DEVELOPMENT OF SOLUTION TECHNIQUES AND DESIGN GUIDELINES FOR EQUESTRIAN TRAILS ON PUBLIC LANDS

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The undersigned, appointed by the dean of the Graduate School, have examined the thesis entitled

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GUIDELINES FOR EQUESTRIAN TRAILS ON PUBLIC LANDS

presented by Nathan Kyle Tabor,

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and hereby certify that, in their opinion, it is worthy of acceptance.

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DEVELOPMENT OF SOLUTION TECHNIQUES AND DESIGN GUIDELINES FOR EQUESTRIAN TRAILS ON PUBLIC LANDS

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ABSTRACT:

Increasing equestrian use on recreational trails puts intense pressure on the environment. Horse traffic produces high stresses that can cause trail degradation such as erosion and muddiness. Trail erosion has been widely studied and found to be controlled by many factors: climate, vegetation, use, topography, and soil. Much is known about causes of erosion, but there are limited solutions and guidance available for equestrian trails. This study takes the knowledge from literature and current engineering solutions to evaluate their effectiveness in preventing trail degradation on horse trails. Guidance for the design and construction of horse trails is to be created from the observations and lessons learned.

Test segments were constructed to evaluate the effectiveness of trail layout and surface stabilization techniques. Trail surfaces tested include natural soil, gravel, gravel with geosynthetic reinforcement, and lime stabilization. Observations were taken over a one year period.

The research findings indicate that natural surface trails are not adequate in resisting intense disturbance caused by horse use. Gravel surfaces increase erosion resistance and surface strength, but are more effective when included with geotextile reinforcement. Lime stabilization was not effective as a trail surface due to exposure to freezing and thawing.

1. INTRODUCTION

Recreational horse use is a large and growing industry. The state of Missouri has the sixth largest horse population in the nation, which is numbered at over 281,000. The economic impact of this ownership is valued at $718 million. Of Missouri's horse herd, over 70% are used for recreation (American Horse Counsel, 2005).

The significant amount of recreational equestrian use in Missouri has put intense pressure on the ecological stability of public lands. The Missouri Department of Conservation (MDC) manages over 370 miles of equestrian trails throughout the state. Many trails have become degraded over time due to poor design. MDC currently does not possess guidelines specifying design or maintenance of equestrian trails. This study will incorporate knowledge from published literature and current engineering technology to develop guidelines specific to equestrian trails design.

Sustainable equestrian trails require stable surfaces and proper layout in order to prevent trail degradation, such as erosion and user disturbance. Trail layout controls the amount of water affecting trail surfaces. The literature shows that trail slope, trail alignment, and topographic location affect how water interacts with a trail. Knowledge of how these factors affect trail degradation can be used to determine the sustainability of trails.

Trails also require stable surfaces to resist water erosion and user disturbance. Natural soil surfaces are often disturbed by equestrian use due to the immense stresses applied by the horses. In addition the strength of natural soil surfaces are greatly affected by the environment. Water reduces the strength of the soil, which creates unstable surfaces. Erosion resistance is low for soil textures that are high in silt and sand. Clay textures soils have high erosion resistance, but are weak when wet. The strength and stability of natural soil trails are greatly affected by the environment, and therefore are questionable as adequate surfaces for sustainable equestrian trails.

Stabilization techniques are available to be applied to trail surfaces. Using gravel as a wearing surface to protect the natural soil has been shown to be effective. Gravel can also be combined with geosynthetics to increase strength and reduce long-term maintenance. Lime stabilization has been used to increase strength of fine grained soils in transportation projects.

Hypothesis

The objective of this project is to provide the MDC with guidance and solution techniques for sustainable equestrian trails. The following hypotheses with be evaluated over the course of this project.

1. A practical set of guidelines for design and maintenance of sustainable trails, required by a public agency, can be created from published literature and preliminary field observations.
2. Natural soil trails with or without proper layouts do not provide a sustainable wearing surface with little maintenance, as required by a public agency.
3. Surface stabilization techniques (such as adding surface aggregate, utilizing geosynthetics, and lime mixing) will provide a stable surface for horses and provide increased erosion resistance.

These are the tasks involved in meeting the objectives:

1. Develop a set of design and installation procedures that can be utilized to manage the various degradation problems.

2. Construct test segments based on the procedures and test the effectiveness and sustainability of each solution in a realistic, typical application.

3. Develop guidelines for design and construction of equestrian trails for MDC based on the experience from this research.

2. LITERATURE REVIEW

Impacts from Recreational Trails

Wilderness recreation is a growing interest for America's public. With decreasing amounts of land available for recreation, the urgency to preserve recreational land increases. More popular activities like hiking and horseback-riding are easily available for enjoyment, but intense usage of these sites can cause damage. Ecological degradation of recreation areas creates an unsightly and unpleasant experience for users. These ugly sights, caused by erosion due to improper use, are the focus of today's recreation managers' attention. Degradation creates two problems: it environmentally degrades ecosystems and detracts from the wilderness experience.

Deteriorating trails are a problem. They detract from the major goals of recreation land: to provide "opportunities for wilderness recreation experiences" (Cole, 1983). "Eroding trails are a clear indication of human impact on the natural landscape" (Bryan, 1977). A recreation manager's main objective is to protect natural areas. With that, trails should be designed and maintained in a way that creates minimal disturbance.

In addition, eroded trails can degrade to a point where muddiness and a lack of footing stability cause problems for users. Erosion of soil can leave loose rocks and deep gullies that may cause users to fall and become injured. Users tend to avoid trouble sites and widen the trail, disturbing more area.

With increasing use and a reduction in the amount of land available, more pressure is being put on conservation agencies for solutions. Understanding the factors that lead to erosion and trail degradation can be a beneficial tool for managers in sustaining the integrity of trails. Guidance is needed to help provide a knowledge base for managers and users.

Impacts of Horse Trails

The effects of horse use on trails can be intense. Impacts from users cannot be related by weight alone. The impact is related to the pressure applied to the ground, and is quantified by the weight divided by the affected area. The static pressure applied by a horse can range from 29 psi to 57 psi (Lull, 1959). That pressure is significantly higher than the pressure applied from an average hiker, approximately 6 psi to 12 psi. The stresses increase when moving due to the weight being distributed on only two hooves and the impact from the inertial force.

Impacts on recreation trails are greater from horses than hikers (Weaver et al., 1978). The increased disturbance is attributed to the difference in applied stresses between users. Disturbance of the soil from external impact is only resisted by the strength of the soil. The greater the stress applied by a user, the greater the disturbance.

The main outcome from the impact of horses is trail rutting due to user impact. Ruts are created by the repeated impact from use. The results are depressions created by compaction and/or displacement of the trail surface. Ruts on the trail surface can focus water into channelized flow. Once water flow is focused, gully erosion occurs quickly.

Erosion Process

Erosion is a natural process that has created the landscape today. Changing land usage, such as for recreational use, changes the rate of erosion. Damage is caused by recreational use that disturbs soil and vegetation, which can lead to trail erosion and its associated problems.

Water erosion is the biggest contributing factor to trail deepening and widening in most environments (Cole, 1983). Flowing water exerts a shear stress on soil due to friction between the water and the surface. The shear stress is controlled by the energy of the flowing water. When the shear stress applied by water, $\tau_{water,}$ is greater than the shear resistance of soil, erosion occurs. The critical shear stress, τ_c , is the stress required to initiate particle movement, and is different for the various soil particle sizes.

A report by the National Cooperative Highway Research Program (2003) examined the critical shear stress for various soils. A v-shaped relationship was found between τ_c and grain size. Clays were found to have higher erosion resistance than silts and sands, while gravels and cobbles were found to have the highest resistance to erosion.

The erosion resistance of soil is dependent on inter-particle forces. For cohesive soils, these forces are dependent on molecular forces. For granular soils, friction between particles resists erosion, and is related to particle size and weight. Larger particles require a greater force for detachment and movement by water (Annandale, 2006).

Factors Influencing Trail Erosion

Many studies have been conducted to evaluate the factors contributing to erosion: climate, vegetation, use, landscape, and soil type (Helgath et al., 1975; Whittaker, 1978; Weaver et al., 1979). These factors explain most erosion on trails. While no single factor causes erosion, it is the combination of all that explains the deterioration of trails.

Climate

Climate sets conditions for the "how and when" erosion will take place. Climate data consists of average temperatures for seasons and average depths of rainfall. The most important facts to know about rainfall are the duration, intensity, and season for individual events. Those factors can indicate how much precipitation events will effect the environment.

Bryan (1977) found that all vegetation is vulnerable to erosion when soils are saturated. Often, in temperate climates, trail damage occurs during the early spring when the soil is saturated. During the winter months, the vegetation dies off and inhibits the evapo-transpiration. Without plants extracting the subsurface water the soil becomes saturated. Sequentially, the spring rains will not infiltrate into the soil and overland flow results. The increased overland flow during late winter and early spring will cause more erosion than at any other time of the year because the vegetation is not yet fully emerged. This means that users will cause more damage during spring rains.

Vegetation

Vegetation can be the single best protection against erosion (Stevens, 1966). Plants reduce raindrop impact and their root structure holds soil particles in place. Root channels help create porosity in the soil which increases infiltration. In addition, roots can create irregularities in the surface which will slow the flow of water and therefore reduce erosion (Helgath et al., 1975).

When vegetation is subjected to excessive trampling, its role in protecting the soil is greatly hindered. The effect of trampling damages and removes the vegetation on the trail. Compaction of the soil reduces the available moisture for plants adjacent to the trail, which can stunt growth and cause the vegetation to die (Weaver et al., 1979). After vegetation is removed, the soil is exposed to further disturbance by water and wind erosion. In heavily used areas, degradation is not limited by vegetation, but by the resistance of soil (Bryan, 1977).

The construction of most equestrian trails involves the removal of vegetation. Vegetation is removed along with the organic soil layer in order to provide a smooth stable trail surface. In these cases, vegetation cannot provide erosion resistance. On the other hand, if vegetation were left, it would not survive due to the compaction of the soil from use.

Use

The most universal effect of using recreational land is compaction and disturbance of the natural soil. Compaction is quantified through bulk density (weight per unit volume). As the bulk density increases, the infiltration, percolation, and water content of the soil decrease (Arndt, 1966; Weaver et al., 1979). Limited infiltration will result in effects similar to an impervious surface, where water will pool to create muddiness or concentrate flow creating gully erosion.

Average bulk densities for various soils range from 50 to 69 lbs/in^3 (0.8 to 1.1 gm/cc). Weaver (1979) found that the bulk density on level grassland increased to 81 lbs/in^3 (1.3 gm/cc) after 1000 passes with a horse. On a slope, bulk density increased to 93 lbs/in^3 (1.5 gm/cc), which is the limit for water and roots to penetrate soil. Once the soil reaches that density, vegetation growth will be limited. The roots cannot penetrate the hardened soil and will suffer from the loss of moisture (Weaver et al., 1979).

Compaction reduces total pore space, therefore infiltration and percolation may be reduced (Kuss, 1983).

Vegetation loss can be directly related to weight of the trampler (Cole, 1995). Horses have been found to cause more damage than a human in the same area. Soil compaction and trail incisions were found to be greater under horses than hikers (Weaver et al., 1978). The average pressure that a full grown horse exerts on the ground is 40 psi in contrast to the pressure exerted by a human of 8 psi (Lull, 1959). The difference in pressure shows how much more impact horses have on disturbing the soil. Whittaker (1978) found that horses were much more damaging to trails verses humans. Horses compact the soil, but then began to break up and disturb the soil leaving some sites muddy. The disturbed soil allows water to easily remove the soil from the trail.

Degradation is not influenced by the amount of use once a certain threshold has been passed. It only takes a few users to cause problems (Helgath et al., 1975; Cole, 1983). Whittaker (1978) found that it only took twenty-five passes of a horse before a trail started to become muddy. Soil properties and landscape features determine the carrying capacity of users. Damage can occur at any location with sufficient use. But even at low intensities of use, degradation is mainly related to topography and soil resistance (Bryan, 1977).

Landscape

The landscape plays an important role in the degradation process. A landscape is defined as a population of landforms geomorphically welded by the through flow of water, nutrients, and energy. Soil and landscape characteristics of recreation sites have the most influence on erosion and degradation (Helgath et al., 1975). These soil-landscape interactions determine the recreation capacity of an area (Stevens, 1966).

Trail erosion is dependent on position in the landscape, because characteristics of trails and terrain will interact regardless of the amount of use (Summer, 1980). Different landform positions have different properties (Figure 2-1 and Table 2-1). Factors such as slope, topography, and elevation can explain the condition of many trails (Helgath et al., 1975).

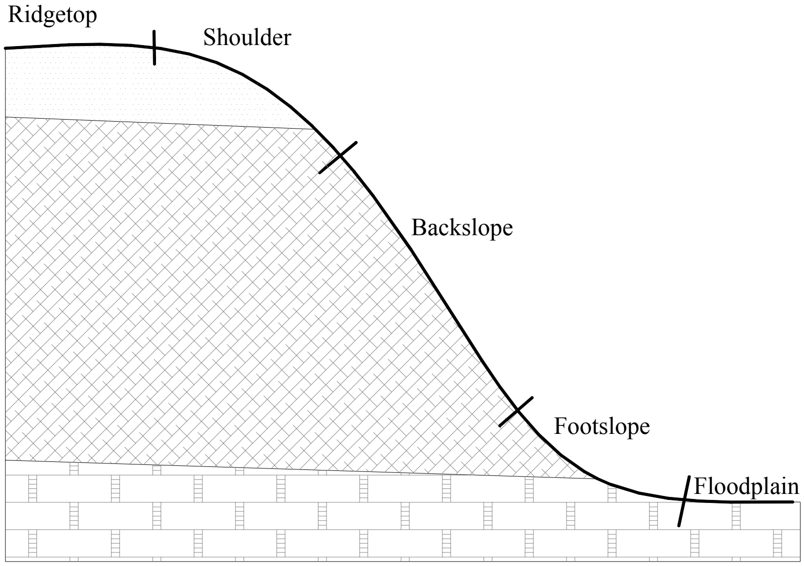

Figure 2-1. Landscape Location Diagram.

Table 2-1. Landscape Location Pros and Cons Regarding Trail Placement.

Landscape Location	Contributing Watershed Size	Pros	Cons
Ridgetop	Small	Small watershed	Difficult to divert surface water
Shoulder	Small	Easy water diversion	Restrictive layers can cause water to seep onto trail
Backslope	Medium	Easy water diversion	Steep side slopes
Footslope	Large	Moderate water diversion	Often wet due to large watershed and concave shape
Floodplain	Large	Minimal Steepness	Often wet due to high water table

Trail steepness and length are highly correlated to the rate of erosion (McQuaid-Cook, 1978). In channelized flow, the slope and length of a trail controls the amount of energy that flowing water has. Steeper slopes allow water to flow with greater velocity. On a trail with a minimal steepness, but where water is allowed to flow for a long distance, water can also reach a significant velocity. With the higher velocity of the water, the erosion rate increases (Annandale, 2006).

If the trail steepness controls the energy of water, then landscape location controls the amount of water that can affect the trail. The size of the watershed contributing runoff for a ridgetop trail is generally less than that for a low-lying trail.

Because of the dynamics of soil properties, critical trail grade will vary depending on the landform shape and soil depth (Helgath et al., 1975). Erosion may occur at 15% trail steepness on one landform, but not on 30% trail steepness somewhere else. In arid environments, erosion may not be found up to 17% trail steepness (Tinsley et al., 1985). Helgath (1975) found that some trails will erode at a 5% grade while others will show no erosion up to a 30% grade, depending on the soil type and landform.

Landform shape determines how trails and water will interact. Convex and concave shaped landforms erode at different rates (Helgath et al., 1975). Flat segments can be prone to poor drainage. These sites become muddy and users cause the trail to widen while going around the muddy area (Cole, 1983).

Benched trails that are cut into a side slope are prone to erosion due to intercepting subsurface flow (

Figure 2-2). Compaction and horizon removal expose the soil and lower the trail surface. Subsurface flow will exit through the exposed soil, concentrate in the trail bed, and flow down the trail surface. Flow down the trail surface causes gully erosion that is almost impossible to stop after it starts (Helgath et al., 1975).

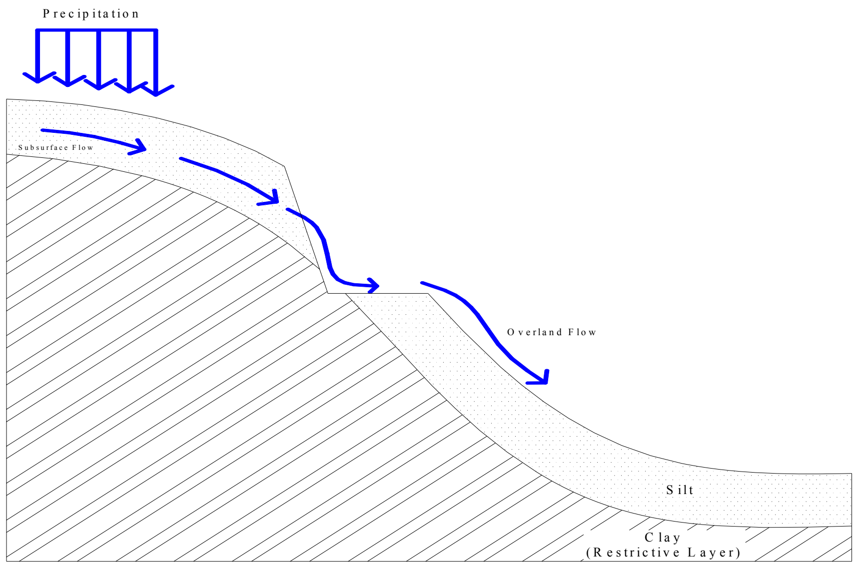

Figure 2-2. Benched Trail Intercepting Subsurface Flow.

Soil Type

Soil also plays an important role in the erosion process. It is the material that is displaced and transported. The erosion resistance of soil can be quantified and related to many factors. Damage depends largely on soil properties such as "abundance of rocks, homogeneity of texture, iron-pan morphology, aggregate stability and organic content" (Bryan, 1977). Soils with high infiltration rates and that are not limited by subsurface barriers will be less likely to erode.

