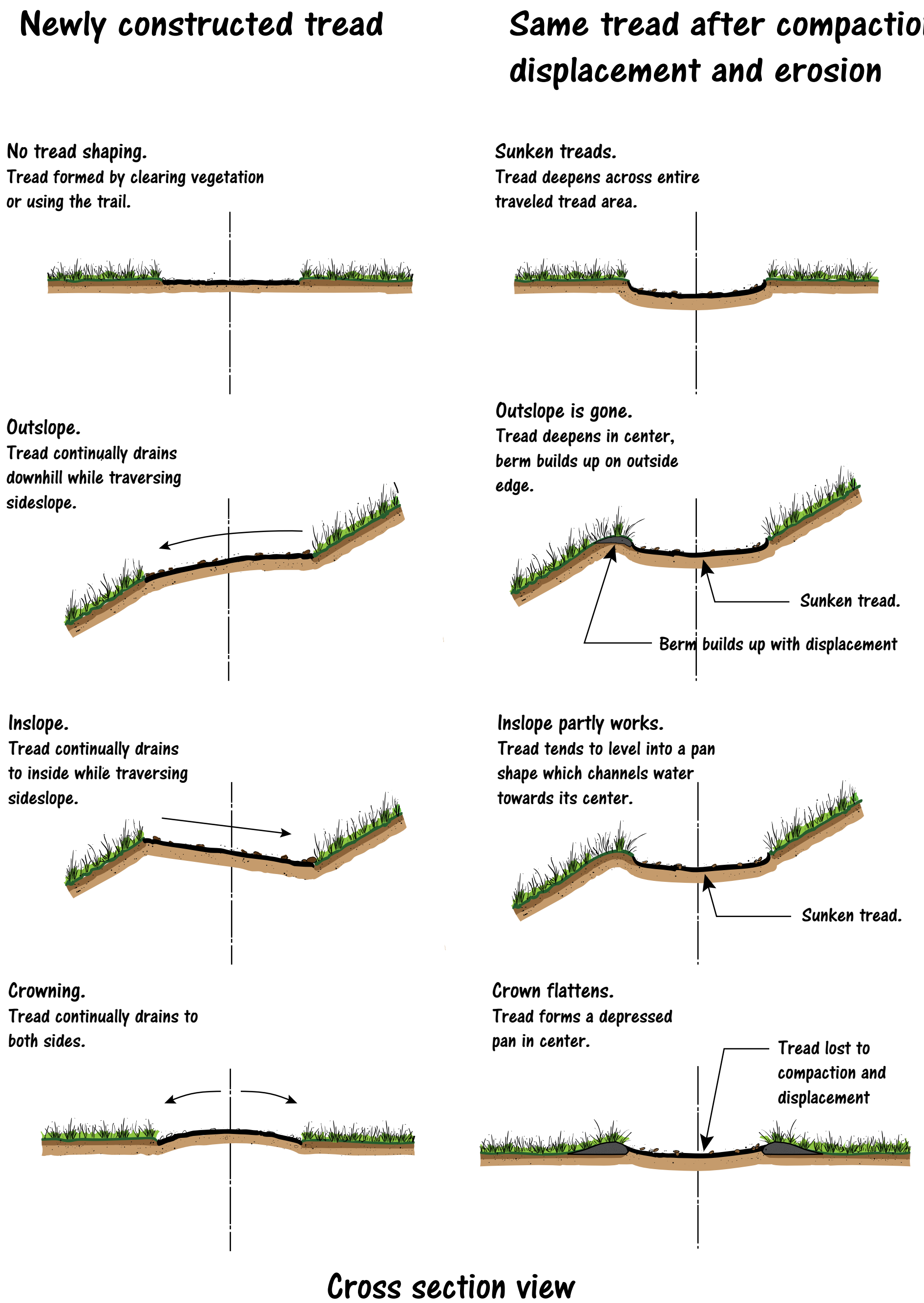
Once all of the voids are filled and the tread is consolidated, compaction will cease unless the vehicle types change. This may happen naturally, as when a new type of allowed vehicle begins to ride the trail. This can also be caused when the land managers open existing trails to new types of vehicles. If the managers allow ROVs on trails that previously only allowed ATVs, the forces on the trail will change because of the difference in vehicle weight and size. It is important that the managers recognize and plan for the potential impacts prior to changing vehicle trail designations.



Effects of Compaction

The trailbed is constructed using one of four shapes: flat, crowned, insloped, or outsloped. The important point to remember here is that unless conditions are ideal, which rarely happens, all of these shapes will change over time with vehicle use and become rutted, entrenched, or concave. After compaction has occurred, the trail could be restored to its original shape through maintenance if the funding and equipment with skilled operators are available to do so. If this is not done correctly, the tread material can easily become unconsolidated and the compaction, displacement, and erosion process will start all over again.

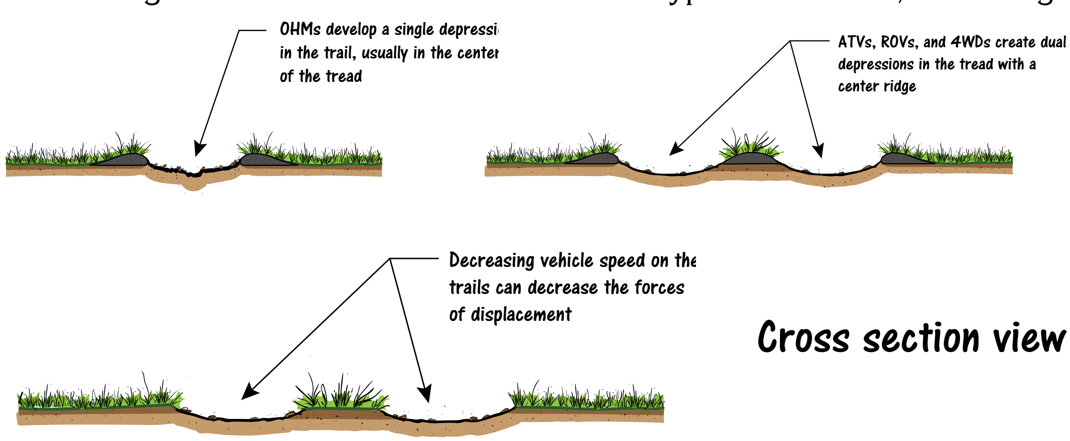
The forces of vehicle compaction can be reduced and the integrity of the trailbed shape can be significantly improved if the trailbed is compacted during construction with a roller or other equipment. This can be labor-intensive and expensive. For the roller to have full ground contact, often rocks and roots are removed. The down side of this is that the trail no longer looks and feels natural and some riders object to that. The character has changed and so has the trail experience, but the tread is far more durable.



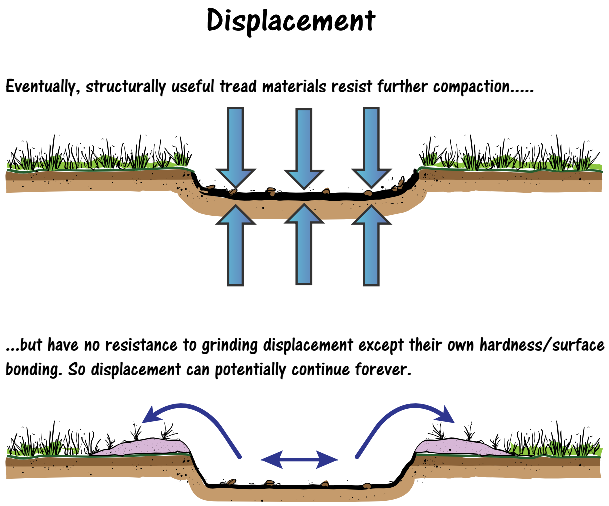
The crowned trailbed is more difficult and expensive to construct, but given good, non-saturated soils, once the forces of compaction, displacement, and erosion are applied, it is the only shape that is still close to the original ground line, rather than a trench below the ground line. This can be a benefit since it will make it easier to drain water off the trail and help keep the trail tread from becoming saturated.

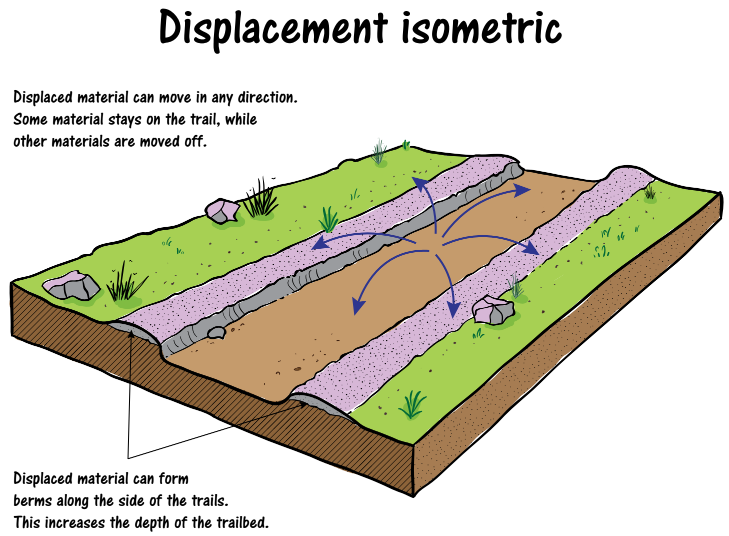
While compaction slows down and can even cease, displacement does not. The force and torque of tires creates constant displacement of the tread surface. In addition, the forces of braking and accelerating and the centrifugal forces try to slide the vehicle to the outside of curves. All of these create progressive grinding of surface particles and displacement of the tread surface. Embedded rocks can get dislodged and solid rock can get ground away over time. Faster speeds and steeper grades will exponentially increase these forces and their effects.