Soil texture is one property that is related to degradation. There are definite relationships between soil texture, erosion resistance and wearing resistance of soils (Table 2-2). Fine grained soils such as clays and silts become muddy when wet and create unstable surfaces. Silts and sands are highly erosive because the small particles lack cohesion and are easily washed away by water.

Table 2-2. Typical Soil Properties Based on Texture.

Soil Type	Erosion Resistance	Trampling/Wearing Resistance	Potential Problems
Clay	High	High (when dry)	Muddy and slippery when wet; High runoff potential.
Silt	Low	Moderate (when dry)	Highly erosive; Muddy when wet.
Loam	Moderate	Moderate	Possibly muddy when wet.
Sand	Moderate	Low	Loose particles can be highly erosive.
Gravely Clay	High	High	High runoff potential.
Gravel	Moderately High	High	Potential erosion with intense flows.

Soils with a high percentage of gravel have high erosion resistance and very high strength (Tinsley et al., 1985). However, if user pressure is great enough to cause breakdown of soil particles, rocks can act to increase erosion.

Management Solutions

Many studies have been conducted to study the factors that effect erosion. Much is known about the causes of erosion, but there are a limited number of solutions for the design of equestrian trails. There are two main concepts to minimize trail degradation from water:

1) Decrease the forces causing trail degradation.
2) Increase degradation resistance.

Depending on the situation, one or both solutions must be applied to reduce erosion and create a sustainable trail.

Trail Layout and Design

Proper trail layout and trail design are two essential factors needed to produce sustainable trails. Trail layout describes the path that a trail takes across the landscape. The layout is quantified by the trail alignment angle, steepness, and length.

Trail Alignment

Trail alignment is the angle between the trail direction and the topographic surface aspect. The possible ranges for trail alignment are from 0º to 90º. A trail alignment angle of 90 º represents the trail direction that is perpendicular to the slope (i.e., the trail follows the topographic contours). A trail alignment angle of 0º represents a trail that travels straight up and down the slope surface.

Trail degradation is highly correlated to the trail alignment angle (Aust et al., 2005). The relationship of trail alignment angle and erosion potential is shown in Table 2-3. Alignment angles between 0º - 22º of result in erosion and muddiness due to the inability to divert surface water from the tread. Alignment angles between 68º and 90º are preferred because of the ease of diverting water from the trail. Ideal trail alignment is between 68º - 90º. Trail with alignment angles between 0º-22 º should be immediately rerouted.

Table 2-3. Trail Alignment Angle and Erosion Potential

Trail Alignment Angle	Water Diversion Potential	Erosion Potential
68-90°	High	Low
46-67°	Moderate	Moderate
23-45°	Low	High
0-22°	Very Low	Very High

Steepness and Length Requirements

The erosive power of water is dependent upon the slope and length of trail in contact with flowing water. Parker (2004) described a hypothetical limit on trail length depending on the slope and soil type (Table 2-4.). The limits were created by using the assumptions of a well compacted surface, moderate hiking use, and no tree canopy. While the limits are not created for horse use, the recommendations can be used as a rough estimate of guidelines for equestrian trails.

Aust et al. (2005) suggests keeping trail steepness less than 10% with a 15% maximum for horse trails on silt loam soils. For trail steepness greater than 13% Aust et al. (2005) recommends a minimum of 2-3 inches of gravel for low use trails.

Table 2-4. Tread Length Limits based on Soil Texture and Trail Steepness.

	Trail Steepness					
Texture	0%	4%	8%	12%	16%	20%
Gravel Loam	160 ft	83 ft	39 ft	17 ft	6 ft	-
Clay	145 ft	74 ft	34 ft	13 ft	4 ft	-
Loam	135 ft	57 ft	23 ft	8 ft	-	-
Sand	100 ft	30 ft	8 ft	-	-	-

Surface Water Control

When creating a trail, some slopes must be sustained for a longer tread length than recommended. Under these conditions, water must be diverted off the trail by using a specific control device.

Out-sloping the trail surface can divert water off the trail immediately, but only works if a rut does not develop. If ruts develop, channelized flow occurs and other measures are needed to divert the surface water.

Waterbars and grade dips can be used to divert water from the trail surface. They can be placed at specific location depending on the tread length requirements.

Surface Stabilization

Surface stabilization is the reinforcement of the tread surface to sustain heavy impact and reduce the erosion potential. Applications of a few selected stabilization techniques are shown in Table 2-5.

Table 2-5. Summary of Stabilization Techniques Pros and Cons.

Stabilization Technique	Typical Applications	Pros	Cons
Gravel Surface	Highly erosive soils: Silts and Sands.	Easy application; Relatively cheap.	Susceptible to rutting on wet fine grained soils: Silts and Clays
Gravel w/Geotextiles	Wet, fine grained soils	Increased strength; Requires less gravel (cost savings); Longer life cycle than gravel alone.	More expensive than gravel alone; Slightly more difficult construction process than gravel.
Geocells	Very weak, wet fine grained soils; Steep slopes.	Very high strength; Very low rutting potential	Expensive; Intensive construction process.
Lime Mixing	Fine grained, highly plastic soils: silts and clays	Increased Strength; Low Erosion Potential	Difficult to install on steep slopes.

Surface Aggregate

Applying 3.5" of gravel to a trail surface can significantly reduce degradation (Aust et al., 2005). Gravel has a higher strength than fine grained soils which increases surface stability. The large particle size of gravel requires a larger force to cause erosion than most fine grained soils.

Geosynthetics

Geosynthetics are man-made materials (usually plastic) that are used for separation, drainage, or reinforcement of soils.

Geotextiles – An old engineering adage is "if you add ten tons of rocks to ten tons of mud, you get twenty tons of mud." Adding aggregate to stabilize fine grained soils can result in the fines migrating into the aggregate and reducing its integrity. This is due to the lack of separation between the two materials (Koerner, 2005).

Geotextiles (Figure 2-3) are polypropylene fabrics that provide separation and reinforcement. The geotextiles recommended for use in trail applications are non-woven (long plastic fibers form a fabric by needle-punching and heat bonding). Non-woven geotextiles allow water to flow through the fabric, but restrict soil particle from migrating upwards.

Figure 2-3. Example of Non-Woven Geotextile Fabrics (Monlux et al., 2000).

Geotextiles can be applied in two techniques: the single-layer technique and the wrapped or "sausage" technique. The single-layer technique is primarily used for separation on trails with fine grained soils. The technique uses one layer of geotextile fabric that is laid over the soil, and is covered with a suitable surface aggregate (Figure 2-4). The wrapped technique encapsulates free draining aggregate within the fabric and is covered with surface aggregate, as displayed in Figure 2-5.

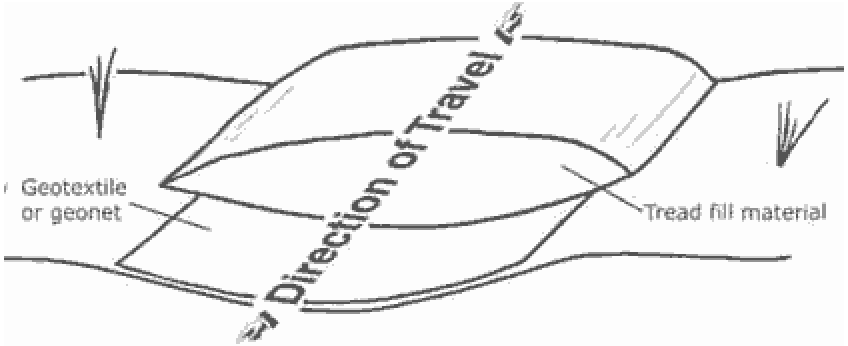

Figure 2-4. Single-Layer Geotextile Used for Separation on Trails (Monlux et al., 2000).

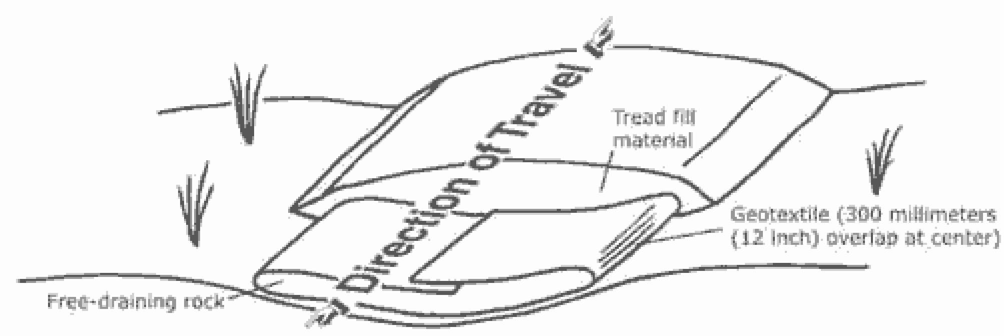

Figure 2-5. Geotextile Wrap used for Separation and Reinforcement of Fine Grained Soils (Monlux et al., 2000).

Geocells – Geocells (Figure 2-6) are plastic strips bonded together to create a honeycomb structure (Monlux et al., 2000). Geocells provide reinforcement over weak soils by spreading loads over a larger area. Construction involves filling the cell structure with free draining aggregate and covering the structure with surface aggregate. Geotextiles are applied to the surface below the cells to provide separation (Figure 2-7).

Figure 2-6. Geocells have a Honeycomb Structure (Monlux et al., 2000).

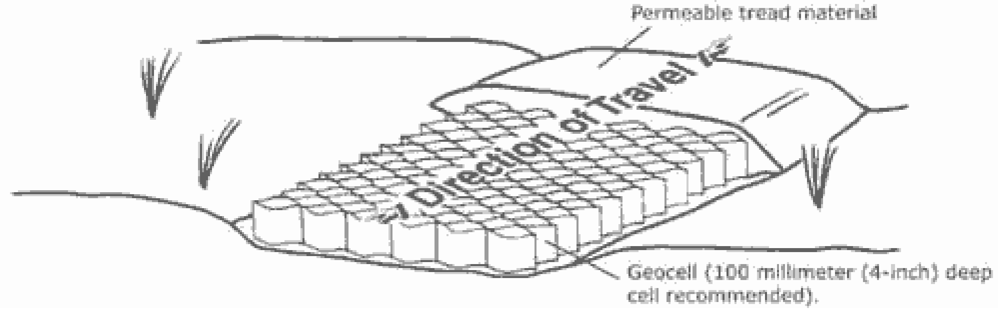

Figure 2-7. Geocells use in a trail application (Monlux et al., 2000).

Lime stabilization

Lime stabilization involves mixing hydrated lime or quicklime with fine grained soils to improve behavior. Lime reacts with fine grained soils almost immediately to reduce plasticity and increase strength. The effects of lime stabilization are dependent on soil type, mixture rate, and curing conditions (Transportation Research Board, 1987).

Lime stabilization is often used in road construction to improve the strength of weak subgrades. The improved strength allows for easier construction and increases the pavement's life.

Literature Summary

Equestrian impact on trails is intense and degradation can occur with little use; after which, degradation is mainly controlled by location and soil type. The amount of water greatly affects trail degradation. Low lying areas are often wet and muddy, and fine grained soils are weak when wet.

Degradation can be reduced if trails are placed in proper locations with strong soils. If problem areas cannot be avoided, surface stabilization can be applied to the trail surface to reduce maintenance. While stabilization techniques are available, their applicability and effectiveness in specific situations needs to be studied.

3. METHODOLOGY

Public Agency Implications

The Missouri Department of Conservation (MDC) requires horse trail design and construction guidelines that are practical for the agency. Therefore, several meetings were held with area managers, department engineers, and construction crews to determine the installation limitations. The trail segments tested needed to be able to be reproduced in other conservations areas. There were many agency constraints due to area usage conflicts, construction equipment, available materials, and construction time allotted. Each of these constraints needed to be discussed and addressed during the initial phase of this experiment in order for proper development of the guidelines.

Trail Analysis and Design

Conservation Areas

Existing horse trails on three conservation areas (Figure 3-1) in Missouri were studied to determine the causes of erosion. In addition, test segments were constructed at each conservation area to determine the effectiveness of each proposed solution technique.

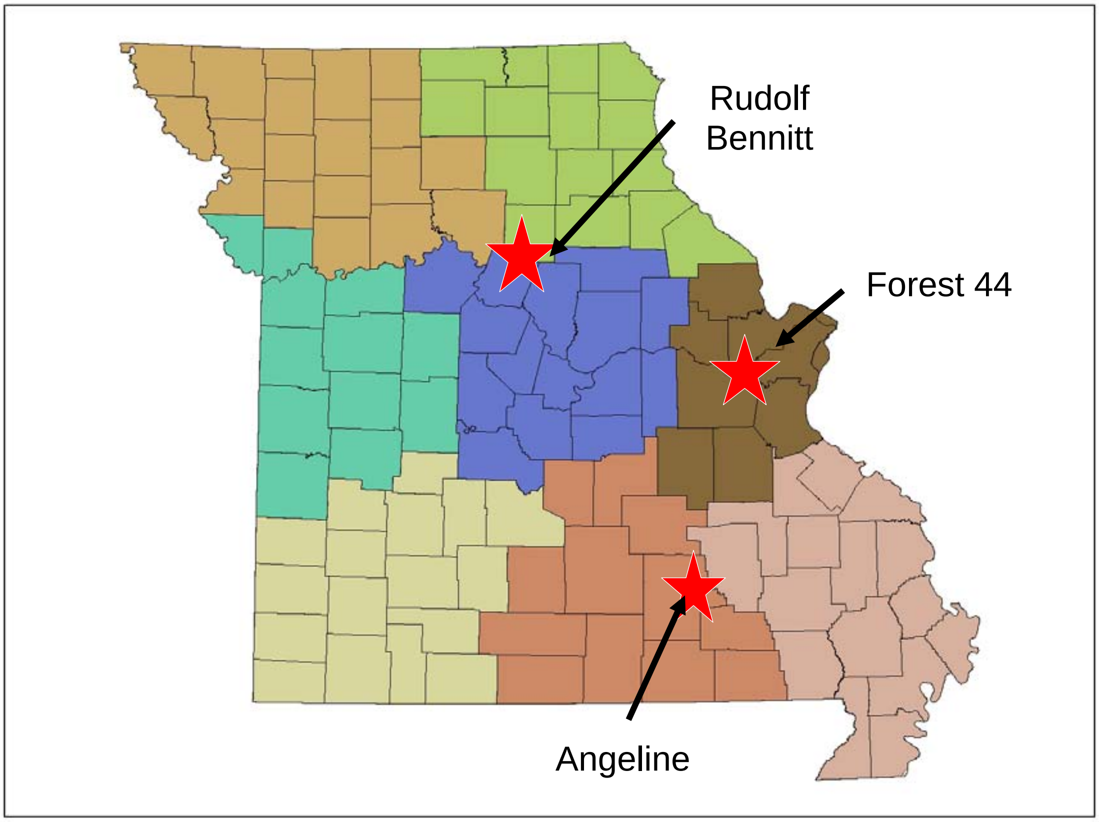

Figure 3-1. Conservation Areas Under Study

Rudolf Bennitt Conservation Area

The Rudolf Bennitt Conservation Area is located 23 miles north of Columbia, Missouri and 6 miles west of Highway US-63. The area contains over 3,500 acres of land, 75% of which is forested. The area has approximately 40 miles of primitive trail (no surface stabilization). Many of the 40 miles are unauthorized trails created by users. A majority of the trails were inherited when MDC purchased the property. Nearly all of the trails have severe erosion problems. Gullies can be seen varying in depth from one foot to four feet deep.

The topography consists of rolling hills with relief of up to 100 feet. The Keswick-Lindley-Gorin Soil association is predominant over the conservation area

(Figure 3-2). Soils consist mainly of silt loams on the ridgetops and clay loams lower in the landscape. Glacial till acts as a restrictive layer on the ridgetops and causes water to seep out over the surface on backslopes. Slopes range from 5% to 30%, and the entire area is known to exhibit high erosion potential.

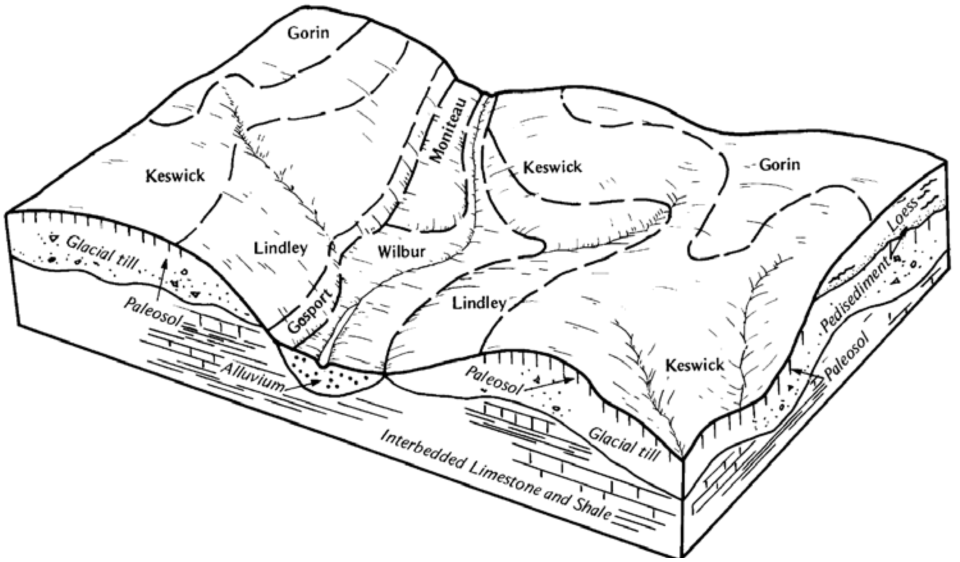

Figure 3-2. Keswick-Lindley-Gorin Soil Association Block Diagram. (Randolph County Soil Survey, 1989)

The important soils characteristics in this landscape are the restrictive layers on the ridgetops and the backslopes. On the ridgetops, a thin loess cap (eight inches) overlying glacial till creates a perched water table. The vertical percolation is limited; therefore water travels horizonally and seeps down backslopes. The backslopes are mainly clay causing limited infiltration which results in increased runoff. That combination of soil stratigraphy in the landscape creates highly erosive conditions.