Since compaction consolidates the tread particles, compaction makes the tread less susceptible to displacement and erosion, but it never stops these other forces. Trails will change over time and designers need to recognize that. In some scenarios of soil type and climate, the change has no effect on the functionality of the trail or can sometimes improve it, but in other scenarios, that change can lead to drainage issues and the loss of the trail's integrity.



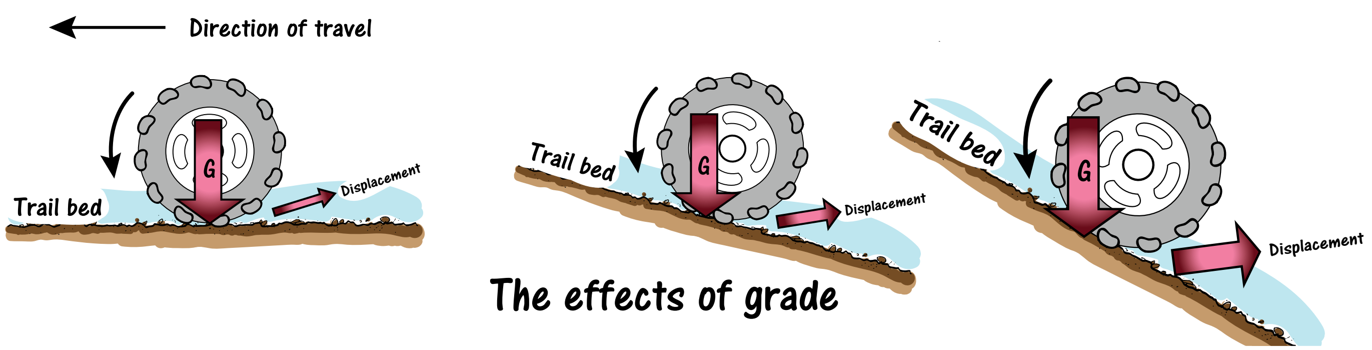
Hardening is a tool that can be utilized where needed in that latter scenario, but as with mechanical compaction, hardening changes the character and feel of a natural surface trail. Instead of riding on dirt and natural terrain features, the riders are now on gravel or some other unnatural surface, which is like riding on a miniature road. While it provides variety, it is not the experience that most trail riders are seeking. What is the effect of displacement on a grade? The gravitational force (G) is always a vertical force. When the trail is flat, the gravitational force is close to perpendicular to the trailbed. The torque of the tire still creates some displacement.





As the grade increases, the gravitational force is no longer perpendicular, but is being applied at an angle to the trailbed. This angle, combined with the torque of the rotating tire, disrupts trail tread. More particles and rocks are dislodged and displacement increases.

As the grade increases more, the angle between the G force and the trailbed decreases, which makes the G force a more effective tool to dislodge tread particles. This increases displacement even more.



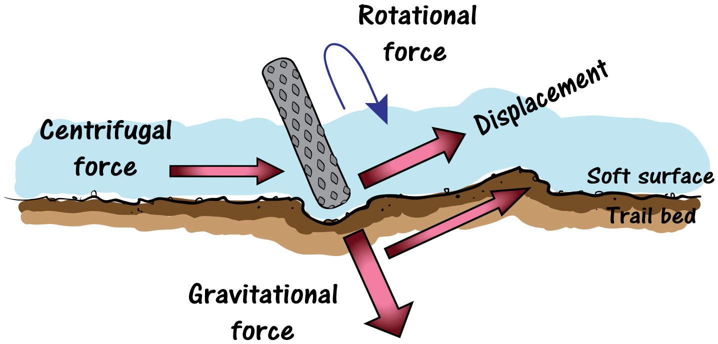
What is the effect of displacement on a curve? Just like on a grade, the angle of the force being exerted combined with the sideways centrifugal force dislodges tread particles. These particles are always thrown to the outside of the curve where they accumulate and eventually form a superelevated curve. The faster the vehicle speed and the softer the trail tread, the more rapidly the superelevation forms. If not confined by vegetation, the trail will continue to widen out until the superelevation is fully formed. Depending on the soil type, speed, and amount of use, this could take a few months or a few years to occur.

Some riders do not like superelevated corners because they don't appear natural and riders feel like they're on a motocross track instead of in the woods. Even in dry climates, superelevated turns can entrap water causing ponding and even soil saturation after heavy rain events. However, one advantage of superelevation is that riders can carry their speed through the turn without braking going into it and accelerating coming out of it. This creates flow and a very high fun factor.

What else does it do? By having a superelevated turn, designers can eliminate or certainly reduce two of the three forces that accelerate displacement: braking and accelerating. Since the angle of the superelevated turn is now closer to perpendicular with the tire, the amount of centrifugal force is also greatly reduced as is the amount of displacement. This reduces tread impacts and reduces maintenance needs and costs.

If the trail was originally constructed with superelevated corners, there is less widening of the trail over time and compactive forces can start much earlier. A superelevated corner increases tread stability and reduces the loss of tread material because the banked tread contains the displaced soil particles and they roll back down into the tread.

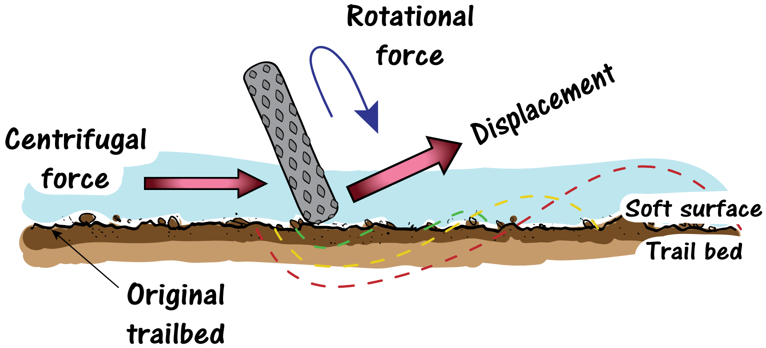
Forces exerted by a motorcycle on a flat curve



Tip, Trick or Trap?

Tip: Superelevated curves equal superelevated rider experience

The development of superelevation

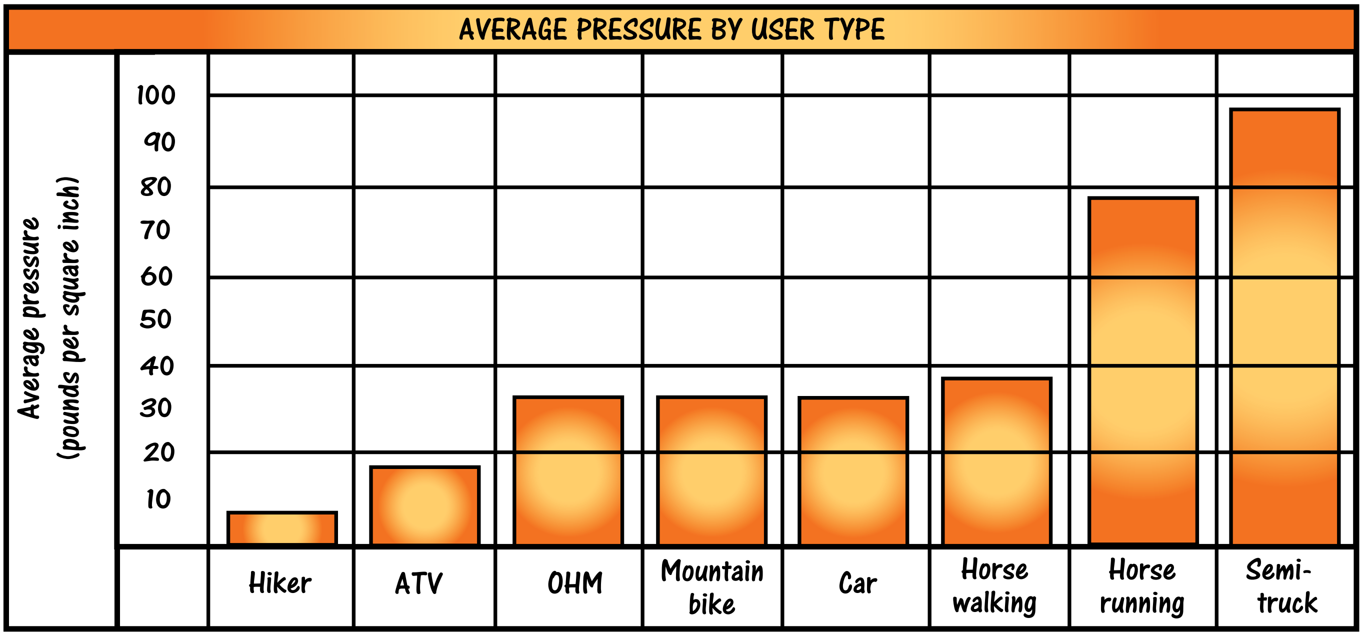


Superelevated curves can reduce the effects of displacement. On a curve like this, any soil particles that are displaced will roll back down into the tread.

A series of back-to-back superelevated curves is like riding a roller coaster with a super high fun factor that produces smiles and adrenaline.

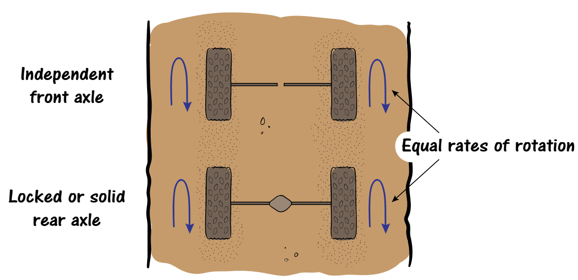
Special Considerations for Four-Wheeled Vehicles

There are some special considerations when the OHV has four instead of two wheels. One obvious difference is that now there can be at least two drive tires next to each other (two-wheel drive OHMs have a single drive tire forward and rear) delivering rotational forces and potential displacement forces to the ground. Depending on tire size, inflation pressures, actual vehicle size, and weight and loading, those forces may or may not exceed those exerted by a motorcycle. The real difference, though, comes into play on curves.

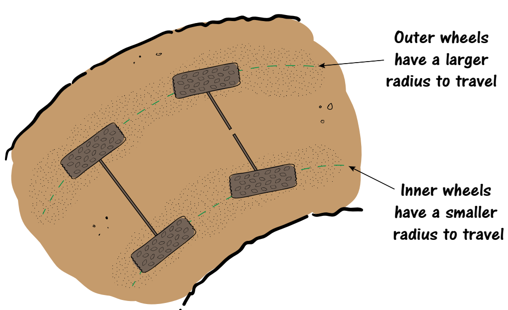


When a four-wheeled vehicle is on a curve, the outside tires are on a larger radius than the inside tires. That means that the outside tires have to travel farther and faster to stay in line with the inside tires. If the tires roll independently like those on the front axle of a rear-wheel drive vehicle, the outside tire will roll more and the inside tire will roll less to get around a curve. The drive tires behave differently. If the drive axle is solid or if the differential is locked, the two tires turn at the same speed and cannot roll independently. This means that as the outside tire is traveling farther to get around the curve, the inside tire is going at the same rate, but has a shorter distance to travel, which causes wheel hop and tire spin on that inside tire. Depending on the trail surface, these forces can cause severe displacement. Non-cohesive soils, loose rocks, or pavers and other materials used for trail hardening can be churned up, broken, or moved. These forces must be considered while designing the trail.

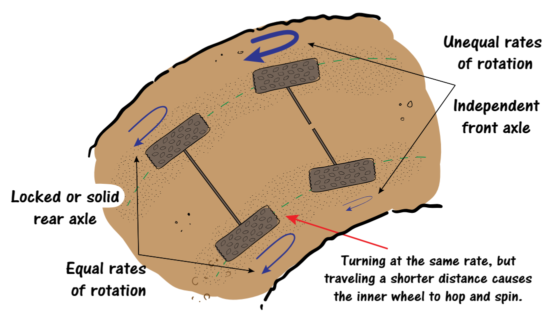
Four-wheeled vehicle on a tangent



Four-wheeled vehicle on a curve



Four-wheeled vehicle on a curve



Increasing the vehicle width increases the effect because of the larger difference in radius between the inner and outer wheels. Increasing the grade increases the effect because of the additional torque being applied to the tires. Increasing the curve radius decreases the effect because the outside tire has to turn less to keep up with the inside tire. Other than rotational forces, there is no churning effect on tangents because both tires travel the same distance at the same speed. The effects will be most noticeable on a climbing turn since it involves grade and a turn.

Erosion

The third force is erosion, which is the movement or removal of the tread surface particles due to natural causes like wind and water. Poor trail design and lack of effective drainage can accelerate erosion. Soil particles displaced by vehicle tires are more susceptible to erosion. Vehicle operation during periods when the soils are most susceptible to displacement, such as very dry or very wet (saturated), can create ruts that channel water and increases its velocity and scouring action.

Erosion is generally viewed as being bad, but it is a natural, ongoing, and eternal process. The Grand Canyon is viewed as spectacularly beautiful, but it is a product of eons of erosion.

Tip, Trick or Trap?

Tip: It is better to understand nature and work with it, rather than against it. We cannot control nature.

Here are some key points on erosion:

- Erosion is a natural process that is caused by weather patterns or weather events, whether they are major or minor events.
- Major rain events and catastrophic storms like tornadoes and hurricanes will happen and they will result in erosion.
- Given the right conditions, even normal weather patterns can and do cause erosion.
- Steep ground is not needed in order for erosion to occur. The potential for erosion is everywhere and it is non-selective.
- Erosion is cumulative. Even minor soil movement from a single storm can add up to significant soil loss over several years of storms.
- While erosion cannot be stopped, designers and managers can take measures to minimize it through good design and trail management.
- The trailbed is a precious resource. Once the tread particles are displaced and eroded, they are generally gone forever. It is more efficient to be proactive and invest time and money up front in design to protect that resource rather than be reactive and try to fix the trail after the damage has occurred.
- Even if everything is done right and a sustainable trail has been built, erosion will occur to some degree. The fact that there is erosion does not necessarily mean that the planners and designers have failed or that the trail will fail.

An early fall event on these dry sandy soils resulted in severe displacement. A high wind or thunderstorm could result in major impacts and soil loss.

Chapter 3 included a tip that said planners and designers are always better off trying to work with human nature rather than against it. That same concept applies here.

They cannot fight a natural process and must learn to live with it. They can, however, do some things through design to reduce the impacts of that process on our trails.

Dirt in the air and grit in the teeth: it's part of the experience, but it's erosion.

The Interaction of Compaction, Displacement, and Erosion

With any natural surface trail, the vegetation at the surface gets removed and roots that hold soil either get cut through construction or broken through use. These actions weaken the soil and expose it to the forces of compaction, displacement, and erosion. Compaction can help minimize displacement. If displacement is minimized so is erosion potential; therefore, compaction helps reduce erosion also.

Many soil types appear to be stable at a given time of year, level of use, and moisture content. Change any of those three variables and the soil stability will change, which means that the potential for displacement will change. Clay soils turn to gumbo when wet. Sandy soils turn to flour when dry. Soils with low stability cannot endure a high volume of use in a short duration of time, as in an OHV event or race, unless they are frozen or have the optimum moisture content, which rarely happens.

A rill of water forming after a rain shower

When the surface of clay or silty soils is dry, the smaller particles become easily dislodged by the displacing action of tires and become airborne, hence dust is created. Most people, especially the riders, see this dust as a nuisance and pray for a breeze to blow it out of their way. However, what is occurring here is erosion. Those soil particles that are blown away are now gone forever, resulting in tread material being lost every year due to dust and wind.

After even a minor rain event, small rills or channels may form in the trail and at the downhill end of each rill will be a small deposit of sediment. These can seem innocuous, but over time they build up and can fill the bottoms of rolling dips and block the entrances to lead-off ditches. These rills can start forming within just a few feet of a drain and they can form on any grade, not just the steep ones.

Notice the rills of water draining down the slope and into this trail. Notice also how quickly the rill down the edge of the trail deepens as more water feeds into it and the water velocity increases.

Sedimentation from erosion can fill up drainage structures and cause them to fail, but ruts caused by displacement can do the same thing. Water collects in those ruts, becomes channeled, increases velocity, and can blow right by lead-off ditches and under-sized rolling dips. This is another reason why properly designed grade reversals are preferred over man-made structures; they cannot fail.

A Closer Look...

Evaluation or monitoring is the fourth E in the 4Es discussed in Chapter 1. Whoever is monitoring a trail needs to have an eye trained to spot those little rills and sediment deposits and watch for the gradual filling of drainage structures so that maintenance can be scheduled in a timely manner. If this is not done and the deposits are allowed to accumulate, the next major rain event could wipe out the drainage structures and create severe trail damage, extensive sedimentation, and unneeded resource impacts. Just as important as scheduling maintenance is to have that monitoring person take the next step and ask: "Where is this water coming from? Can we reduce or eliminate it?" This is what the 4Es are all about: asking why and implementing adaptive management. Too often, the issue is overlooked and these questions are not asked as the person climbs on his OHV and rides on up the trail. In doing so, the trail manager is taken from a potential proactive position and placed in a potential reactive position after the real damage occurs. Chapter 2 stressed that assessments need to be done on foot. On a machine, managers are traveling faster and are focused on other things besides the little insidious forces at work on the trail tread. Managers can see more, understand more, and be more effective on foot.