Forest 44 Conservation Area

The Forest 44 Conservation Area (Figure 3-1) is located adjacent to I-44 near Fenton, Missouri. This area is over 1000 acres in size. Almost twelve miles of trails are located throughout Forest 44 and were inherited when the land was acquired by MDC. The trails in the area cannot be relocated due to the close proximity of other trails, protected archeological sites, and negative user response to discussions on relocations and closings. This area is intensely used by the local population in the St. Louis area.

The Goss-Gasconade-Menfro soil association (Figure 3-3) encompasses the conservation area. Slopes range from 5% to 50%. Soil textures at the conservation area range from clay and silts intermixed with 0% to 50% cherty gravel. Ridgetop soils are moderately well drained silts. Some ridgetops have a fragipan which causes a perched water table. The backslopes range from cherty silt loams (well drained) to clayey silts (poorly drained). The low lying areas such as the footslopes and flood plains consist of well drained silts, but are often saturated due to their low position in the landscape.

Most of the landscape is moderately well drained with gravely silts. The erosion potential is low in these cases. In cases where restrictive layers exist, such as ridgetops with a fragipan, muddiness can occur. Ideal trail placement should be located on the ridgetops and back slopes on well drained soils.

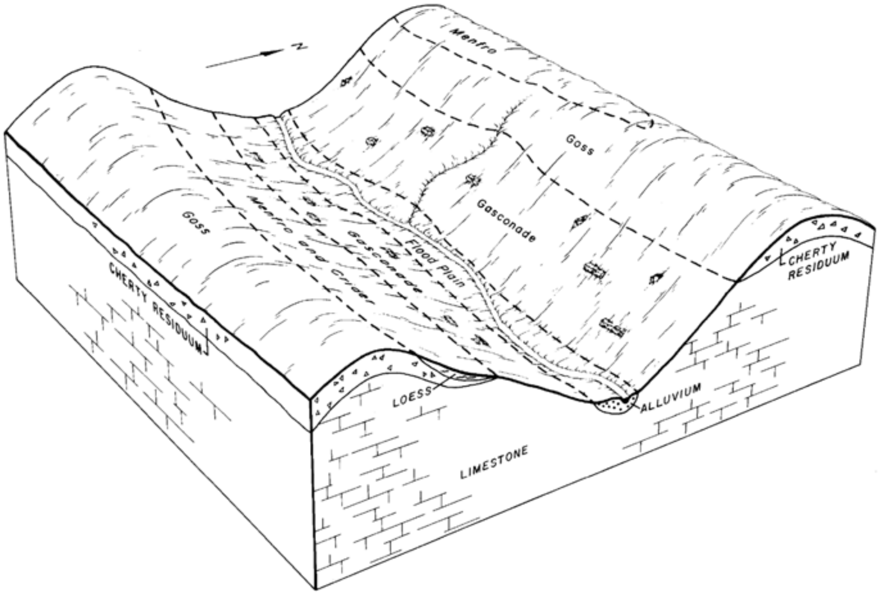

Figure 3-3. Goss-Gasconade-Menfro Soil Association Block Diagram (St. Louis County Soil Survey, 1982).

Angeline Conservation Area

The Angeline Conservation Area is located near Eminence, Missouri (Figure 3-1). The conservation area is in the heart of the Missouri Ozarks and features steep topography. The area under study is almost 1000 acres in size and contains over twelve miles of equestrian trails. Many of the trails follow the steep terrain and have shown significant erosion. The area is currently part of a trail renovation plan. Each trail is being reconstructed and will need to perform as a trail and as a logging road because the area is included in a timber harvest.

The soils at the Angeline Conservation Area vary from rocky to very clayey. There are two main soil associations in the area: Clarksville-Sholten-Gepp (Figure 3-4) and Niangua-Reuter (Figure 3-5). The landscape has steep slopes ranging from 5% to 50%. The landforms consist of narrow ridges with structural benches. Soils on the ridgetops and backslopes are mostly well drained silts with 5% to 30% gravel content.

Low areas in the landscape consist of highly active clay with 15% gravel and underlain by bedrock. Important problem areas are concave footslopes above benches and floodplains due to restrictive clay layers over bedrock.

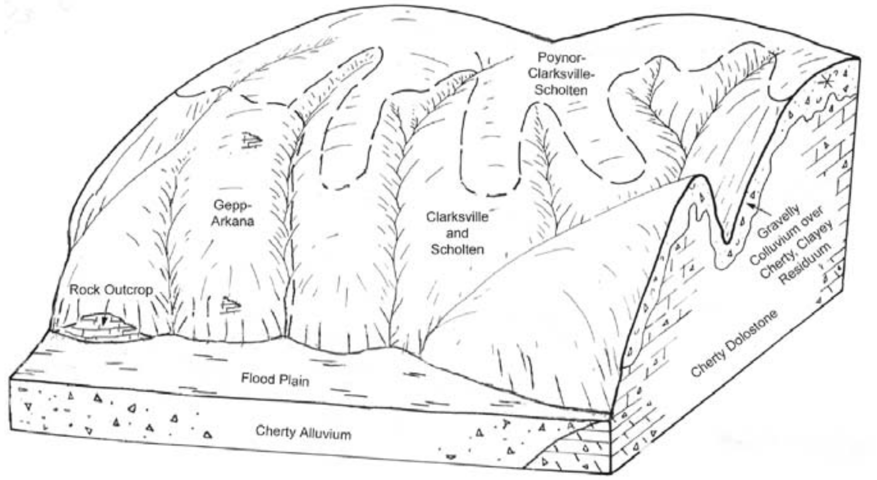

Figure 3-4. Clarksville-Scholten-Gepp Soil Association Diagram (Shannon County Soil Survey, 2005).

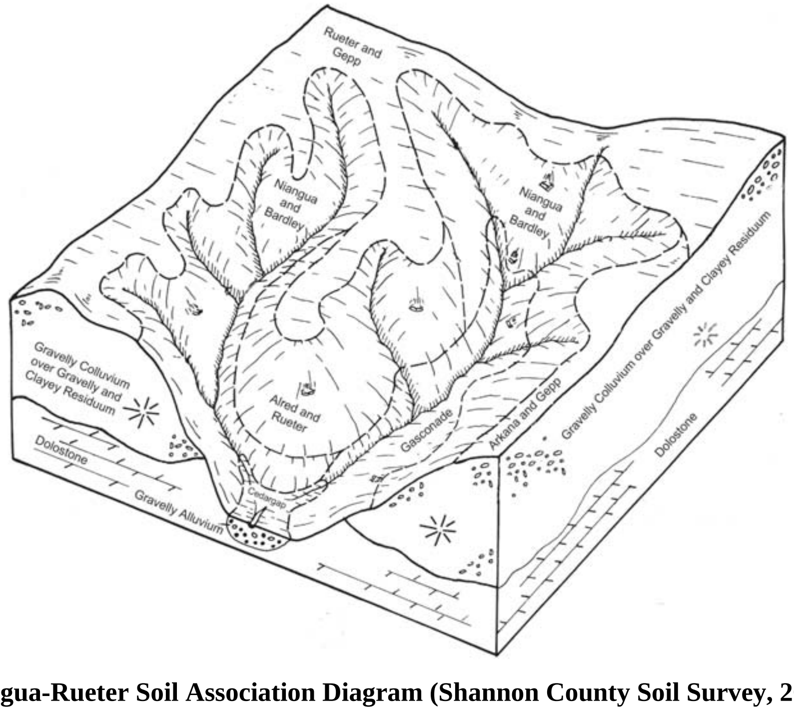

Figure 3-5 Niangua-Rueter Soil Association Diagram (Shannon County Soil Survey, 2005).

Design

Initial Assessment of Trail Problems

Each conservation area's trail system was investigated to determine the present problems. Trails were walked to observe the current conditions and to locate problem areas. A majority of the trails that had significant erosion had either steep slopes or inadequate water control. Muddy areas were found in low lying areas near the water table, and in places where drainage of surface water was not allowed to occur. Trails crossing ephemeral drainages often diverted water onto trails causing erosion.

Surface Stabilization

Surface stabilization is achieved by increasing the strength of the surface material. The concept is to provide a stronger wearing surface than the natural soil that can better withstand the use from horses and thus lower the erosion potential. This can be accomplished by adding surface aggregate (with or without geosynthetics) for strength or using an admixture such as hydrated lime to increase the shear strength of the soil.

Surface Aggregate **-** The aggregate used for the surface application is called one-inch minus base. Specifications for the aggregate are listed in Table 3-1 . The largest particle size is one inch, which is small enough for horses to walk on.

Table 3-1. Surface Aggregate Particle Size Specifications.

Sieve Size	Percent Passing
1 inch	100
1/2 inch	60-90
No. 4	40-60
No. 40	15-35

Geosynthetics - The geosynthetics used for surface improvement were geotextiles and geocells. There were used in specific applications that are described below.

Geotextiles - The geotextile used was a needle punched non-woven polypropylene fabric. The main application of the geotextiles was to provide separation between the trail's natural soil and the surface aggregate. Without separation, fines from the natural soil can migrate upward into the surface aggregate causing trail rutting and muddiness.

The geotextile was used in two different applications: wrapped and non-wrapped. The wrapped design method consisted of wrapping the geotextile fabric around a three inch layer of free draining aggregate, and then capping it with a two inch layer of surface aggregate. A profile of the wrapped design can be seen in Figure 3-6. The wrapped design provides separation of fines, and also provides increased strength.

The non-wrapped design utilized a single layer of geotextile below the surface aggregate. This design provides separation between the natural soil and the surface aggregate, in order to prevent rutting.

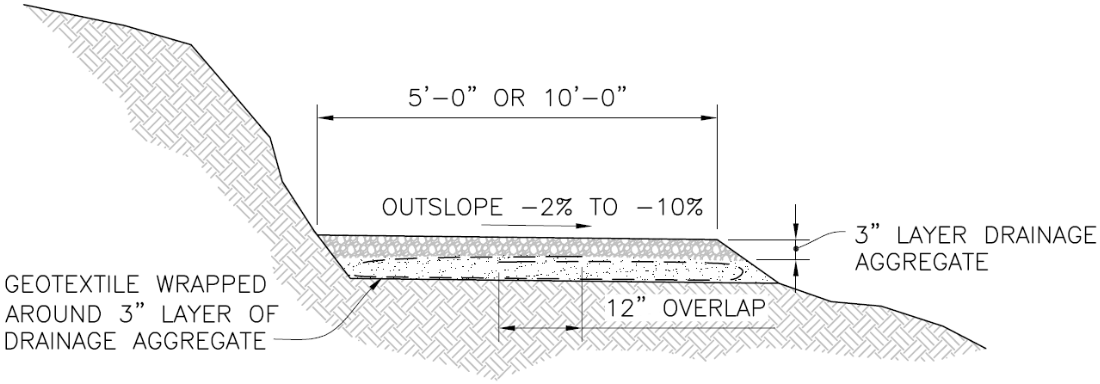

Figure 3-6. Geotextile Wrapped Design Profile.

Geocells - Geocells are a series of connected polyethylene cells that is akin to honeycomb. The geocell reinforcement consisted of either four or eight inch thick perforated geocells filled in with one inch clean drainage aggregate and covered with 2 inches of surface aggregate. The four inch thick geocells can be installed on steep trail sections to prevent rutting and provide a stable surface. A cross-section can be seen for a four inch thick geocell installed on a slope in Figure 3-7. The eight inch thick geocells can be used to provide a stable foundation for stream crossings. The plan view and cross-section of the stream crossings can be seen in Figure 3-8 and Figure 3-9.

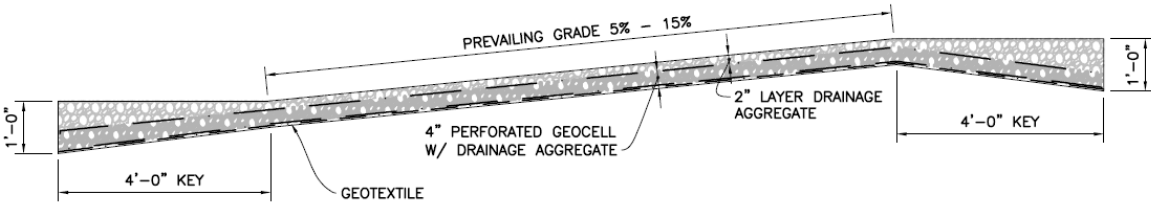

Figure 3-7. Longitudinal Geocell Protection

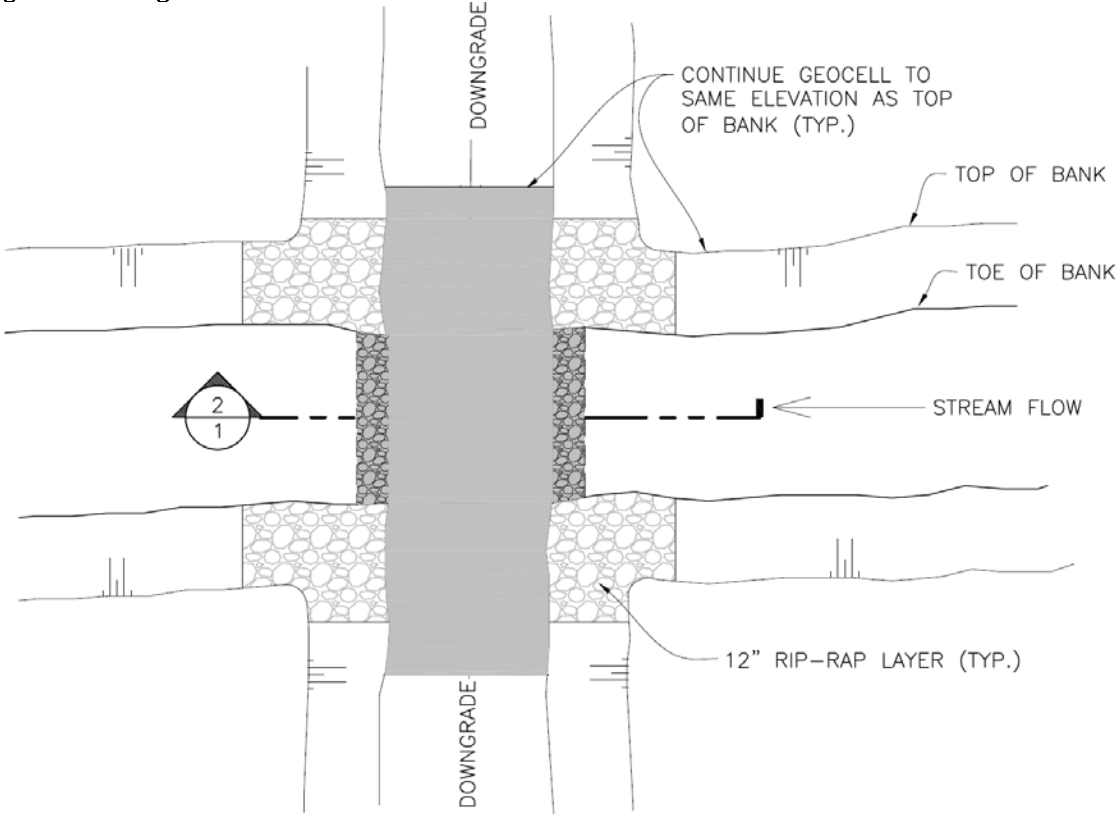

Figure 3-8. Plan View of Stream Crossing.

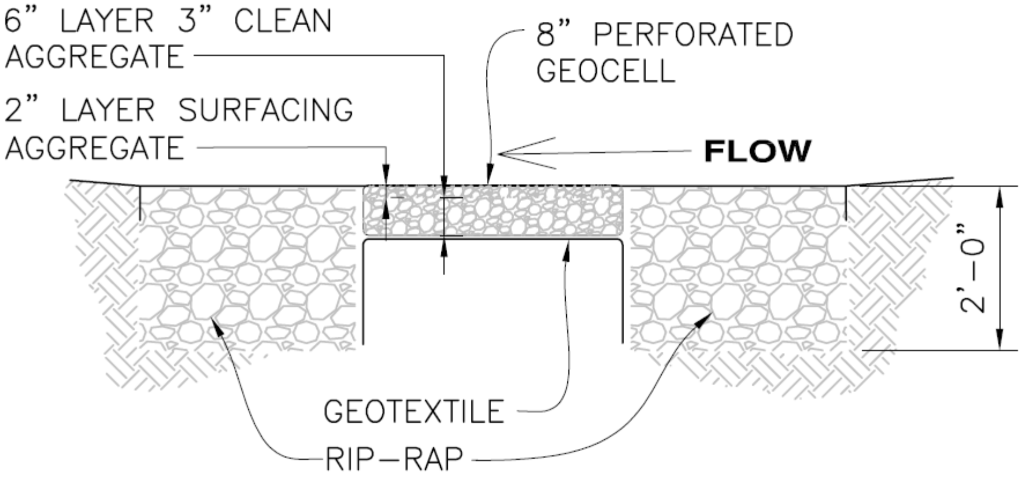

Figure 3-9. Cross Sectional View of Stream Crossing.

Lime Stabilization **-** Lime admixtures can be used where soil conditions are not adequate to provide a stable surface. Mixing lime with fine grained soils can reduce the swelling potential and increase the strength by cementation. Lime stabilization is to be applied by tilling the top six inches of soil and then mixing 10% hydrated lime by weight. Compaction of the trail surface is then performed. Water is to be added to help with compaction.

Surface Water Control

Designing for sustainable trails requires controlling surface water. There are many techniques for diverting water from a trail's surface. The most common technique is shaping the trail's surface, but water diversion structures such as waterbars and grade dips can also be utilized

Tread Shape **-** Shaping the surface tread can divert water off of a trail. Outsloping, insloping, and crowning are the three surface shapes available in trail design. Outsloping involves lowering the downhill side of a trail surface to immediately divert water. This method is adequate for trails that are located on a side slope. Insloping involves lowering the uphill trail surface to collect uphill water and divert it in another place down the trail. This method is adequate for intercepting water that may affect trails that are downhill from the current trail. Crowning a trail surface involves having the outside edges of a trail lower than the middle. Water is shed from both sides of the trail with this method.