As the rills join together farther down the slope, the volume and velocity of the water increases even more resulting in scouring and erosion. If the source of the water feeding into this slope cannot be diverted, there will be long-term issues. A mitigation here could be to install an armored ditch to collect and channel the water down the slope. The ditch would need to be lined with cobble size or larger rocks to prevent further erosion and to dissipate the energy of the water.

Water will always take the path of the least resistance. This lead-off ditch gradually filled up with sediment due to lack of maintenance and the next major rain event blew right by the ditch and over the rolling dip.

This trail appears to be stable, but it is actually the product of years of sedimentation as evidenced by the log buried in the fill. Unless the source of the water carrying this sediment is found and corrected, this trail will not be sustainable.

The alluvial fans in the desert appear timeless and unchanging, but they are the product of erosion and sedimentation that started when the mountains were created. The sediment in these fans can be several thousand feet thick. The erosion process has not stopped and will continue forever.

This is a good example of displacement and erosion at work. This grade is too steep and too long without adequate drainage. Over time, water has carried away all of the fine material that bound this tread together leaving only a loose "rock garden." The trail above and below this section would be rated as EASIEST, but this section is no longer suitable for novice motorcycle riders. This lack of drainage has not only removed a lot of soil, it has created inconsistent difficulty which could put a novice rider at risk.

A Second Look...

It was discussed previously how erosion has washed away the fines and left a rock garden on this section of trail. What if that water has no direct connectivity to a stream? What if this trail had a higher difficulty level? What if our options to relocate this long grade are limited? Is it okay to accept this? Under certain conditions, the answer can be yes. For example, as long as signing and mapping reflect the appropriate difficulty level, the trail could be managed as More Difficult. On the easier trail sections on both ends of this, some simple entrance management techniques could be implemented to indicate to the riders that there will be more difficult sections to negotiate.

Section 3: Understanding Tread Materials

Natural surface trails generally use the native soil as the tread surface. Some soils are more stable and durable than others. Indeed, soil type is one of the key elements, if not the key element, in trail design. Unless the soil is modified or hardened, it will dictate the steepness of grade, tightness of alignment, frequency of drainage, smoothness of the trailbed surface, and the level of difficulty. Tread materials are generally composed of a mixture of soil and rock.

Soils

Soils are composed of different mixtures of sand, silt, and clay (called the soil separates) with the additives of organic matter (humus) and larger mineral fragments such as gravel-sized material. The mixtures of the soil separates define the texture of the soil and the texture influences the behavior of the soil. Will it drain? Will it displace? Will it be slippery? It is very common for the soil type or soil mix to change several times on any given trail, so the designers must be constantly watching for these changes and adjust the design accordingly.

Clay soils have the smallest particle size and the particles are shaped like flat platelets. The platelet shape makes clay very durable when there is sufficient moisture to bind the particles together. They can hold a lot of water, which makes them poor draining, and when wet, those platelets slide over each other, which is what makes a clay soil so slippery. Clay has high cohesion and that means it holds onto and binds particles together. That's why it feels sticky when moist. A quick field test is to take a handful of the soil, apply enough water so the sample is moist (wet, but not saturated), and then make a fist to form it into a ball. A clay soil will form a ball. Then rub hands together to try to roll the material into a pencil shape. A clay soil will roll into a pencil; the thinner the pencil, the higher the clay content.

Silt soils are the next larger particle size though the particles are still small and not visible. Silt feels smooth like flour. Due to their particle size, there are numerous voids between them, so they can hold a lot of water but not as much as clay, so they drain better than clay. Silt has medium cohesion, so it will also bind particles together to make a firm trail tread. In the field test, a silty soil will form a ball and feel smooth, will not be as sticky as clay, and will not roll into a pencil.

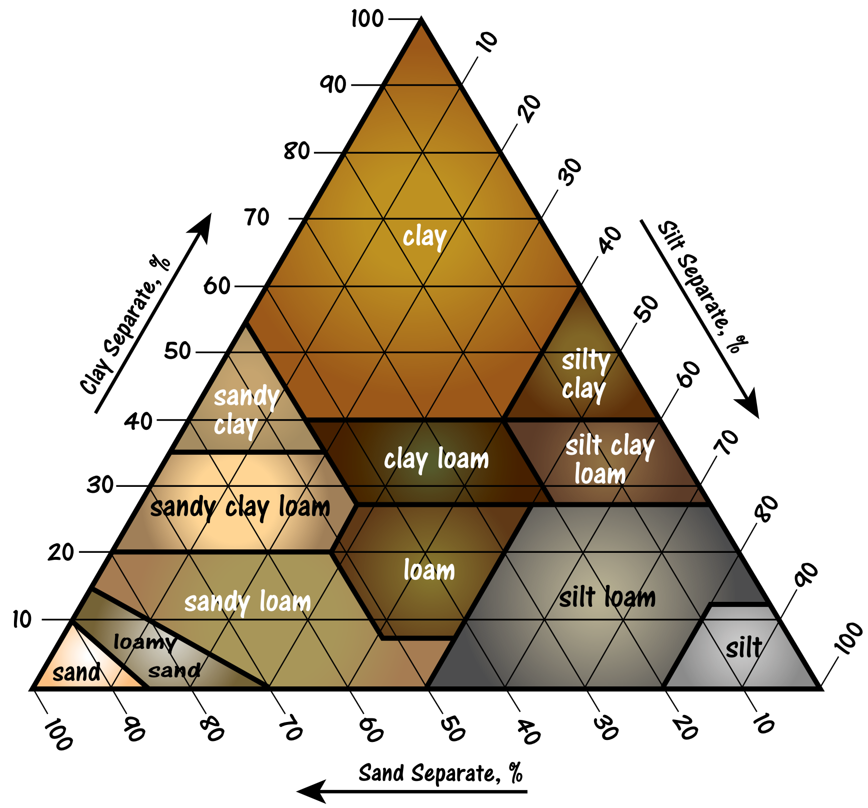
Sand has the largest particle size and is visible and gritty. The pores between the particles are large, so water drains through them very easily. Pure sand has no cohesion and does not bind with other particles, so sand does not compact and is therefore easily displaced. In the field test, pure sand will not form a ball and will disintegrate easily when pressed lightly.

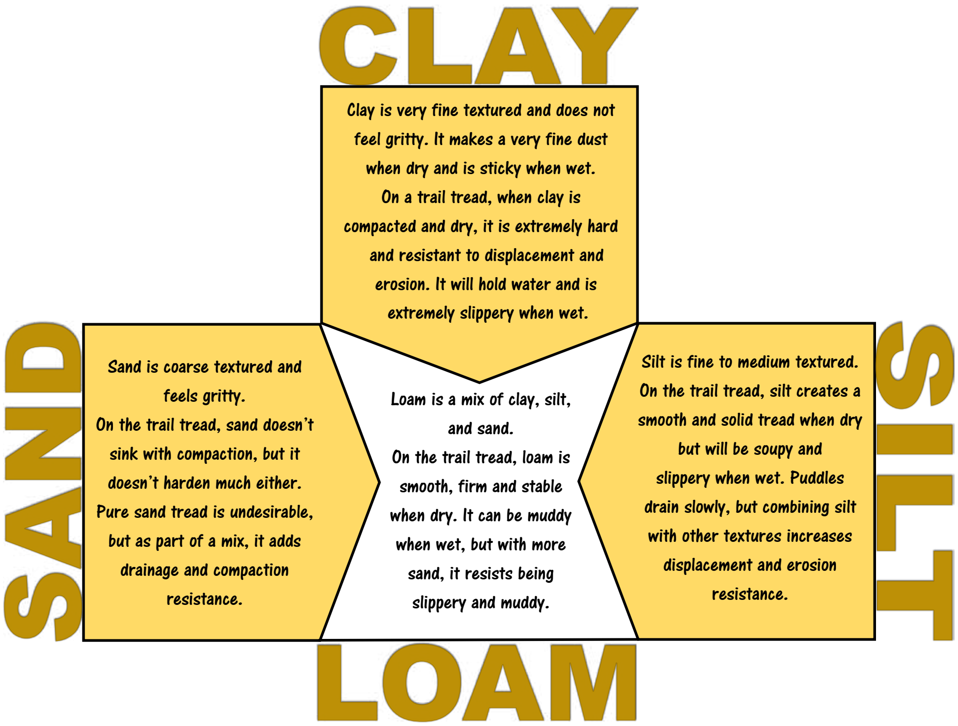
Rarely is a soil one pure particle type. Instead, it is a mixture of the three soil separates, which is a good thing since pure soils are not desirable for a trail tread. When mixed together though, the soil, which is called **loam**, tends to have more of the advantages of each of its components and less of the disadvantages. The relationship between the particle types is often displayed in what is called the soil triangle with clay, silt, and sand in each of the three corners and the combinations of loam near the center.

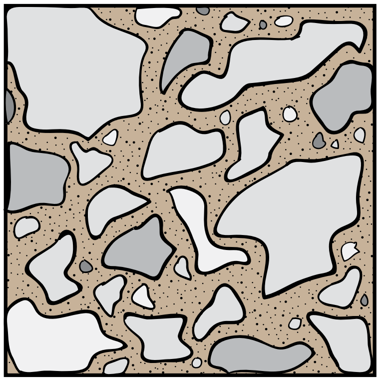
The table displays the properties and behaviors of each soil type.

Humus is a dark brown to black layer of decomposed organic material often referred to as the A horizon. When mixed with the soil separates, humus significantly increases the bulk density and moisture retention characteristics of the soil. Being organic, it also adds nutrients that stimulate plant growth which in turn can help stabilize the soil. Like the soil separates, in the right mix humus is good, but the higher the percentage of humus, the more muddy the soil will become making it very susceptible to displacement and erosion.

Soil texture triangle





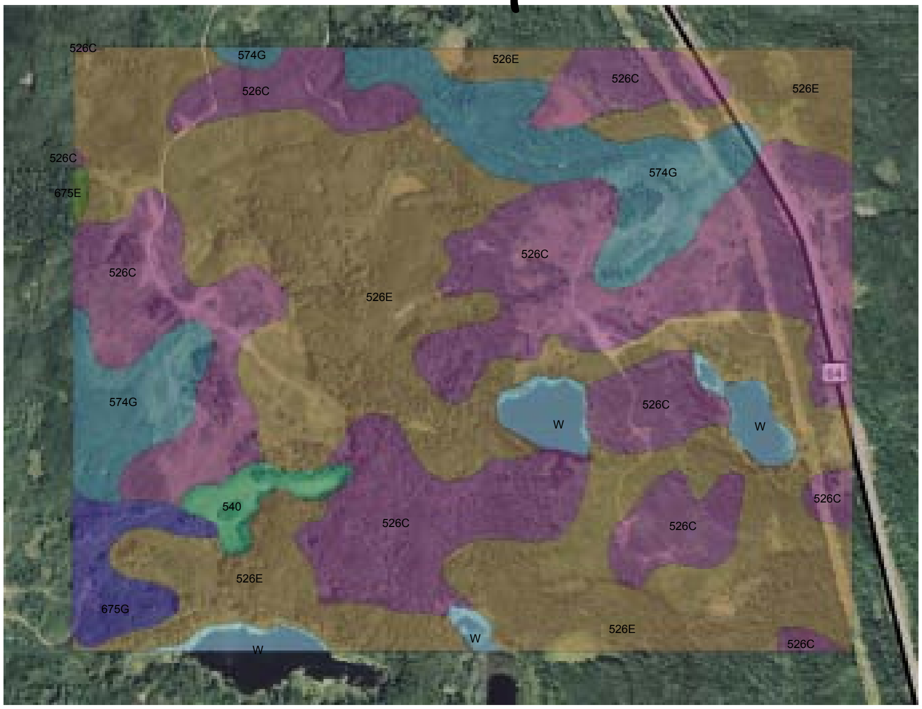


A wide range of particle sizes from clay and silt and larger makes the best soil for trail tread. The smallest particles are binders, larger particles better resist displacement and erosion while providing strength in wet conditions, and medium particles of all sizes add structure that helps stabilize the tread. Compaction greatly strengthens such treads by eliminating spaces and improving binding.

The ideal tread material is a loamy mix with humus and a significant gravel content. Such a mix will provide stability, durability, and drainage. The mixture will be able to withstand the forces of compaction, displacement, and erosion. Unfortunately, that ideal mixture is generally not very prevalent, hence the need to either modify the trail design parameters or modify the tread material.

There is comprehensive soil mapping and information available for every state and county in the United States through the USDA National Resources Conservation Service (NRCS). NRCS provides tables that interpret soil map units for different uses. Those interrelations vary depending upon the age of the surveys, but often there are interpretations for light roads, or foundations that may be useful to the trail planners. Their website has just about everything planners and designers would need to know about soils. Soil mapping for Canada is available through the Agriculture and Agri-Food Canada, National Soil DataBase (NSDB). Many federal, state, and provincial agencies also have their own soil mapping database. As with any area mapping product, the level of detail may not be sufficient for the desired application, so some level of ground verification is usually needed to ensure the accuracy of the data.

Soils map



An example of soil inventory mapping from the NRCS. Depending on the detail of the mapping effort, the mapping polygons may include small areas of other soils called "inclusions," or may describe soil complexes or associations. The mapping unit description and interpretive tables that accompany the maps will help you extract valuable information from the soil survey.

Rocks

Most tread materials also contain unconsolidated bedrock or loose rocks. In the right mix of size, shape, and content, rocks can add to the durability of the soil. And like soils, these materials are also categorized by size. There are four classes:

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

These materials are a benefit to any trail tread because they provide weight bearing and durability by resisting the forces of compaction, displacement, and erosion. They also add to the natural character of the trail, so they increase the rider experience. A challenge for OHV trail designers is how to provide challenge and still have sustainability. Rocks can help provide that opportunity. Soils with a high angular rock content may allow the designers to increase the grade. Exposed bedrock, firmly embedded rocks, slab rock, slick rock, and boulders can provide outstanding technical challenge while maintaining tread durability.

This rock outcropping was used as a pivot point for a curve in the trail. The rocks help stabilize the soil and increase the variety in the trail.

Unfortunately, a rock is not always as hard as a rock; some are durable and others are not. The three types of rock are igneous, sedimentary, and metamorphic. Igneous rocks have solidified from a molten state. They are tough, hard, and have little texture or layering. Examples are granite, dense basalt, and obsidian. Sedimentary rocks have been formed by the accumulation of particles that have been compressed under heat and pressure to create rock layers of hardened sediment. These are not as hard or durable as igneous rocks. Because the rocks are compacted in layers, each layer may have a different density and bonding strength, hence the layers can separate under the forces of turning tires. Examples are sandstone, limestone, shale, and gypsum. Metamorphic rocks are older rocks that have been altered by extreme pressure, temperature, or chemical actions. These are tough, hard rocks. Examples include quartzite, schist, marble, and gneiss.

The high rock content on this grade has made it durable. The grade is steep (25%) but short (50'). In spite of a dramatic increase in use, this slope has changed little in 15 years of monitoring.

Depending on their compositon and hardness, some rocks on or near the surface tend to weather more than others. The forces of expansion and contraction created by hot and cold cycles cause micro-fractures and the freeze-thaw action of water expands those fractures and weakens the rock. Therefore, rocks near the surface may become rippable even though they appear solid. Depending on the type of rock, this weathering could make the rock rippable for a few inches or a few feet. As designers lay out a trail, they should be looking at and assessing the protruding rock. Is it rippable or is it tied to the center of the earth? Should it be taken out, circumvented, or left as a challenge feature? A couple of quick pokes with a pick or other implement will give designers a hint as to the solidity of the rock. The designers should remember that the material will be harder below the surface.

With the softer rocks moguls can actually develop in the rock; grooves can be cut into it by tires. Softer rocks used as technical features can literally disintegrate over time. Rocks that have cracks or fracture lines are likely to break along those lines under the forces of vehicles. Does that mean that the designers should avoid utilizing the softer rocks? No, any rock is better than no rock, but the designers need to realize that changes will occur. Ten years of durability is better than none, and ten years of providing a high-quality rider experience is better than none.

Another type of common tread material is decomposed granite or DG. It is granite rock that has weathered and broken down into various sizes from gravel to sand-sized particles. Depending on the area and the mix of sizes, it can be a good tread material or a very poor one. It tends to have round particles, but if there is a good mix of sizes, or if they have been mixed with other soil types, especially clay, they can produce a durable tread. If the particles are homogeneous regardless of their size, they do not bond together and displace very easily.

Volcanic rock, being molten from the ground, is igneous rock that includes basalt, rhyolite, and andesite. Basalt is the most common and it has several forms depending on how quickly the lava cooled and how much gas was trapped in it forming vesicles. A gray lava flow is basalt. It can be very hard and durable with a low vesicle content, but it gets weaker as the size and number of vesicles increases. The reddish lava rock are cinders. They are highly vesicular. The tan to white pumice has so many vesicles and trapped air that it floats. Cinders and pumice make poor tread materials because they are granular, weak, and non-cohesive. They will compact over time, but they are dusty as they break down and with no cohesion, they displace very easily. Loose pumice on the surface of the trail tread can float away in a heavy rain, which is undesirable in a tread material.