Water Diversion Structures **–** Water diversion structures are required on sloping trails where water cannot be diverted by the tread shape alone.

Broad Based Dip (Waterbar) - The broad based dip is constructed by digging a ditch across a trail surface at a 45º angle. The excavated material is then compacted into a hump below the ditch to divert surface water off of the trail. A cross sectional representation of a typical waterbar can be seen in Figure 3-10.

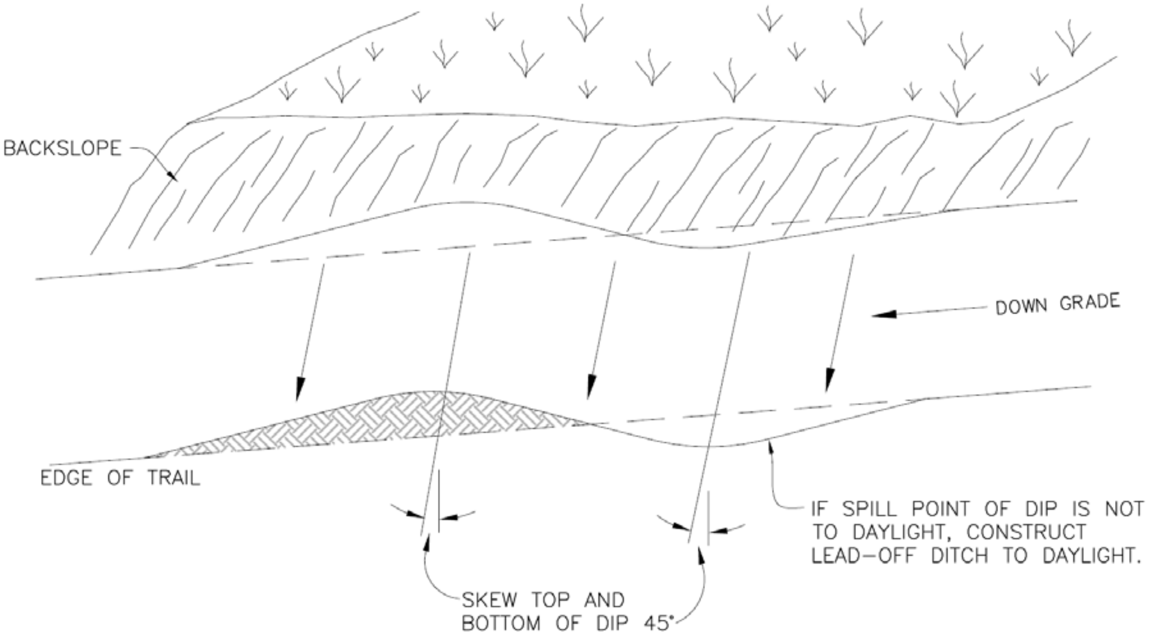

Figure 3-10. Cross Section of a Broad Based Dip.

A modified version of the waterbar is the use of geotextiles to provide separation and reinforcement in the hump. The modified version is constructed by digging the ditch and removing the material. Geotextile fabric is laid where the hump will go. Free draining aggregate is laid on the geotextile parallel to the ditch. The geotextile is then wrapped around the aggregate with a twelve inch overlap. Surface aggregate is then placed on top of the geotextile rap and compacted. A cross section of the modified broad based dip can be seen in Figure 3-11.

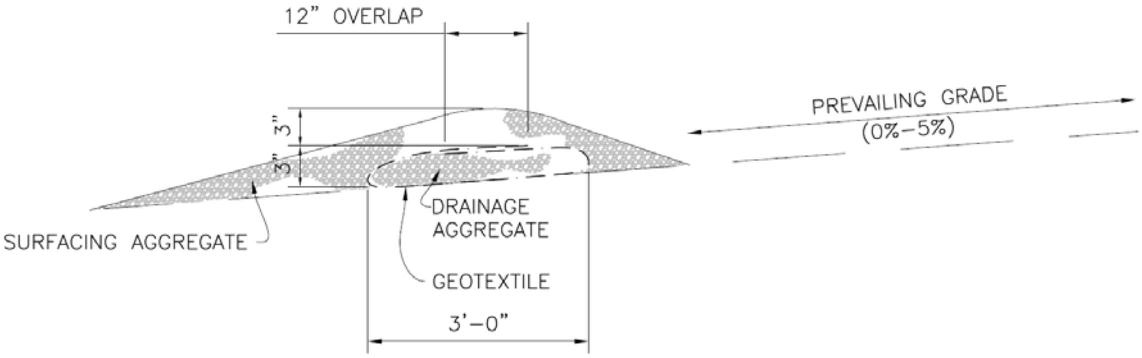

Figure 3-11. Cross Section of the Modified Broad Based Dip.

Grade Dip or Grade Reversal - A grade dip diverts water from a trail by changing the direction of the trail to make the trail drop and then rise back up. This method can be used when crossing side-slope drainages, or whenever water needs to be diverted off of the trial. When crossing side-slope drainages, four inch geocells can be used as an intermittent stream crossing. Plan and cross-sectional views of the grade reversal can be seen in Figure 3-12.

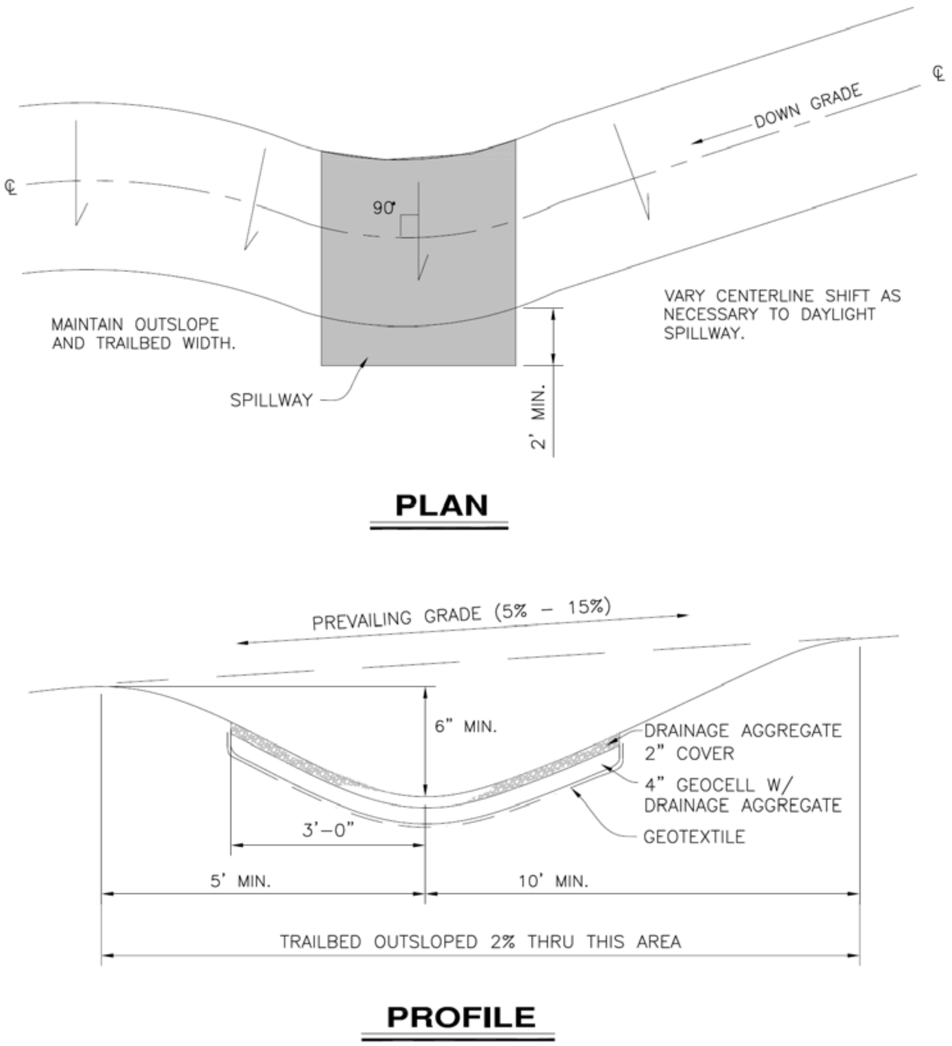

Figure 3-12. Plan View and Profile View of a Grade Reversal

Experimental Design Procedure

Sustainable trail design is accomplished by addressing the three issues of trail design in a sequential fashion: layout, surface stabilization, and surface water control.

Preferred Trail Layout

The trail layout can be analyzed by considering the trail slope, landscape location, and alignment. Trail slope should be held below 10% where possible. If not, a surface stabilization technique should be used. Trail alignment should be maintained almost perpendicular to the side slope (i.e., following the topographic contour). Under no circumstances should the trail go straight up and down a hill (i.e., the fall line). The trail should be located on a side slope to allow water drainage off of the trail. Trails located directly on a ridge top do not easily allow for drainage. Trails located low in the landscape on a foot slope also do not allow drainage, and thus are also prone to become muddy. If any of these conditions cannot be met, surface stabilization needs to be applied.

Surface Stabilization

Where an appropriate trail layout is not possible, surface stabilization needs to occur. If unsuitable soils are encountered (i.e., muddy or highly erosive) on a slope less than 10%, non-wrapped geotextiles should be used for surface reinforcement. If steep areas with a slope greater than 15% are encountered, four inch geocells should be used to provide a stable surface that will not rut. If a trail is in a muddy low lying area, a wrapped geotextile technique should be used for reinforcement and separation. Ephemeral drainage crossings should have a four inch geocell grade dip reinforcement applied. Stream crossings without a stable bottom should use 8 inch geocells to provide a stable surface.

Surface Water Control

After the trail layout has been established and the surface has been chosen, water controls can be designed. Trails with a slope of less than 5% should have an outsloped tread. If a switchback is used to climb a hill, an insloped climbing turn should be used to control water. A detailed drawing of an insloped climbing turn can be seen in Figure 3-13.

Once the tread surface has been selected, placement of water diversion structures can be determined. Either structure can be used (water-bar or grade reversal); the placement is dependent on the slope. The slope and length requirements (Table 3-2) were adapted from the recommendations in the literature.

Table 3-2. Theoretical Length Limits Dependent on Slope.

Slope (%)	Maximum Trail Length (ft)
0%	135
2%	90
4%	57
6%	37
8%	23
10%	14
12%	8
14%	4

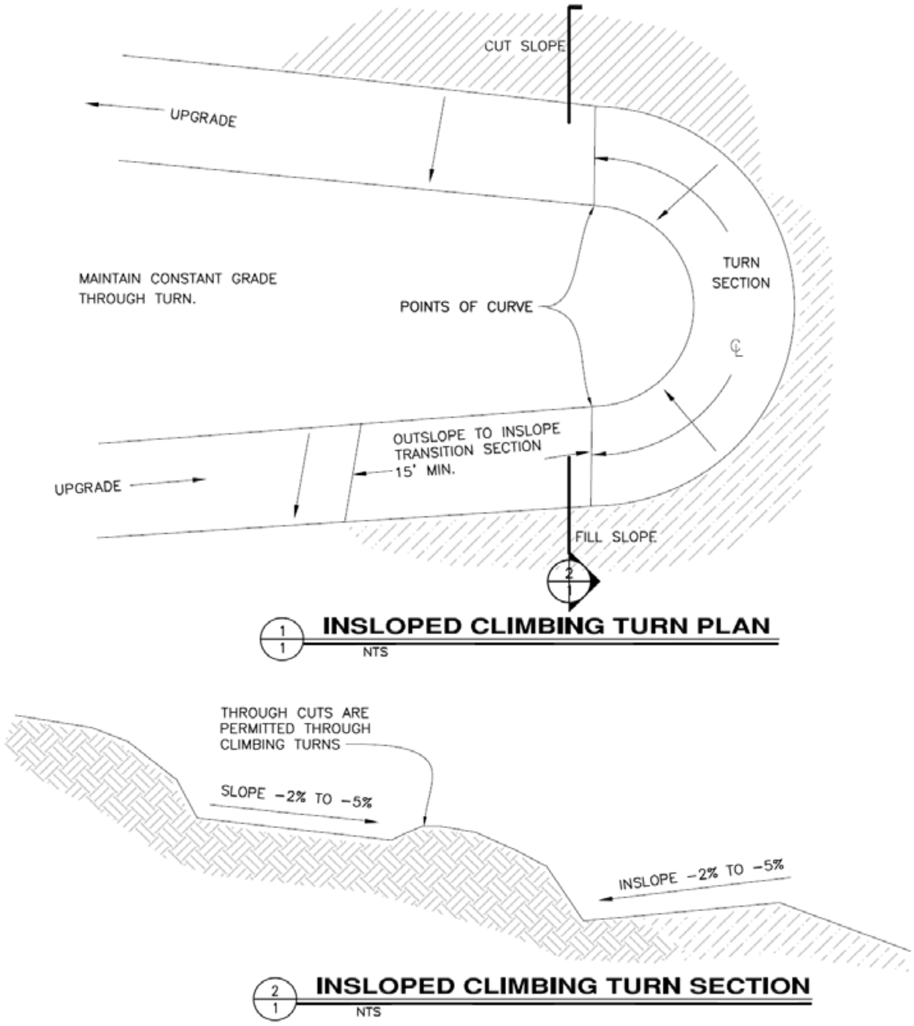

Figure 3-13. Insloped Climbing Turn.

Old Trail Retrofitting

If old trails do not meet the preferred trail layout criteria, they need to be rerouted. If they cannot be rerouted, then the proper surface stabilization techniques and water diversions should be applied.

Construction

Trail construction was conducted between February and July of 2006. Trails segments selected for construction were chosen based on location, constructability, and solution type. Construction consisted of either retrofitting an existing trail or re-routing a trail with poor a location.

Construction observation was performed on site during construction to supervise construction and help determine the best construction practices. The observations made during construction are to be used to develop lessons learned for the equestrian trail guidelines.

Trail Test Segment Monitoring and Testing

Monitoring of test segments began immediately after construction. Observations and measurements were initiated during construction and were continued at two-week intervals until March 2007. Each segment and structure installed had its location recorded by GPS.

Initial measurements for each trail segment are as follows:

- Length
- Slope
- Soil type
- Surface type:
    - Natural Surface
    - Aggregate
    - Aggregate w/ Geosynthetic
- Landscape Location:
    - Ridgetop
    - Shoulder
    - Backslope
    - Nose Slope
    - Head Slope
    - Foot Slope

The observations recorded were: if the trail was disturbed by users, the occurrence of muddiness, and the formation of ruts. Photographs were taken of each incident and its location recorded by GPS. If ruts formed, their length, width and depth were recorded.

Soil data was obtained by a field investigation conducted by Dennis Meinert, a Soil Scientist from the Missouri Department of Natural Resources. The trail surface was examined for every segment tested. The data recorded consisted of surface texture, surface thickness, restrictive layer depth, parent materials, trail and slope alignment, and the topographic surface shape: horizontally and vertically.

4. RESULTS

Definitions

For the purpose of the clarity the general terminology used in this chapter is defined as follows:

Gully - A linear depression greater than six inches deep on a trail surface caused by erosion.

Incised Surface – A depressed trail surface shape that can cause surface water to remain on the trail.

Muddiness – A trail surface condition on saturated natural soil where a two inch or greater depression is created by an external load, such as users' hoofs, feet, or wheels.

Natural Soil Surface – A trail surface that is comprised of in-situ soil.

Rill – An erosion feature less than two inches deep on a trail surface, caused by flowing water.

Rut – A linear depression two to six inches on a trail surface caused either by disturbance from use or by flowing water.

Trail Disturbance – Any surface material that is loosened by the impact of user traffic.

Construction and Observations

Rudolf Bennitt Conservation Area

Three separate test sections were constructed at the Rudolf Bennitt Conservation Area (Figure 4-1) from March through June 2006. The sections were chosen based on the severity of degradation and the potential for solution application.

The equipment utilized for construction of Section 1 was a bulldozer with a ten foot wide blade, a tracked Bobcat®, and a backhoe. The bulldozer was used to shape the new surface and remove trees and vegetation blocking the trail corridor. The Bobcat® was used to build water diversion structures and place aggregate surfacing. The backhoe was used to place riprap for the construction of the stream crossing on Section 1.

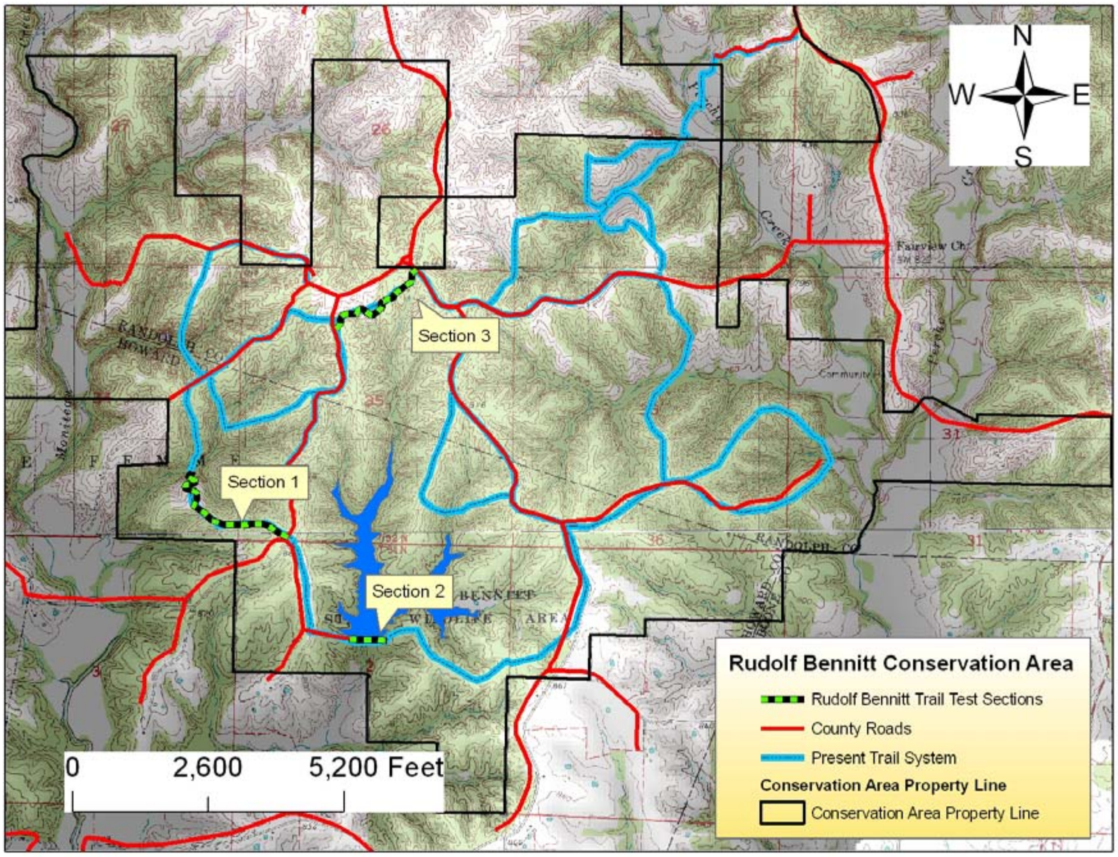

Figure 4-1. Rudolf Bennitt Conservation Area.