Design Implications of Rocks

- Bedrock or well-embedded rocks provide superior resistance to compaction, displacement, and erosion.
- Angular rock binds well with other tread materials as long as the voids between the rocks are filled with a variety of other rock and soil particle sizes. The more rock, the more durable the tread becomes. This could allow for steeper grades.
- Round rock like river rock does not bind well with other tread materials and can be easily displaced.
- If all of the rock particles are homogeneous in size, both angular and round rock can be displaced. Consider mixing in clay and other soil and rock particles as a binder.
- Rocky treads tend to drain well so they do not become muddy when wet, but they can get slippery.
- Gravel, cobbles, and stones can be used to harden wet areas.
- Hard rock doesn't erode, but the soil particles around it does. Frequent drainage is still important to control water volume and velocity.
- Soft rock can break down and erode.
- Rocks with horizontally oriented sharp edges can be tire busters and rim benders. Either break off the edges or pad the approaches to them to reduce the angle and force of impact.
- While surface rocks provide variety and challenge, less experienced riders will often try to ride around them if possible, which creates widening of the trail. Strategically place boulders, logs, or other barriers to deter this widening. Better yet, if possible, provide an easy-out around the rocky area.

As the soil at the base of this rock slab gets displaced, it will be increasingly difficult to negotiate this black diamond designated trail. This rock slab provides challenge and a WOW experience.

Solid rock outcroppings make great opportunities for challenge.

The natural process of erosion has provided a durable and exciting technical challenge along this stretch of trail.

Firmly embedded angular rocks on trail providing technical challenge

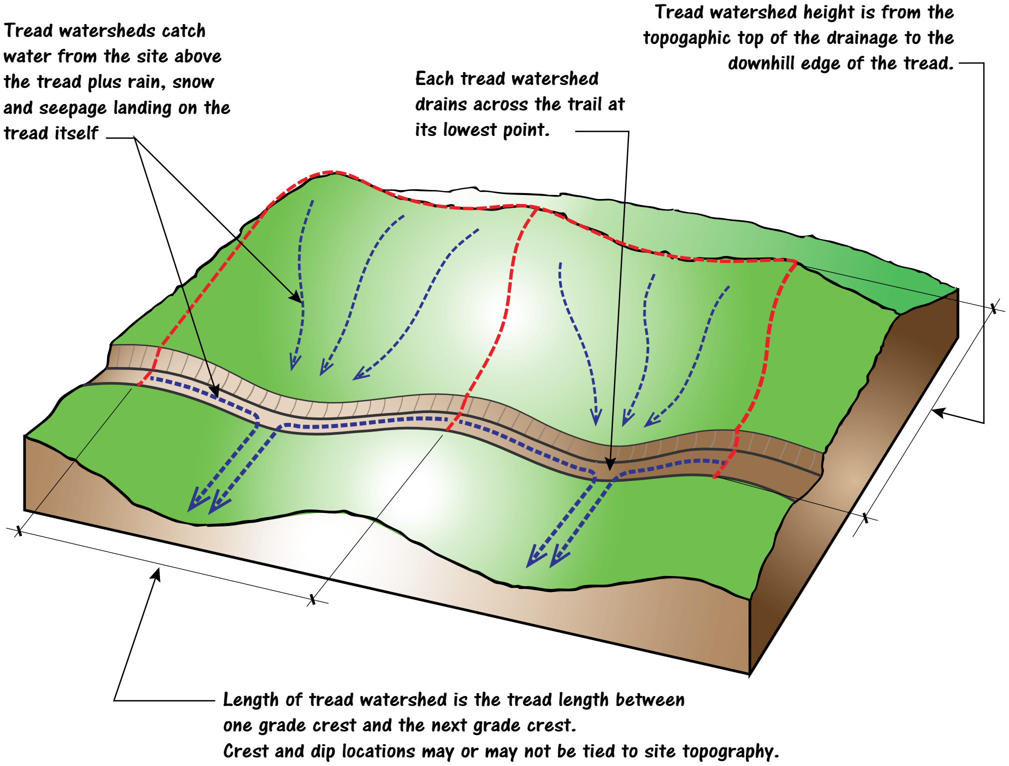
This trail uses a short, but steep climb, to add challenge. The steep grade is stable because the tread is made up of large rocks firmly embedded in the soil.

This shale rock is durable, technical, and has an outstanding WOW factor.

These rocks are too small and not embedded well enough to withstand the forces of this 4WD trail. They will displace causing diminishing challenge of this run and potentially unacceptable site impacts.

Section 4: Understanding the Dynamics of Water

In trail design, speed and water create issues, but both can be managed through proper design. Designers can roll the grade to force water off the trail at regular intervals. Many factors influence how water is forced off the trail, including soil type, topography type, frequency and intensity of use, control points, trail grade, tread width, vegetation (ground cover and tree canopy), climate (arid or wet), and seasonal weather patterns (potential for high-intensity thunderstorms). All of these can affect the amount of water collecting on the trail tread and the behavior of that water. To manage that water, designers need to focus on not only the water on the trail but also the sources of that water. Certainly, as it rains water is falling directly onto the trail tread, but it is also falling on the land above the trail. Some of this water is absorbed into the ground, some of it runs as an overland flow onto the trail, and some of it drains as a subsurface flow and spurts like a spring in the trail. How much water is this and how does it influence the design? Determining how much water may enter the trail profile involves looking at the bigger picture of the landscape and dividing it into tread watersheds.



Tread Watersheds

The tread watershed is the area from one grade crest to the next grade crest and all of the land that drains into it from the top of the ridge or a topographic crest.

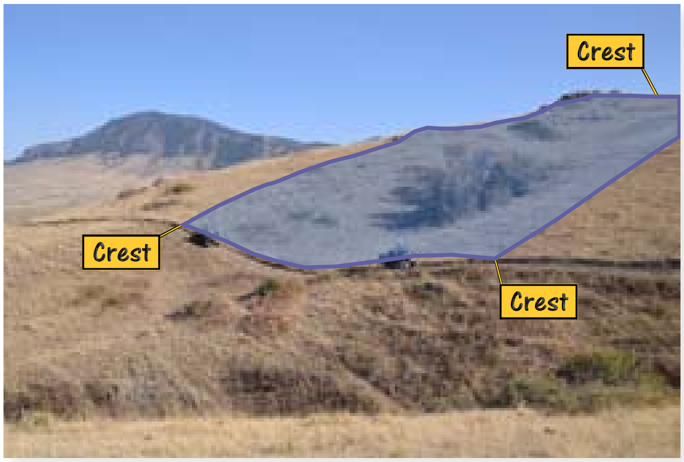
The topography of the site controls the height of the tread watershed, but designers can control the length of the watershed. Through the actions of compaction, displacement, and erosion, the tread sinks over time and the integrity of whatever shape it had at the time of construction is usually lost. When the tread sinks, it traps the water and the tread becomes a conduit or channel for the water to run. The water will run from the top of the grade crest to the bottom of the grade sag. The longer water runs on a grade, the more velocity it gains, and the more potential it has for scour or sediment delivery. This is called runoff erosion. To increase sustainability, these runs must be as short as possible.

Tools to Manage Water

The designers control water by rolling the grade, which not only helps make the trail sustainable, it enhances the rider experience and fun factor. This is one advantage of designing for OHVs: with a motor, riders don't mind going up, back down, and up again. It's not a chore, it's fun.

Tip, Trick or Trap?

Tip: Topography is your friend because it can be drained. Avoid flat ground.



In order to roll the grades and provide point drainage, designers must have the trail on a sideslope. Flat ground with flat grades does not allow the designers to control the size of the tread watershed and it becomes difficult to drain the water away from the trail.

This is one of many reasons why roads do not make good sustainable trails: the grades do not roll enough and their watersheds are too large. Roads are generally much wider than a purpose-built trail; therefore, the road surface is collecting more water volume than a trail, which can result in accelerated erosion, washouts of the road shoulders, or slope failures below the road drainage points.

This severe erosion occurred below a road drainage point after a high-intensity thunderstorm. The sediment carried all the way to a sensitive creek below.

When rolling dips are constructed on roads with long sustained grades to provide additional drainage, what is really occurring is that those grades are being broken up into smaller tread watersheds. This works but rolling dips require regular maintenance or they are prone to failure under normal or extreme weather events. The better alternative, if available, is to take the trail off those road segments so it can be built with rolling grades that provide shorter tread watersheds and will not fail.

Water Volume + Water Velocity = Increased Runoff Erosion Potential

Here is one example to put things into perspective. A mile of 12-foot roadway has a surface area of about 1.5 acres. A rain event of only 1" will produce about 40,000 gallons of water on this roadway. That same 1" rainfall on a mile of trail with a 50" tread will yield about 14,000 gallons of water. If that trail has a grade break every 300', then the amount of water flowing to each drainage point will be reduced to about 315 gallons. This is the water just landing on the trail. It does not include the water flowing onto the trail from the rest of the tread watershed. As the velocity of the water increases, the number of soil particles and the size of the soil particles being carried away increases. There are variables, but the velocity of the water can double when the grade quadruples. The velocity of the water flow on an 8% grade is twice that of a 2% grade. When the velocity is doubled (2X), the volume of sediment that can be moved quadruples (4X), and the size of particles that can be transported octuples (8X). Clearly, the key to creating a durable trail is to effectively control and manage the water.