Section 1

Section 1 is over 3000 feet in length and begins at an intersection with the county road and continues past a stream crossing (Figure 4-2). The trail follows the ridge top and then travels down hill to the stream crossing.

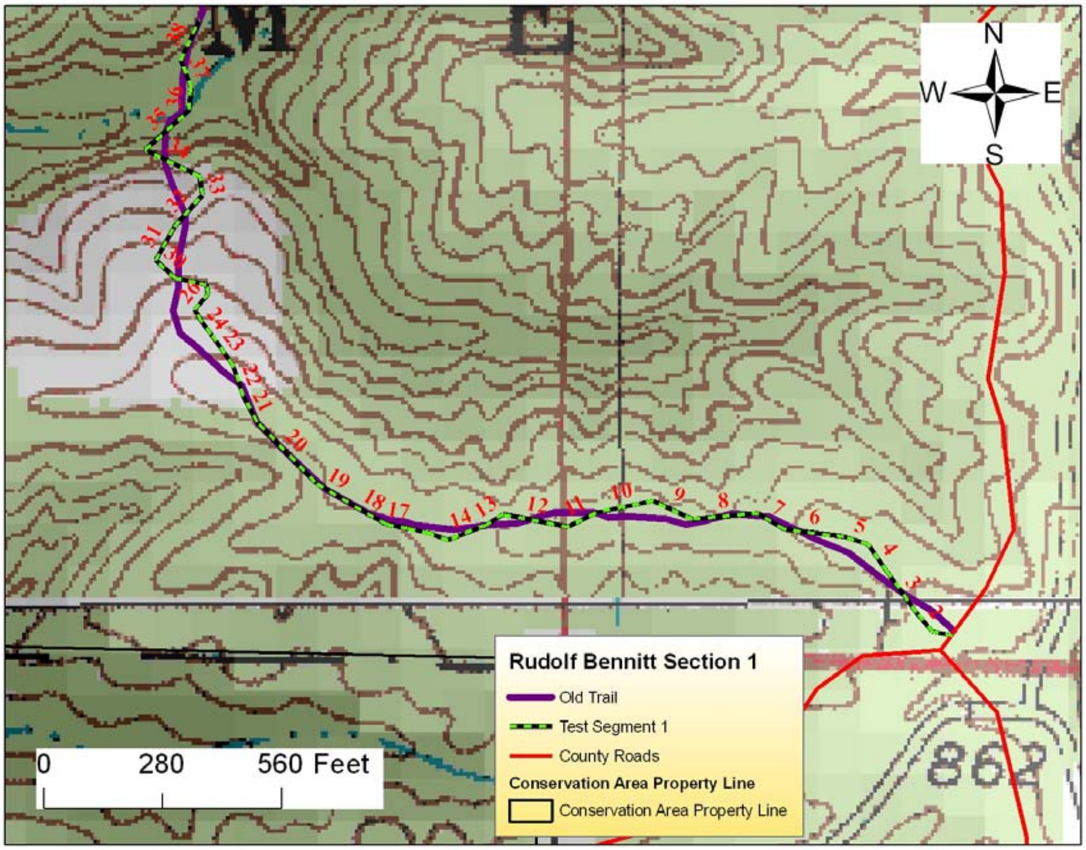

Figure 4-2. Rudolf Bennitt Test Section 1.

<u>Existing Conditions</u> - Along the ridge top, the old trail follows an old road bed (Segments 1 through 21). The old road bed was almost ten feet wide and truncated approximately six to twelve inches below the surrounding ground. The soil surface was highly plastic clay. The section was muddy where drainage was not allowed, and several six inch deep hoof prints could be seen on the surface.

Between the ridge top and the stream crossing, the trail heads downhill. Gullies were observed ranging from one to four feet deep (Figure 4-3). The trail did not feature any methods for diverting water off the trail. All surface runoff from the upper portion of the trail was focused on the trail for several hundred feet.

Figure 4-3. Gully Observed along Section 1.

At the bottom of the hill, near the stream bed, the surface was muddy and saturated (Figure 4-4). The trail had widened to more than ten feet due to users trying to avoid muddy sections.

Figure 4-4. Trail Widening near Stream Crossing on Section 1.

Solutions Applied - Along the ridge top, the trail was rerouted away from the truncated old road bed (Figure 4-2, Segments 1 through 21). The rerouted trail meandered back and forth across the old trail in order to provide an outsloped tread for drainage. The trail surface utilized the in-situ soil. Vegetation was removed along the width of the trail corridor.

Access to the old trail was blocked with the vegetation and trees removed from the new corridor. Check dams were built along the old trail to prevent water from intercepting the new trail.

Segments 22 through 34 were also rerouted to avoid the ruts from the old trail. Switchbacks were used to lengthen the trail and minimize slope. The tread was outsloped and in-situ soil was used as a trail surface.

Segments 35 through 38 followed the old trail corridor because it provided the lowest available slope. Segment 35 was in-sloped and utilized 4 inch geocells due to the steepness of the segment (17%). Segment 36 utilized a geotextile wrap to provide stable footing over a saturated area near the stream bed.

Segment 37 was the stream crossing. The segment used 60 feet of eight inch deep geocells. The stream crossing used 60 linear feet of eight inch geocells. The downstream side was raised six inches to cause water to pool slightly and not scour the surface aggregate.

Lime admixtures were used along Segment 6. Construction, lab testing, and observation results are discussed later in this chapter. Geosynthetic waterbars were installed at varied intervals along the entire section.

<u>Post-Construction Observations</u> - Rills were observed on the silt surface after rain events on Segments 1 though 22. The silt along the ridge top segments was often muddy after rain events, and deep hoof prints could be seen. Later, on the same sections, the hoof prints left from the muddiness appeared as dimples on the trail surface. Raindrop impact remolded the loess soil and erased the proof of the hoof prints.

Water diversion measures (water bars, infiltration bars, and grade dips) effectively controlled water on the trail surface. A few water bars had their geotextile wrap exposed and ripped due to removal of aggregate surfacing. The initial aggregate thickness on the ripped bars was less than two inches deep. Infiltration bars without surface aggregate filled up with sediment, loosing their effectiveness.

Segments 22 through 34 had a clay surface tread. This surface was almost always muddy, and several hundred hoof prints four to six inches deep could be seen long these segments.

Four of the waterbars on Section 1 had surface aggregate removed and the geotextile fabric was ripped due to traffic. The waterbars were covered with less than two inches of surface aggregate for cover. All remaining waterbars had more than two inches of surface aggregate and removal from traffic was not observed. None of the waterbars exhibited any settling or depressions during the observation period.

A rut was observed on Segment 35 traveling perpendicular to the trail. The rut was formed by water traveling directly across the trail. The surface aggregate on Segments 35 was always observed to be stable.

Section 2

Section 2 (Figure 4-5) is over 750 feet in length and consisted of a newly created path across the earthen dam for Rudolf Bennitt Lake. A path across the crest of the dam was required to complete a loop trail across the conservation area. Because MDC is responsible for ensuring the integrity of the dam, the crest of the dam cannot be allowed to settle or rut due to trail use. Therefore it was decided to apply geosynthetics and build up the surface six inches in order to prevent rutting.

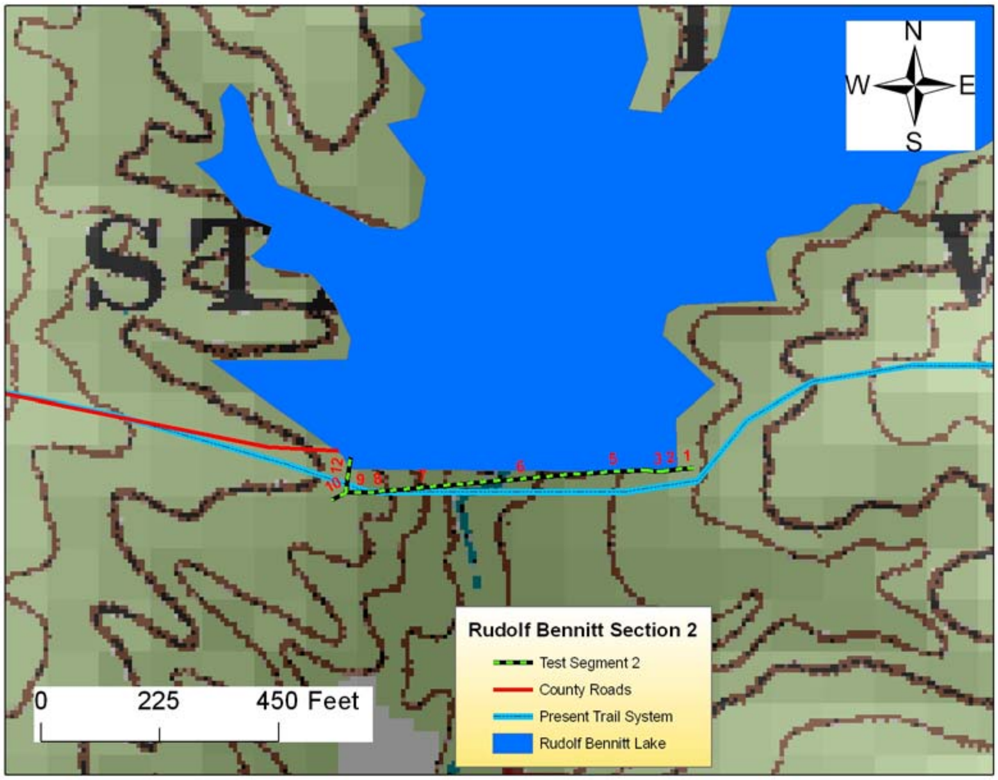

Figure 4-5. Rudolf Bennitt Test Section 2.

Two methods of geotextiles were used in Section 2, wrapped and non-wrap. The methods were alternated across the crest of the dam and had a crowned surface. Geocells were installed on Segments 1, 3, and 11. Segments 1 and 3 are on the slopes of the spillway. The slopes crossing the spillway were greater than 10%.

A concern was that riders would try to direct their horses to drink from the lake whether or not an area was provided. Therefore, a segment was installed on the upstream face of the dam to provide a location for horses to drink from the lake without damaging the structure.

<u>Post-Construction Observations</u> - No ruts or disturbances were observed on Section 2 during ten months of observations. Many vehicles have been driven over Section 2 for other trail renovations, with no visible impact.

Section 3

<u>Existing Conditions</u> - Section 3 (Figure 4-6) was an existing trail where little use was observed. The trail was 1000 feet in length and followed a path that went straight up

and down the hills. The path had steep slopes ranging from 10% to 20%. Ephemeral drainages that were crossed by the trail were often muddy and did not provide stable footing.

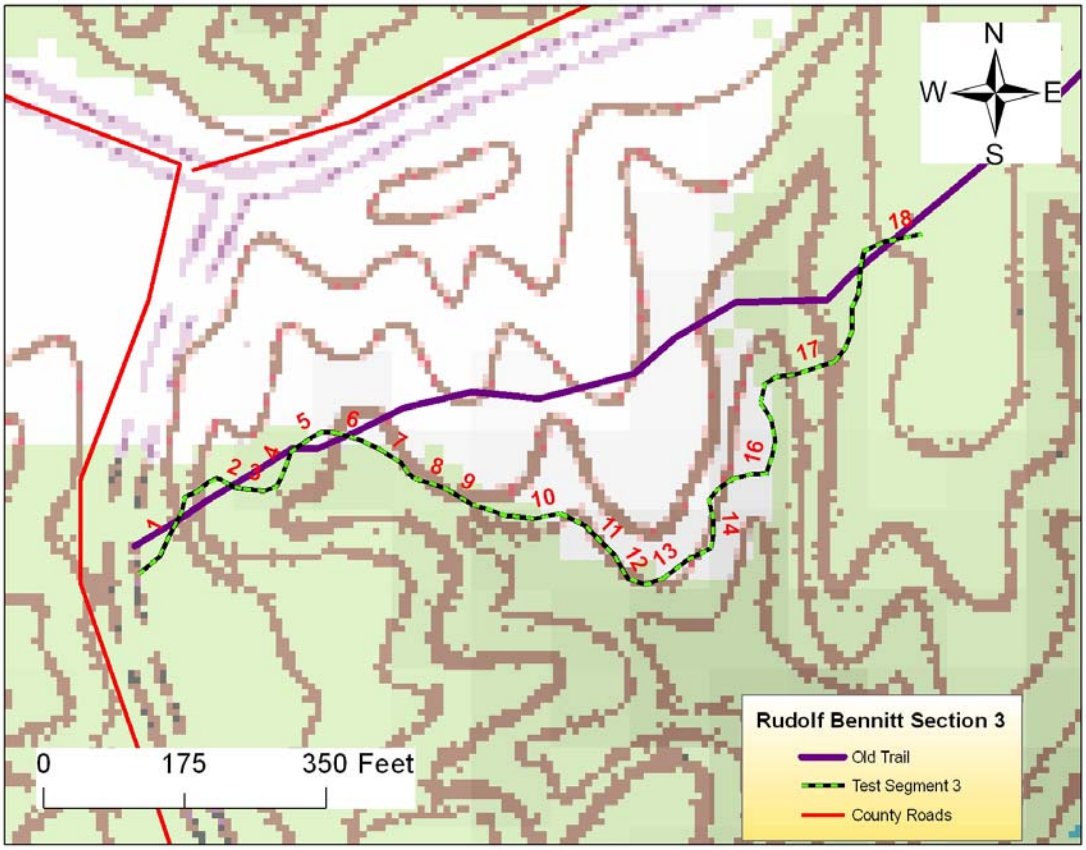

Figure 4-6. Rudolf Bennitt Test Section 3.

Solutions Applied - Section 3 was rerouted to follow the topographic contours with a final length over 1400 feet. The surface was outsloped and the in-situ soil was used for the surface. Any ephemeral drainages crossed were filled with riprap (for water to flow through) and covered with one-inch clean aggregate. No water diversion structures were installed or needed due to the outsloped tread and minimal slope.

Post-Construction Observations - Minimal traffic traveled on the trail during the observation period. No ruts or disturbances were seen for most of the observation period. In March 2007, severe muddiness occurred along the entire length of the section. The trail surface was disturbed by six inch deep hoof prints that were filled with water. It was difficult to obtain stable footing.

Two of the four ephemeral drainage crossings clogged with sediment and water ponded behind the structures. Clogging of the largest drainage structure caused water to flow over the structure leaving four inch deep ruts on the surface.

Forest 44 Conservation Area

Three test sections were created at Forest 44 Conservation Area (Figure 4-7). Each section involved repairing troubled trails within their present corridors. Area managers could not reroute trails due to limited space between trails and archeological sites.

Equipment used for construction consisted of a Bobcat® to shape the trail surface and a small utility ATV with a dump bed for hauling aggregate. The equipment's small foot print (less than five feet wide) allowed for the trail corridors to remain small.

Construction was completed during a one week period in February 2006. The construction crew had several people available along with several pieces of equipment. This allowed for speedy trail construction.

Only a small portion of construction was observed. The quick speed of construction was unexpected, and the work was completed before observations could be made. The only record of construction methods are from pictures and eye-witness accounts by area managers.