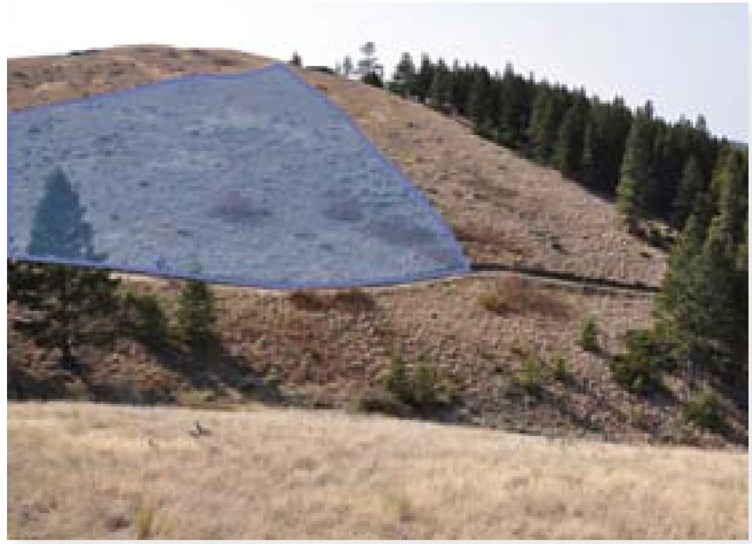
This trail has a long, steep grade, and poor soil type; all ingredients of non-sustainability. Like the rolling dips in roads, these belted waterbars reduce the distance that water runs thereby reducing the size of the tread watersheds. Unfortunately, these won't work. As you can see, riders are already starting to ride around the waterbars and as soon as this happens, ruts will form to channel the water and bypass the waterbars. The result is failure. A bandage fix like this is all too common and it doesn't address the root of the problem: poor trail location.

Designers can reduce the water volume by keeping the tread width as narrow as possible and by reducing the size of the tread watershed. They can reduce the water velocity by reducing the grade and reducing the size of the tread watershed.

There are four factors which affect the runoff volume and speed:

- The height of the tread watershed affects the volume of water.
- The steepness or slope of the topography affects the speed of the water.

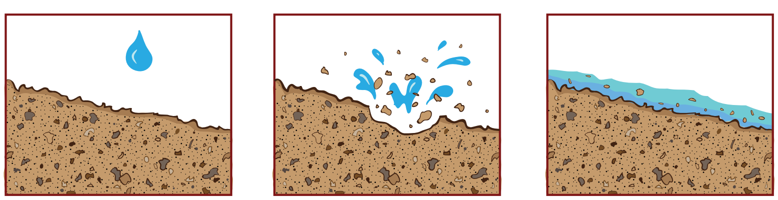
- The soil type affects the absorption of the water. If the soil type is hard like clay, has a high rock content, or is slab rock, very little water will seep into the ground and the runoff potential increases.
- The amount of vegetative cover affects the speed of the water. Thick forests or grasslands slow the runoff rate and act like energy dissipaters to stop or divert the direction of the runoff. The less the vegetation, the higher the runoff potential. With vegetation comes vegetative debris called litter such as sticks, branches, needles, and leaves on the ground. This accumulation of litter helps reduce runoff potential. This is why there can be devastating erosion after a wildfire; the vegetative cover has been removed.



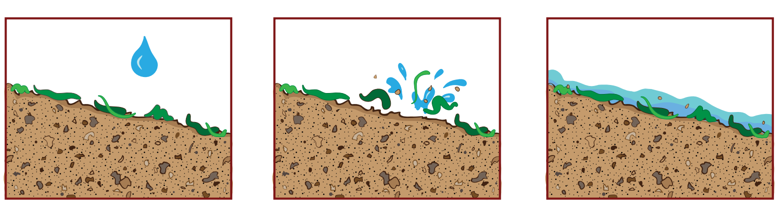
The height of the watershed above this trail is relatively low, but the topography is steep with low vegetative cover and exposed soils. The runoff potential here is high.

Runoff erosion is created by water volume and speed, but there is another type of erosion: splash erosion. The force of the water, even a raindrop, hitting the surface dislodges soil particles and can actually make little craters in the soil. This displaced soil then becomes subject to being carried away by surface water. A tree canopy can act like an umbrella by intercepting the initial force of the raindrops and allowing them to fall gently to the ground below. By locating a trail in the trees, the potential for splash erosion can be reduced. Ground cover and the accumulation of vegetative litter also protect the soil from splash erosion.

The ideal time to design or assess a trail is during the wet season when the amount and effects of the water are clearly visible. Unfortunately, that isn't always possible, so it's important to visualize how the site looks when wet. Sometimes looking at existing road and trail cuts can give clues as to the water dynamics. As a trail is being located, all potential water sources to the trail must be examined. Direct rainfall or snowfall, perennial streams and creeks, and seasonally wet drainages are obvious, but other water sources may not be that obvious. There may be a subsurface flow of water and the trail, once cut into the sideslope, may intercept that water. Groundcover can often



With no protective cover, raindrops can splash soil particles up to 3' away. Soil particles and aggregates that have been detatched are then transported down the slope by runoff water.



Tree canopies and vegetative cover cushions the fall of raindrops and reduces or eliminates splash erosion.

This heavy tree canopy helps protect this trail from splash erosion. The high rock content in the tread will add to the durability of this trail.

A high-intensity rain storm shortly after this fire resulted in a massive overland flow that washed across this trail, filling it with mud.

Tip, Trick or Trap?

Tip: Significant weather events such as 100-year floods can't be predicted, but designers must assume they will occur and protect the trails accordingly

Though not steep, the grade on this fenceline trail is too long making the tread watershed very large. This area is subject to high-intensity thunderstorms, so the erosion risk here is high.

This is a view of the bottom of a large tread watershed. The soils on this site are very poor. When the spring storms started, so did the erosion. Though grassed in, look at the rills on the slope that are feeding water to this drainage point.

Though dry, the rills at the base of these rocks indicate springs during the wet season. Even in the winter, the moss is an indicator of a different micro-climate.

cover up tiny rills that will feed water into the trail. Springs can dry up and be hidden. Designers should look at the base of rock outcrops for evidence of seeps. A change in vegetation to a type more indigenous to moisture can be a good clue along with moss, lichens, and small dry rills.

A Closer Look...

Designers should keep trail grades as low as possible. What does that mean? Increasing grade increases the risk of erosion, but increasing grade also enhances the rider experience. If the rolling grades on the trail never exceed 10%, it would probably be quite sustainable, but how fun would it be to ride? Provide for the riders' needs has been a fundamental guiding principle throughout this book. The designers must be constantly assessing the risk factors in each segment of a trail and weighing reduced grade vs. increased rider satisfaction. The designers should ask if they can push the grade at this point or not. If not, what other options can be employed to enhance the experience? Trail layout and design involves a very complex mental process of asking questions and answering them. The intent of this book is to teach designers and planners which questions to ask.

Some of the erosion risk factors are listed below:

Risk Factor	Lower Risk	Moderate Risk	Higher Risk
For the Tread			
Tread Grade	<12%	12%-20%	>20%
Length of Tread Watershed	Short	Medium	Long
Tread Width	Narrow	Medium	Wide
Stability of Tread Material	High	Medium	Low
Tree Canopy Over Tread	Thick, continuous	Intermittent	None
For the Watershed Above Tread			
Surface Area	Small	Medium	Large
Slope	<20%	20%-40%	>40%
Soil Type	Well-drained, sandy	Loamy, moderately drained	High rock content, clay, impervious
Vegetative Cover	Thick forest, thick litter cover	Medium vegetation, grassy, shrubby, no litter	Light vegetation, bare soil

The higher the number of risk factors, the shorter the tread watershed should be unless other mitigations are implemented like hardening or ditching.

Design Implications of Water Dynamics

- During trail layout or trail assessment, carefully examine all potential water sources and analyze their effects.
- Trail grades should be kept as low as possible, yet still provide the desired experience.
- Tread watersheds should be as short as possible by rolling the grade.
- Trail tread should be as narrow as possible. If converting a road to a trail, any excess width should be removed.
- Seek out vegetative cover whenever possible.
- Avoid steep, open slopes whenever possible.
- Consider other design or management mitigations such as reducing the grade, hardening the tread, increasing the maintenance frequency, or temporary closures to minimize potential effects.

Management Implications of Water Dynamics

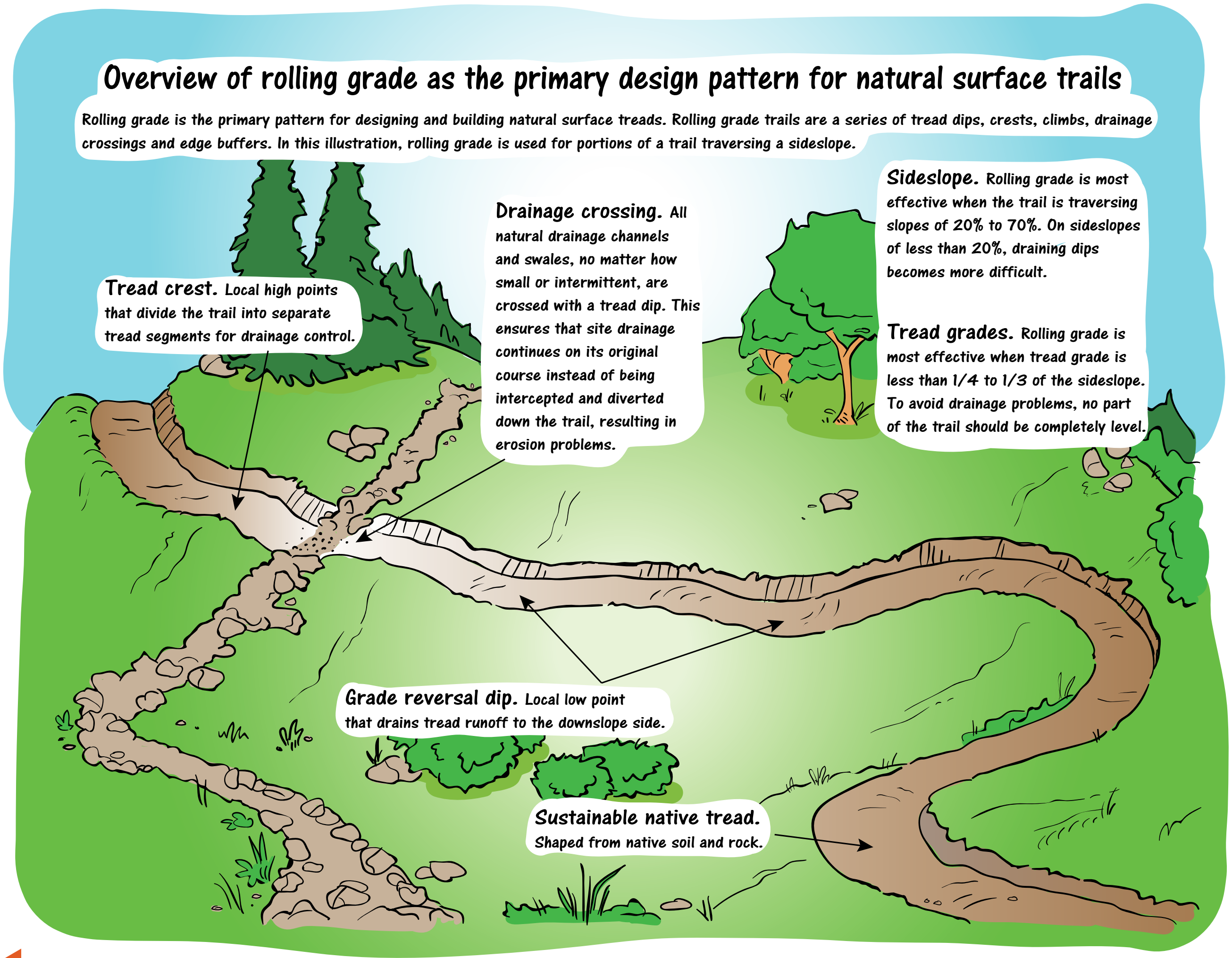
If designed properly, trails will be most susceptible to compaction, displacement, and erosion within the first year after construction. After the first year, compaction helps reduce displacement and erosion risk to some degree. Delaying the opening of a trail can assist natural weather events to help compact trail tread. If a trail is constructed in the fall, consider closing it to use until the following spring. If a trail is constructed in the spring, consider closing it until there have been several weather events.

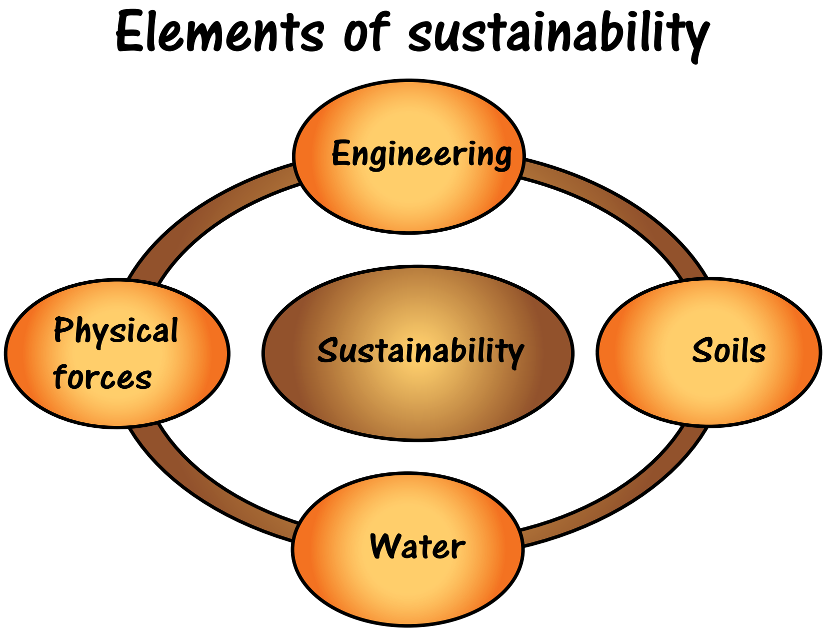
- If possible, do not schedule an event on a trail within the first year after construction.
- Schedule events during the times when soil stability is likely to be the highest.
- Train trail personnel to look for indicators of problems before they become major issues.
- Schedule and perform routine maintenance.
- Consider closing the trail to use during periods of tread instability.
- Use websites and other media to educate riders to avoid riding during periods of tread instability.

The Elements of Sustainability

It is important to understand the elements of resource sustainability: engineering, the physical forces, soils, and water. This gives a better understanding of the natural environment and how to create a great and sustainable trail.

Who needs this understanding? ALL field personnel. The trail planners and designers, but also the people conducting assessments or condition surveys, maintenance personnel, key volunteers and partners, construction supervisors, and the managers all need to have the ability to look at a piece of ground and understand what is or could be going on there. With that knowledge, they can be pro-active and implement adaptive management in a timely fashion. It isn't by accident that all of these personnel fit into the Great Trail Continuum. A great trail is only created by effectively and equally applying all five elements of the continuum together.





Tip, Trick or Trap?

Trap: The "it's been there forever" trail: It is not uncommon during planning for riders to show planners one of their secret trails. It is often an old race trail that runs up the slope at 40+%. It is stable, grown in, shows little signs of erosion, and can be a really fun trail. The riders want this trail incorporated into the designated trail system and their argument is that "it's a great trail and it's been there forever."

Often, the only reason that trail is stable is because just a handful of riders know about it. If incorporated into the trail system, instead of having six riders per year, the trail could have six riders per day. The trail will not be sustainable and will fail because the use level was changed significantly. Designers should not fall into this trap.

Need more? Learn more here…

NRCS website: http://www.nrcs.usda.gov/wps/portal/nrcs/site/national/home/

NSDB website: http://sis.agr.gc.ca/cansis/nsdb/index.html

Designing Sustainable Off-Highway Vehicle Trails, Kevin G. Meyer, USDA Forest Service, Technology & Development Program, November 2013

Natural Surface Trails by Design, Troy Scott Parker, Natureshape, LLC, 2004

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Water Harvesting from Low-Standard Rural Roads, Bill Zeedyk, Zeedyk Ecological Consulting, LLC, 2006

A Look Back...

Here are some of the elements discussed in this chapter:

- Engineering is the link between providing for the riders' needs and designing for sustainability
- Vision without action is a daydream, action without vision is a nightmare, but vision and action without engineering ensures disaster
- How to calculate grade: Rise/Run x 100 = Grade
- Sustainability Basics: Designers should keep the horizontal alignments moving by using curves and short or no tangents, keep the vertical alignments moving by rolling the grades, minimize the grades, minimize tread width, minimize the size of the tread watersheds, avoid the fall line
- Curvilinear trails increase sustainability
- Both circular and non-circular curves can affect flow and trail difficulty
- Grade reversals provide the most effective drainage
- The physical forces of compaction, displacement, and erosion must be managed through design
- The key to good design is to understand the natural forces and predict their effects
- The trail tread is composed of a mixture of soil and rock. The designer must understand the mixture and the properties of the soil and rock at the trail location
- Designers should keep tread watersheds as small as possible
- Speed and water are issues. Vegetation and topography are friends.
- The key to a durable, quality trail is to effectively manage water
- A quality trail depends on the effective and equal application of all five elements of the process: planning, design, construction, maintenance, and management