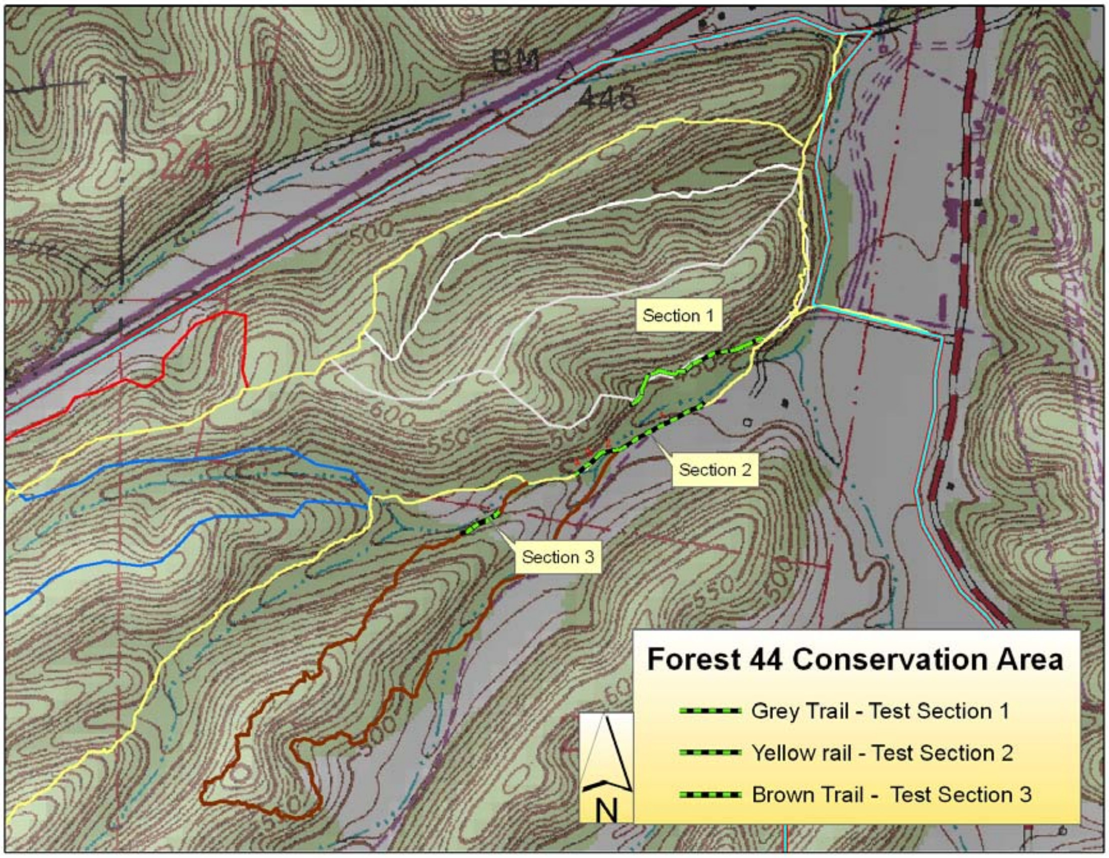

Figure 4-7. Forest 44 Conservation Area

Section 1

Existing Conditions - A section of the locally known "Grey Trail" at Forest 44 was used for Section 1 (Figure 4-8). The trail was located on a back slope and traveled parallel to the topographic contours in most places. Trail alignment was almost perpendicular to the slope face so rerouting was not required. The average width of the trail corridor was three feet.

While the trail had a good location and layout, incised ruts could be seen along the trail due to compaction and displacement of material. Steep sections of the trail had ruts four to twelve inches deep. Segments with lesser slopes were often muddy or had water ponding on the trail surface.

Segments 16 through 18 had steep slopes, 15%-17%, and were incised four inches deep and four feet wide. Trail alignment was seventeen degrees. The surface was constantly muddy and the corridor had widened to more than ten feet wide due to users avoiding the mud.

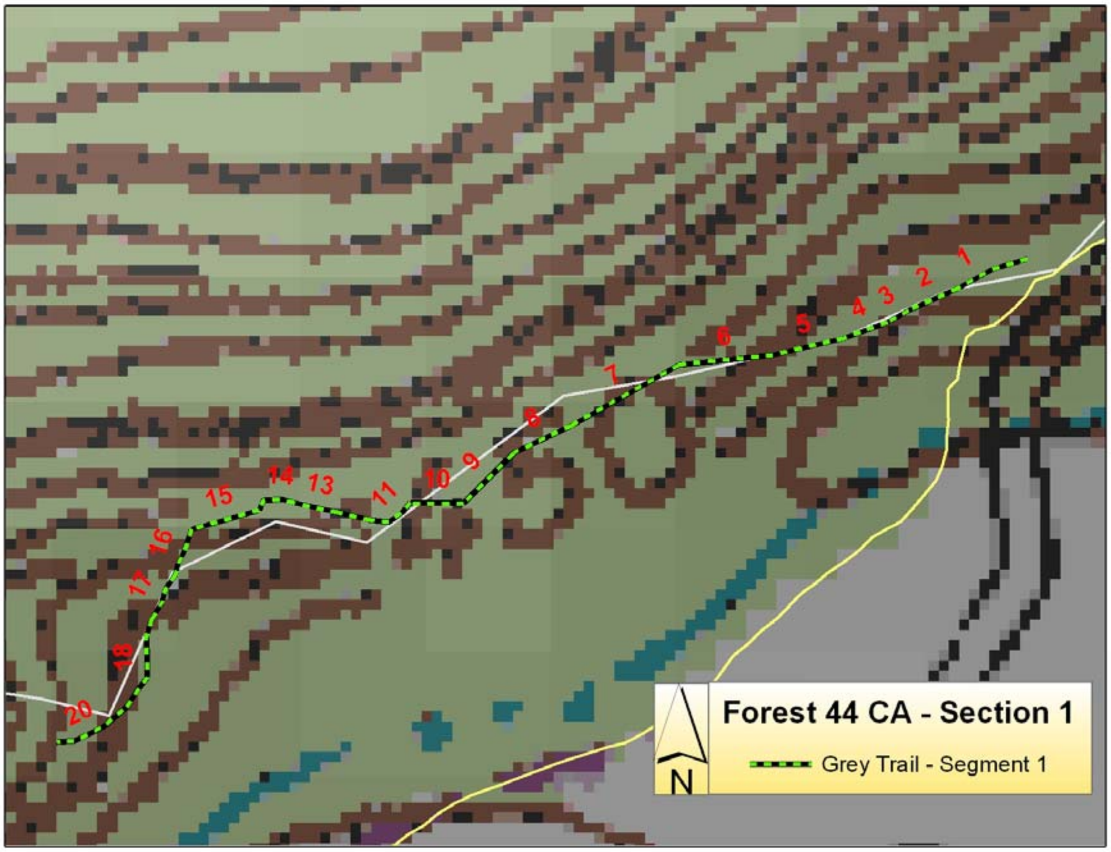

Figure 4-8. Forest 44 Test Section 1.

Solutions Applied - The incised sections were remolded with equipment to outslope the tread surface. Geosynthetic waterbars were installed on sections with slopes greater than 10% to divert water from the trail.

The majority of the segments were assigned to have the natural soil as the trail surface, but segments 1-4, 9, and 11-12 had surface aggregate applied (without geosynthetics) to the trail surface. The reason for the application, according to the construction workers, was to fill in ruts and level the trail surface so equipment could traverse the trail.

Figure 4-9. Segments 16 through 18 Before and After Treatment.

Segments 16 though 19 had geosynthetics applied to the surface. Because the surface was muddy during the reconnaissance visits, it was decided to improve the strength of the surface with geosynthetics. The solutions applied were two geotextiles segments (wrapped and non-wrapped) and two segments with four inch Geocells.

Section 1 crossed two ephemeral drainages (Segments 6 and 20). Both segments crossed the trail at grade. Grade dips with four inch geocells were installed to provide a stable surface and allow water to flow over the trail without ponding.

Post-Construction Observations - A path of disturbance one or two feet wide was observed on all natural soil and surface aggregate (without geosynthetics) segments. Evidence of this is shown by slight depressions. The depression was located parallel to the trail corridor and was usually on the lower side of an outsloped surface. On the natural soil segments, the depression was filled with rock fragments (Figure 4-10). It is believed that disturbance from users loosened the soil. Then, smaller particles were removed by water erosion, leaving larger particles behind.

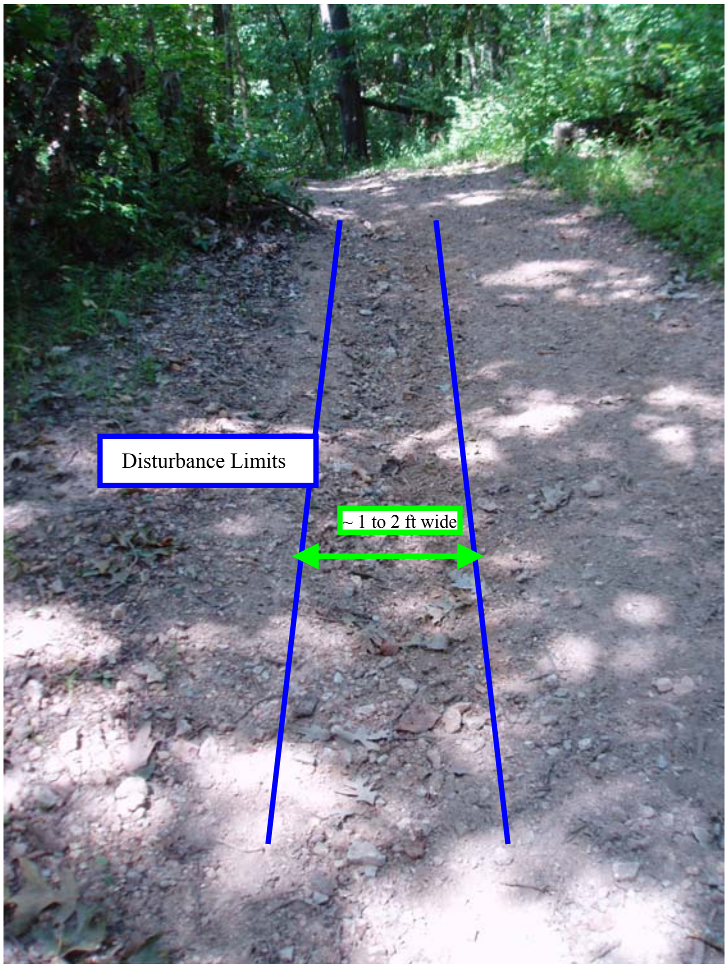

Figure 4-10. Rut Created by Disturbance on Natural Soil Segment (Segment 7).

All of the nine geosynthetic waterbars were observed to "sag" on Segments 1 through 14 within two months (Figure 4-11). The sags were observed as depressions of one to two inches on the waterbar where traffic was focused. Evidence of surface traffic showed that most users followed the same one foot wide path on the trail. The waterbars appeared to be trampled by the users traveling over the same one foot wide section. Because limited construction was observed, it is difficult to provide reasoning why this happened. The lowest part of the water bar was still higher than the trail surface, enabling it to continue to divert surface water.

The three geosynthetic waterbars on Segments 16 through 19 (sections with geosynthetic surface stabilization) did not sag during the twelve month observation period.

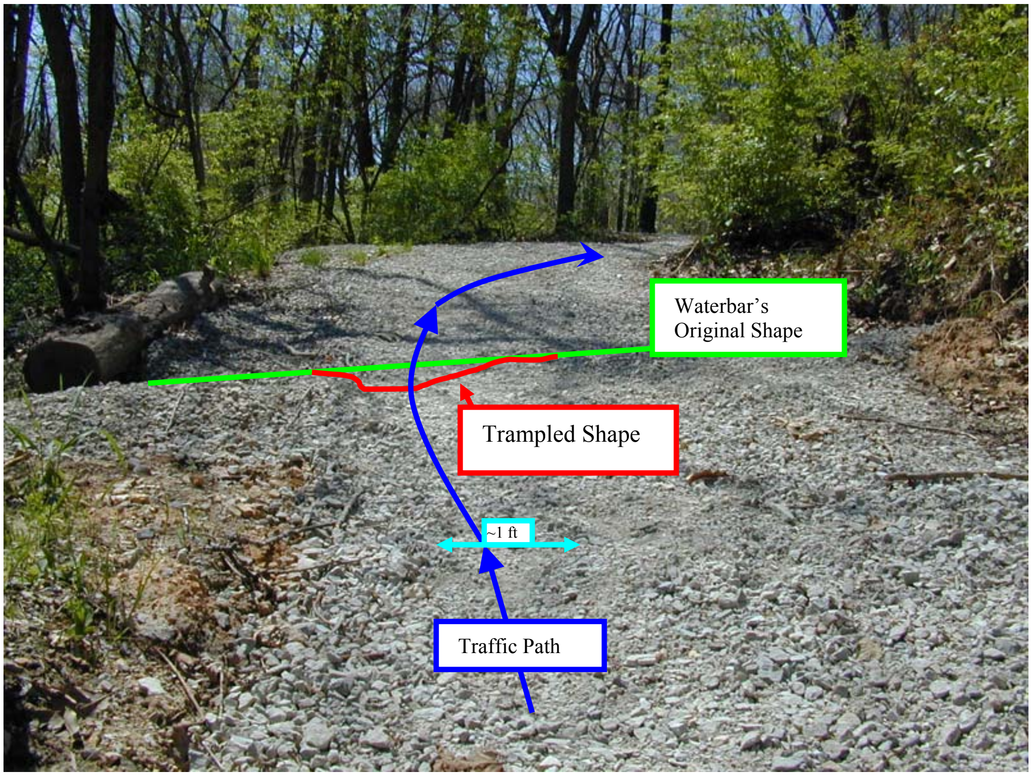

Figure 4-11. Trampled Waterbar.

Segments 16 through 19 were not observed to have ruts caused from disturbance by users. Although a path could be seen along the crowned surface due to user traffic, no depressions along the path were observed. The path created was approximately one to two feet wide.

During January 2007, the aggregate surface (within the path of use) appeared to have a significant amount of fines (Figure 4-12). Hoof prints could be seen ¼ inch deep in the aggregate surface.

Figure 4-12. Segments 16 through 19 (Observed during January 2007).

Section 2

Existing Conditions - Section 2 (Figure 4-13) was located in a valley along the Yellow Trail in the conservation area. The trail is twelve feet wide. All users travel on this trail because all other trails are only accessed by this main trail. The test section is over 800 feet long and crosses a stream.

The low lying trail was incised below the surrounding soil surface. After rain events, the trail was muddy for a significant amount of time because it was so low in the landscape. Because of the incised surface, surface water runoff often flowed on the trail surface and discharged into the nearby stream. The trail had become an ephemeral drainage for water during rain events.

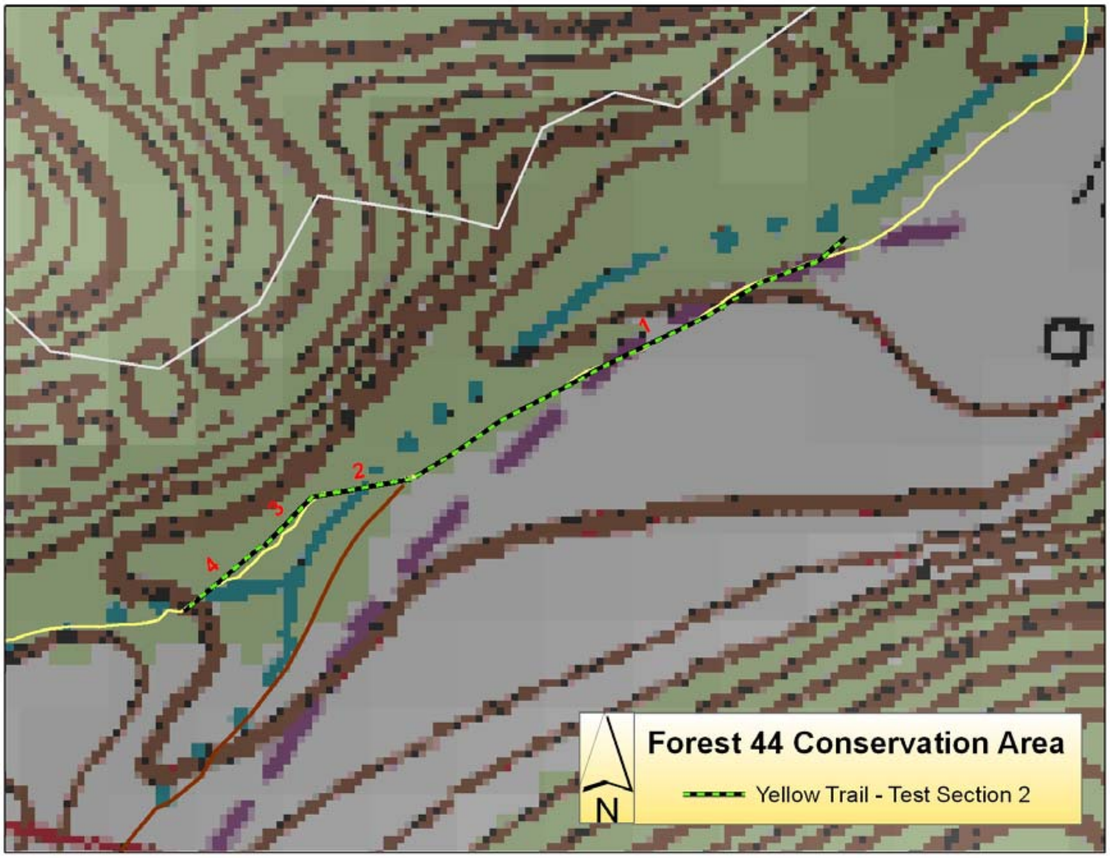

Figure 4-13. Forest 44 Test Section 2.

<u>Solutions Applied</u> - Segment 1 remained as a natural soil section and was left alone. Segments 2 and 4 were constructed with a geotextiles wrap. The trail surface was crowned. Segment 3, the stream crossing, was treated with eight inch geocells.

<u>Post-Construction Observations</u> - The natural soil segment (Segment 1) was muddy after rain events. When the surface was dry, disturbance broke up the soil to create a loose dust two inches deep (Figure 4-14).

Figure 4-14. Forest 44 - Section 2 - Segment 1- Muddy and Dry.

A two foot wide path was observed on Segments 2 through 4 that suggests that a majority of user traffic was focused on only one part of the trail corridor. The trail surface remained crowned during the entire observation period and no depressions from disturbance were observed. During January 2007, the two foot wide user path appeared to be smooth and have more fines. The one inch particles were not seen on the surface. Again, this observation was only seen on geosynthetic stabilized segments.

Section 3

Section 3 (Figure 4-15) consisted of a 300 foot section of the Brown Trail. The section travels from the footslope, uphill along the backslope of a finger ridge. The soil on the section was clay that was often wet and muddy. The steep slope of the trail combined with the clay created a slippery condition. Hoof prints four inches deep were observed many times along the section, along with evidence of hoofs sliding downhill.

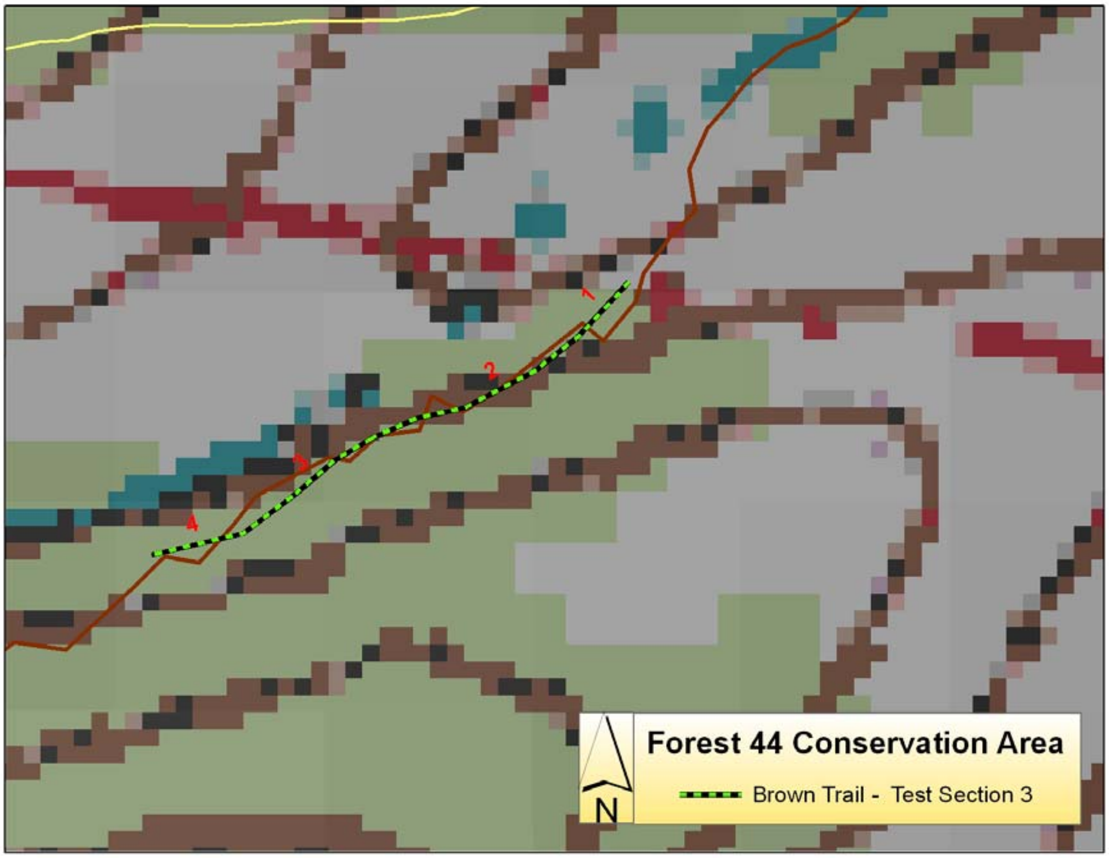

Figure 4-15. Forest 44 Test Section 3.

Solutions Applied - Geosynthetics were applied to each segment along Section 3 because of the muddiness and the steepness of the trail. Segment 1, the steepest segment (18%), was constructed with 4 inch geocells. Segments 2 and 3 were constructed with geotextile wraps. Segment 4 was constructed with the non-wrap geotextile fabric. The surface of each trail was crowned and waterbars were installed between each segment.

Post-Construction Observations - The crowned surface was not observed to have any depressions or ruts due to disturbance. The aggregate surface revealed a path of travel created by users to be two feet wide. During January 2007, the aggregate surface appeared to be smooth and have more fines along the path most traveled.

Angeline Conservation Area

One test section was created at the Angeline Conservation Area (Figure 4-16). The single test section involved rerouting a trail with poor slope alignment. A decision was made by area managers to put surface aggregate on all trails and make them eight feet wide; therefore maintenance could be completed with four-wheel drive vehicles.

Equipment used for construction was a bulldozer with a thirteen-foot wide blade, a road grader for surface shaping, dump trucks for placing aggregate, a large front-end loader with back-hoe attachment, and a Bobcat® for refined surface shaping.

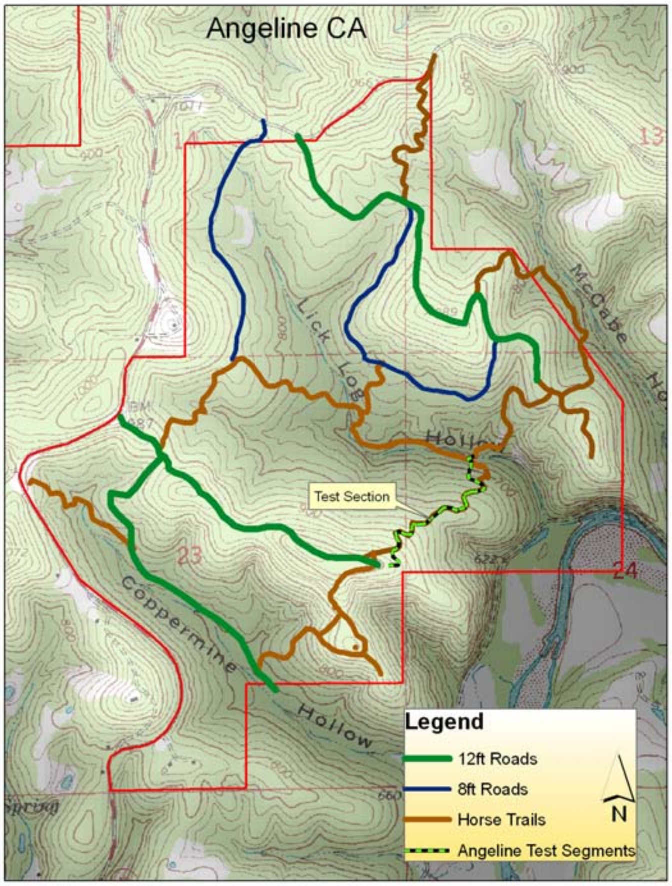

Figure 4-16. Angeline Conservation Area.

Section 1

Existing Conditions - Section 1 (Figure 4-17) involved rerouting an old degraded trail. The old trail traveled straight down the hill with no provision for water to be diverted off of the trail. The steep parts of the trail had been incised from disturbance and erosion. The remaining surface particles were large rock fragments and cobbles ranging from three to five inches, which made stable footing for the horses difficult. The section near the stream, in Lick Log Hollow, had weak soil. The surface was saturated clay that was underlain by a dolomite rock outcrop. The area was constantly muddy and saturated during every observational visit.

The topography for Section 1 is stair stepped or benched. The trail begins on the ridgetop and heads downhill along a shoulder slope. The trail follows a flat bench (near Segments 12 and 13) and then heads downhill along the backslope.

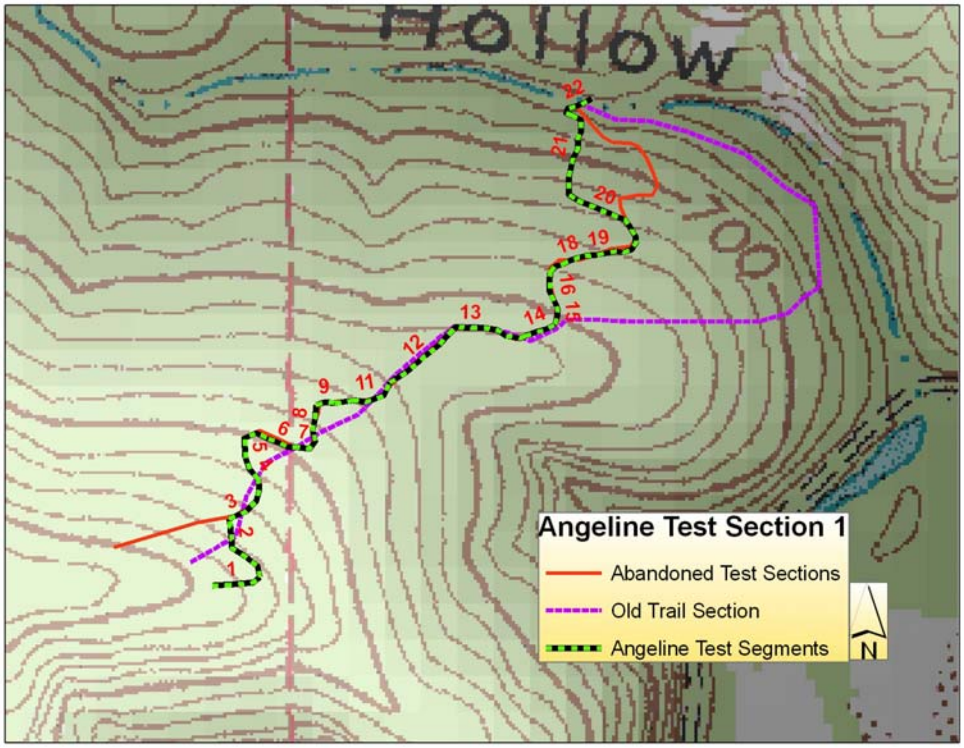

Figure 4-17. Angeline Test Section 1.

Solutions Applied - The original trail was rerouted to create better trail alignment, decrease the slope, and allow the trail surface to be outsloped. Segments 1 through 3, and 18 through 19 were treated with surface aggregate (no geosynthetics). Segments 4 through 11, and 13 through 17 had non-wrap geotextile fabric applied.

Segment 12 was the only segment that had wrapped geotextiles applied to it. It was determined all the other sections were too steep to install the wrapped geotextile fabric.

Segments 20 through 21 had extremely high slopes, 20% and 40+% respectively. No solutions were prepared for slopes that steep. Therefore they were covered with surface aggregate (no geosynthetics).

Segment 22, near the stream crossing, was treated with an eight-inch layer of two-inch clean aggregate and then covered with surface aggregate. The stream crossing at the bottom of the hill had a solid bedrock bottom, and was left asis.

All sections were covered with surface aggregate to match all other trails on the conservation area. No natural soil surfaces were included in the test section. All aggregates were placed by backing dump trucks downhill while dumping the aggregate. The dump trucks were then hauled uphill by a small dozer, because the trucks could not climb the steep hills on their own. This method was not effective in obtaining the desired aggregate cover of four inches. The final average surface aggregate thickness was greater than six inches.

Post-Construction Observations - A rainstorm occurred the night before the initial measurements of the test section. Water was observed running on the trail surface on Segments 9 through 10, and 20 through 22. Both of these stretches are located within 36 inches of bedrock. Segments 9 and 10 are located directly above a benched topography and Segments 21 and 22 are located directly above a footslope.

Six inch deep ruts were observed in September 2006 caused by stormwater runoff from an intense thunderstorm. The switchbacks between Segments 3 through 11 were outsloped. All water on the trail was successfully diverted downhill, but unfortunately the next switchback intercepted the water. Water from uphill was not successfully diverted away from the downhill trails.

Ruts from wheeled vehicles were observed around sharp corners several times throughout the observation period (Figure 4-18). The ruts were most likely created by four wheel drive vehicles digging in while making sharp turns. While in four wheel drive, the wheels all turn at the same speed. When turning, the inside wheels turn the same number of revolutions, but travel a smaller distance than the outside wheels. The excess revolutions of the inside wheels can dig into the surface creating ruts. While ruts and disturbance could be seen due to flowing water and wheeled vehicles, no rutting or disturbance caused by horses was observed on Segments 1-21.

Figure 4-18. Ruts from Wheeled Vehicles on Sharp Turns.

Segment 21 and 22 were observed to have ruts four to six inches deep from wheeled vehicles due to inadequate surface strength. Hoof prints were observed between the ruts from wheeled vehicles. Evidence of users sliding was observed by smearing on the surface. Both segments were muddy and water was ponded in the ruts (Figure 4-19). Geosynthetic separation was not installed on either segment. The surface aggregate had mixed with the underlying clay. The surface on Segment 22 was always observed to have a wet appearance. That segment crosses a large concave topographic shape that collects water from a large watershed drains onto the trail.

Figure 4-19. Ruts and Muddiness Observed on Sections 21 and 22.

Lime Stabilization Results

Lime stabilization was suggested for use as the surface treatment to be used on Section 1 of Rudolf Bennitt CA. The incised road bed had highly plastic clay on the surface rather than the silt surrounding the trail. The treatment was planned to be used on the trail, but the new path created during construction. In early June 2006, the decision was made to proceed with the experiment. Lab testing was not performed prior to field construction. Therefore the amount of lime required had to be estimated.

In June 2006 lime stabilization was performed on Test Segment 6. Lime was mixed at a rate of 10% by dry weight with the “mixed soil.” It was estimated that mixing lime at rate of 6% would be adequate in lab conditions. Mixing and compaction in the field would not be as efficient; therefore, a rate of 10% was used.

Mixing was accomplished by using tilling attachment on a Bobcat®. The surface soil was tilled six inches deep by making several passes with the Bobcat® with the tiller attachment. Hydrated lime was dumped on the loose soil in 50-pound bags. Water was added by making a few passes with a pick-up truck with a water tank. The soil-lime mixture was then mixed by making several passes with the Bobcat®. The soil was compacted with the Bobcat® making several passes over the section.

Lab Testing

Lab testing was performed on samples taken from Segment 6 prior to construction. The tests performed involved particle size analysis, Atterberg limits, and unconfined shear strength testing of lime cured compacted samples. The mixture rate of lime was varied (0%, 3%, 6%, and 9%) at different curing time intervals (1-day, 7-day, and 28-day). Shear strength testing was also performed on dry and wet samples to observe the effect of water content.

The hydrometer analysis (Figure 4-20) and Atterberg limit testing (LL= 40, PI=20) reveal the in-situ soil is classified as silt.

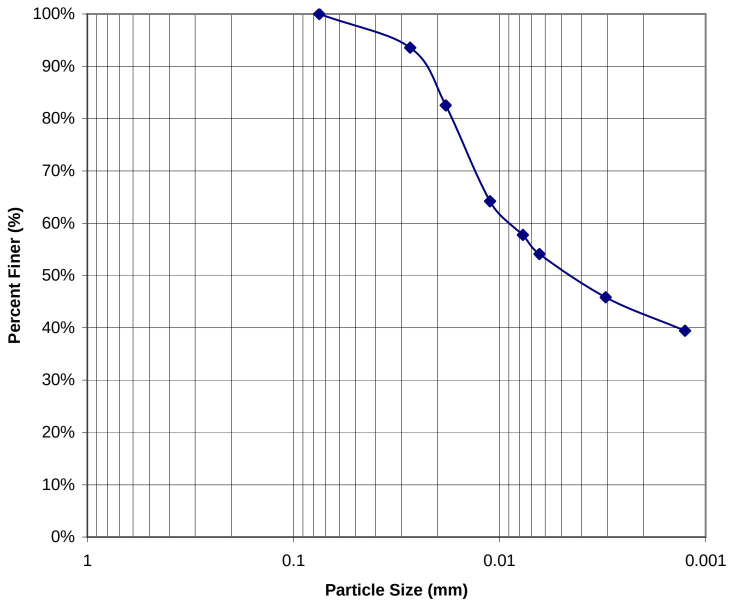

Figure 4-20. Hydrometer Analysis of the In-situ Soil.

Shear strength increase over time for the lime cured samples can be seen in Figure 4-21. After one day of curing, a strength gain of 100% occurred with the 3%, 6%, and 9% samples. For the seven and twenty-eight day curing times, a significant strength increase was not seen.

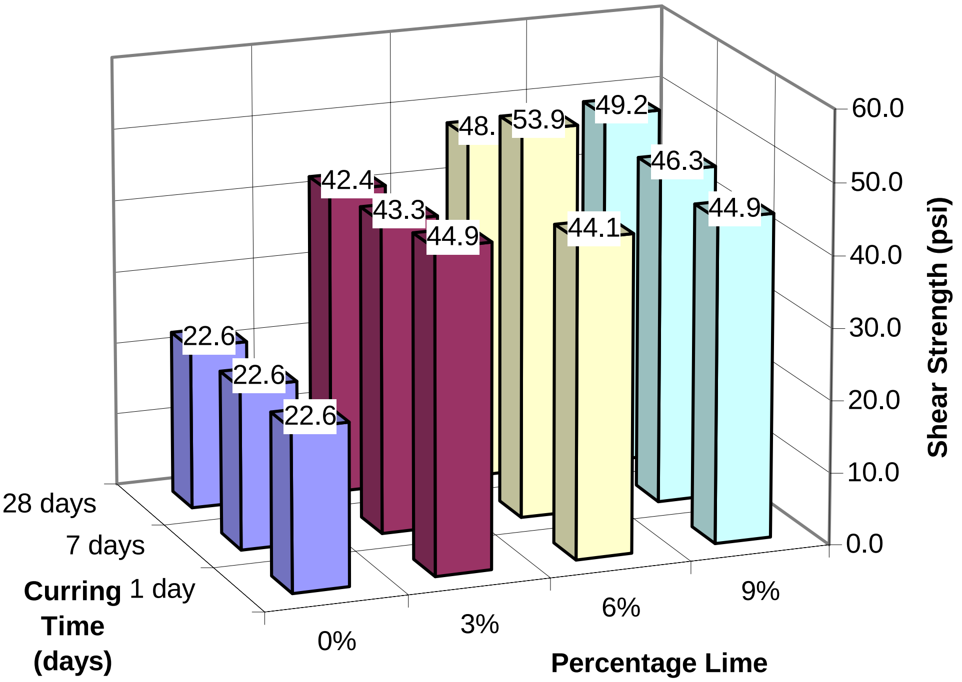

Figure 4-21. Maximum Shear Strength for Lime Cured Samples.

A shear strength comparison for wet and dry samples can be seen in Figure 4-22. The strength when wet decreases for all levels of lime mixtures. The average shear strength decreases by 30% for samples with no lime, and almost 50% for the lime cured samples. Although the shear strength decreases more for the lime cured samples, the strength is still higher than the in-situ soil. The 6% and 9% samples average wet shear strengths of 25 psi, which is stronger than the in-situ soil when dry.

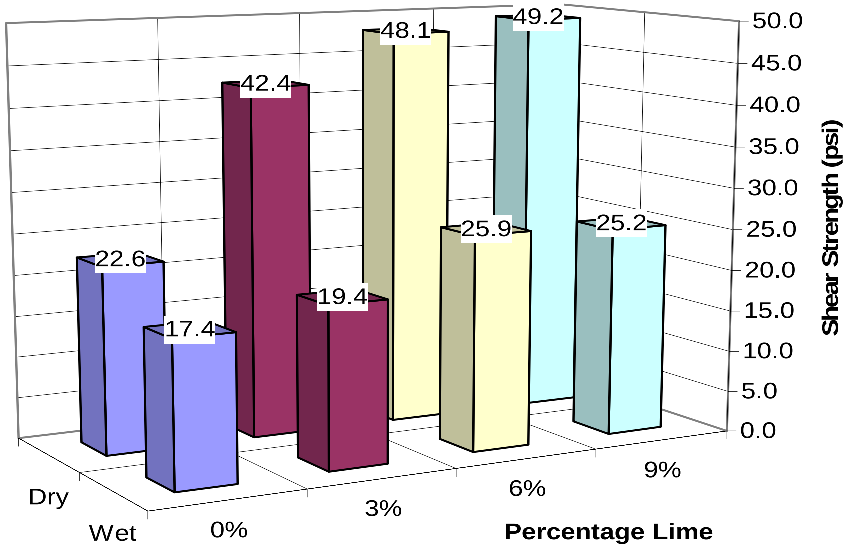

Figure 4-22. Average Shear Strength Results for Wet and Dry Lime Cured Samples (28-day curing).

Atterberg limit results (Table 4-1) show that the lime stabilization was effective in decreasing the plasticity index of the in-situ soil. The plasticity index of 20 was reduced to 9 by adding only 3% lime. The 6% and 9% samples broke apart and were not able to be rolled to the 1/8" diameter. They were considered non-plastic behavior.

Table 4-1. Atterberg Limit Results of Lime Cured Samples.

Percent Lime	Atterberg Limits		
	PL	LL	PI
0%	20	40	20
3%	26	35	9
6%	Not Plastic	35	N/A
9%	Not Plastic	N/A	N/A

Post-Construction Observations

The lime stabilized trail segment was not observed to rut from water erosion or become muddy during any part of the observation period. The surface appeared to be solid and stable even when adjacent sections were observed to be muddy. Imprints left on the surface from traffic were different than adjacent sections. Outlines of horse shoes could be seen on the lime stabilized section, versus an entire hoof prints were observed on adjacent sections. These different imprints show the difference strengths between the treated and untreated sections.

During the winter months of December 2006, January 2007, and February 2007 the site had undergone several cycles of freezing and thawing and experienced several winter storms. In late February 2007, the final snow cover had melted to reveal a highly disturbed surface. The lime treated soil was broken up and loosened along the entire segment's surface. The loose particles consisted of chunks varying in size from 0.1 to 2 inches. Hoof prints two inches deep were observed from a few horses.

5. DISCUSSION

Wearing Surface Effectiveness

Natural Soil Surfaces

The soil textures studied were clay, silt, clay loam, and gravely silt. These textures represent just a limited sample of spectrum of potential soil textures that may be encountered, but conclusions can still be drawn about their applicability for equestrian trail surfaces. All of the natural soil segments exhibited rutting at least inch inch deep due to user disturbance. When dry, natural soil surfaces were broken up and turned to dust by horse traffic. When wet, the surfaces were muddy and unstable. Sliding was observed on segments with slopes greater than 10% when wet. Hoof prints remained on the natural soil surface in muddy areas after the soil dried.

Evidence of erosion due to dispersion by water was observed by rills forming in the silt segments at Rudolf Bennitt. On segments with textures other than silt, rills were not observed due to water erosion. However, it is possible that with a longer period of observation, these would be witnessed.

The observations of user disturbance, muddiness, and erosion provide evidence that natural soil textures tested cannot withstand the impacts and stresses applied by horses.

Surface Aggregate without Geosynthetics

Trail segments that were constructed with surface aggregate without geosynthetic protection were effective in providing stable surfaces under certain conditions. These trail segments at the Angeline CA were successful near the ridgetop while overlying soils with high percentages of silt and gravel. Ruts did not appear from the upward migration of fines into the aggregate surface. Ruts and muddiness did appear in sections in low lying topographic areas overlying fine grained soils. The soils on those segments were often observed to be saturated and weak. This is expected due to the differences in subgrade texture and landscape position. High landscape positions usually have less water affecting the surfaces than sections lower in the landscape. Fine grained soils are weaker than soils with high gravel content.

Ruts from user disturbance were witnessed at the Forest 44 CA. Compaction from horses caused depressions one to two inches deep with subgrades consisting of silty gravel textures.

Ruts created by four wheel drive vehicles on sharp corners were observed at the Angeline CA. The ruts were caused by the tires digging into the surface while taking sharp turns. The use of vehicles was not expected, and the trails were not designed for those users.

Erosion of the surface aggregate sections was observed at the Angeline CA. The ruts created by erosion were caused due to inadequate surface water control. The climbing switchback turns were not insloped to intercept runoff from uphill trails. The trails were outsloped allowing water to flow over the trail surface and onto downhill trails. A simple solution would be to inslope the surface shape as originally designed.

Surface Aggregate with Geosynthetics

Segments with geosynthetics provided a stable surface during the entire observation period. The three different applications (wrapped geotextile, non-wrap geotextiles, and geocells) outperformed the surface aggregate segments without geosynthetics. The segments provided adequate strength to support horses and wheeled vehicles. Ruts due to upward migration of fines were not observed due to the separation from the geotextiles. Geosynthetic reinforcement is an acceptable solution to increase surface strength.

Effectiveness of Lime Stabilization

Lab tests revealed that lime stabilization is effective in increasing the shear strength of the tested soil. The field application confirmed the increase in shear strength and erosion resistance during the initial observation period. While the initial observations were positive, failure did occur during winter due to freeze-thaw effects. The trail surface was broken up into small pieces. The resulting effect was a loose trail surface with decreased strength. The loose surface was susceptible to disturbance and displacement from trail users. In addition, the lack of cohesion between the loose particles allowed for surface water to carry them away. Lime stabilization is not an effective trail wearing surface, due to the negative effects from freeze-thaw occurrences.

Surface Water Control

Geosynthetic Reinforced Waterbars

All of the waterbars constructed were geosynthetics reinforced water bars. All of the waterbars were successful in diverting water from trail surfaces. Waterbars at the Rudolf Bennitt CA with less than two inches of surface aggregate cover were observed to be ripped by horse hooves.

None of the waterbars at the Rudolf Bennitt CA were observed to have depression created by users. It is unclear why depressions were observed in the waterbars at the

Forest 44 CA on natural soil segments because construction was not observed. It is possible that the geosynthetic wrap was not wrapped “tight” enough to provide adequate reinforcement, or not enough of an overlap was installed.

These observations suggest that the construction of waterbars required more than two inches of surface aggregate cover and that the geotextile wrap be as tight as possible with an overlap greater than the original twelve inches.

Surface Shape

The outsloped surfaces were successful in diverting water on the trails, except where switchbacks were used to reduce slope. In these conditions the outsloped surface diverts water onto other trail surfaces. Therefore, it is necessary to inslope or crown trail surfaces when using climbing turns.

Another alternative would be to always use an insloped or crowned trail surface. This method could reduce the amount of water affecting the trail surface. Any water collected by insloping or crowning could be diverted off of the trail at certain exit points by using waterbars or grade dips.

6. CONCLUSIONS

There are two methods available to reduce trail degradation: decrease the causative forces or increase the resistive forces. Improving trail layout by reducing slope and controlling surface water reduces the causative effects. Increasing surface stability and erosion resistance increases the resisting forces. Preventing trail degradation on equestrian trails requires both methods.

The high stresses applied by horses to trail surfaces require strong resistance. Natural soils are not effective in providing adequate resistance. Horses disturb the surface by loosening soil particles which are then free to be carried away by water. Surface stabilization is required to improve strength and provide a surface that will resist the impacts from horses.

Stabilizing the trail surface can improve resistance from the high stresses of equestrian impact, but it does not protect against erosion unless it is combined with proper trail layout. Surface stabilization is not a fix-all solution. Erosion of surface aggregate will occur if water's energy is not reduced by the trail layout.

In summary, natural soil trails are not adequate trail surfaces due to the intense impact of horse. Surface aggregate is an effective technique when combined with geosynthetic reinforcement; lime stabilization is not effective due to the impact of freezing and thawing during winter.

Recommendations

While this study reveals that the combination of surface stabilization and proper trail layout were able to resist trail degradation during the observation period, the life expectancy of these solutions is still unknown. Observations were only conducted over a one year period. Further research should be conducted to determine the exact maintenance requirements and associated costs. As with highways and other infrastructure, maintenance is always required. Maintenance costs have to be considered along with the initial costs to determent the most efficient designs.

Other recommendations would be to use the technology of Geographic Information Systems (GIS). A GIS database could be created combining soil data and topographic data. Trail planning could be accomplished by laying out proposed trails in GIS before field visits. The database could predict possible problem areas and help produce the optimal trail layout.

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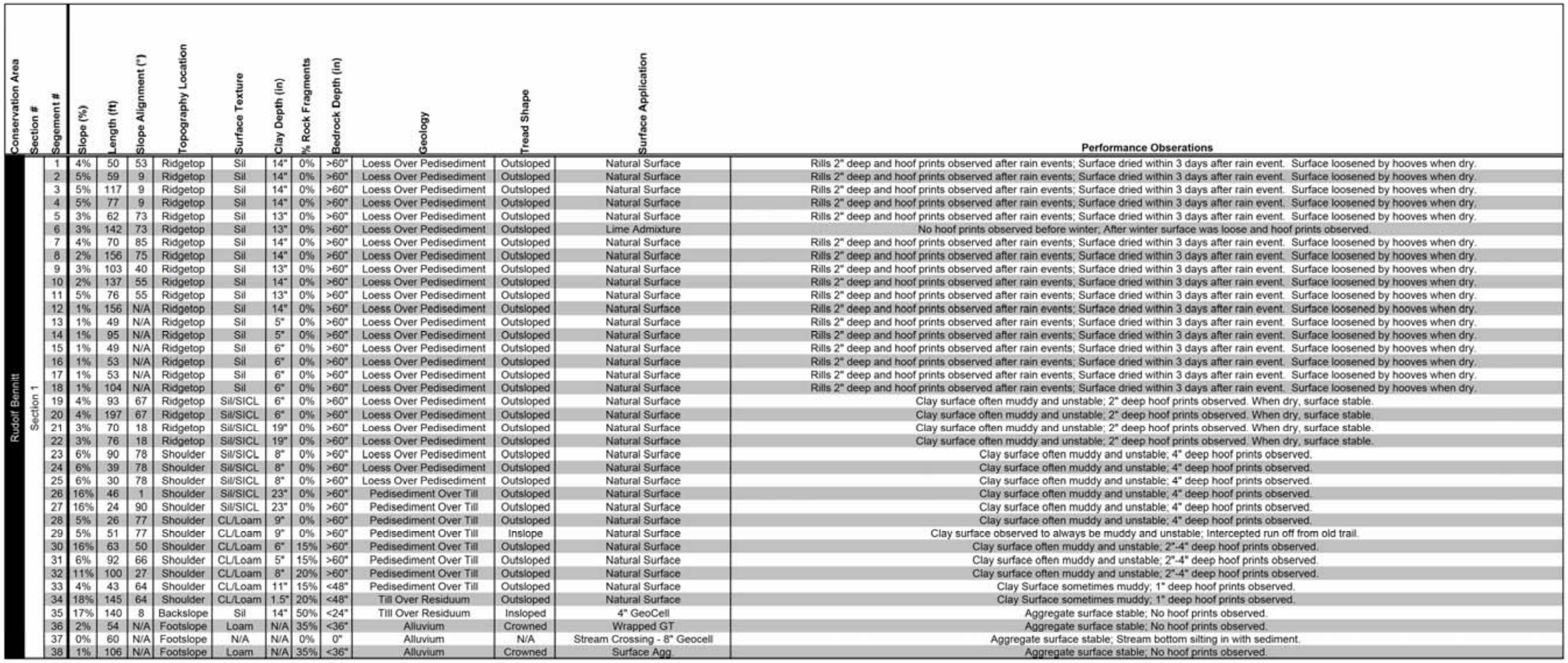
A. APPENDIX A: TRAIL MEASUREMENT DATA

Table A-1. Rudolf Bennitt CA – Trail Measurement Data

Conservation Area	Section #	Segement #	Slope (%)	Length (ft)	Bearing (°)	Surface Aspect (°)	Slope Alignment (°)	Topography Location	Surface Shape Across	Surface Shape Down	Surface Texture	Surface Thickness (in)	Sediment Thickness (in)	Clay Depth (in)	Clay Activity	% Rock Fragments	Bedrock Depth (in)	Geology	Tread Shape	Surface Application
Rudolf Bennitt	Section 1	1	4%	50	82	315	53	Ridgetop	Convex	Linear	Sil	4"	35"	14"	SuperActive	0%	>60"	Loess Over Pedisediment	Outsloped	Natural Surface
		2	5%	59	141	330	9	Ridgetop	Convex	Linear	Sil	8"	21"	14"	SuperActive	0%	>60"	Loess Over Pedisediment	Outsloped	Natural Surface
		3	5%	117	141	330	9	Ridgetop	Convex	Linear	Sil	8"	21"	14"	SuperActive	0%	>60"	Loess Over Pedisediment	Outsloped	Natural Surface
		4	5%	77	141	330	9	Ridgetop	Convex	Linear	Sil	8"	21"	14"	SuperActive	0%	>60"	Loess Over Pedisediment	Outsloped	Natural Surface
		5	3%	62	282	355	73	Ridgetop	Convex	Linear	Sil	7"	21"	13"	SuperActive	0%	>60"	Loess Over Pedisediment	Outsloped	Natural Surface
		6	3%	142	282	355	73	Ridgetop	Convex	Linear	Sil	7"	21"	13"	SuperActive	0%	>60"	Loess Over Pedisediment	Outsloped	Lime Admixture
		7	4%	70	295	290	85	Ridgetop	Convex	Linear	Sil	7"	35"	14"	SuperActive	0%	>60"	Loess Over Pedisediment	Outsloped	Natural Surface
		8	2%	156	80	335	75	Ridgetop	Convex	Linear	Sil	8"	38"	14"	SuperActive	0%	>60"	Loess Over Pedisediment	Outsloped	Natural Surface
		9	3%	103	120	340	40	Ridgetop	Convex	Linear	Sil	7"	36"	13"	SuperActive	0%	>60"	Loess Over Pedisediment	Outsloped	Natural Surface
		10	2%	137	260	25	55	Ridgetop	Convex	Linear	Sil	4"	37"	14"	SuperActive	0%	>60"	Loess Over Pedisediment	Outsloped	Natural Surface
		11	5%	76	60	205	55	Ridgetop	Convex	Linear	Sil	4"	34"	13"	SuperActive	0%	>60"	Loess Over Pedisediment	Outsloped	Natural Surface
		12	1%	156	276	Neutral	N/A	Ridgetop	Linear	Linear	Sil	5"	32"	14"	SuperActive	0%	>60"	Loess Over Pedisediment	Outsloped	Natural Surface
		13	1%	49	63	Neutral	N/A	Ridgetop	Convex	Linear	Sil	5"	38"	5"	SuperActive	0%	>60"	Loess Over Pedisediment	Outsloped	Natural Surface
		14	1%	95	63	Neutral	N/A	Ridgetop	Convex	Linear	Sil	5"	38"	5"	SuperActive	0%	>60"	Loess Over Pedisediment	Outsloped	Natural Surface
		15	1%	49	109	Neutral	N/A	Ridgetop	Convex	Linear	Sil	4"	33"	6"	SuperActive	0%	>60"	Loess Over Pedisediment	Outsloped	Natural Surface
		16	1%	53	109	Neutral	N/A	Ridgetop	Convex	Linear	Sil	4"	33"	6"	SuperActive	0%	>60"	Loess Over Pedisediment	Outsloped	Natural Surface
		17	1%	53	109	Neutral	N/A	Ridgetop	Convex	Linear	Sil	4"	33"	6"	SuperActive	0%	>60"	Loess Over Pedisediment	Outsloped	Natural Surface
		18	1%	104	109	Neutral	N/A	Ridgetop	Convex	Linear	Sil	4"	33"	6"	SuperActive	0%	>60"	Loess Over Pedisediment	Outsloped	Natural Surface
		19	4%	93	132	245	67	Ridgetop	Convex	Linear	Sil/SICL	7"	32"	6"	SuperActive	0%	>60"	Loess Over Pedisediment	Outsloped	Natural Surface
		20	4%	197	132	245	67	Ridgetop	Convex	Linear	Sil/SICL	7"	32"	6"	SuperActive	0%	>60"	Loess Over Pedisediment	Outsloped	Natural Surface
		21	3%	70	332	170	18	Ridgetop	Convex	Linear	Sil/SICL	5"	33"	19"	SuperActive	0%	>60"	Loess Over Pedisediment	Outsloped	Natural Surface
		22	3%	76	332	170	18	Ridgetop	Convex	Linear	Sil/SICL	5"	33"	19"	SuperActive	0%	>60"	Loess Over Pedisediment	Outsloped	Natural Surface
		23	6%	90	147	45	78	Shoulder	Corrigate	Linear	Sil/SICL	5"	N/A	8"	SuperActive	0%	>60"	Loess Over Pedisediment	Outsloped	Natural Surface
		24	6%	39	147	45	78	Shoulder	Corrigate	Linear	Sil/SICL	5"	N/A	8"	SuperActive	0%	>60"	Loess Over Pedisediment	Outsloped	Natural Surface
		25	6%	30	147	45	78	Shoulder	Corrigate	Linear	Sil/SICL	5"	N/A	8"	SuperActive	0%	>60"	Loess Over Pedisediment	Outsloped	Natural Surface
		26	16%	46	41	40	1	Shoulder	Linear	Linear	Sil/SICL	5"	N/A	23"	SuperActive	0%	>60"	Pedisediment Over Till	Outsloped	Natural Surface
		27	16%	24	180	90	90	Shoulder	Linear	Linear	Sil/SICL	5"	N/A	23"	SuperActive	0%	>60"	Pedisediment Over Till	Outsloped	Natural Surface
		28	5%	26	287	30	77	Shoulder	Linear	Linear	CL/Loam	4"	N/A	9"	SuperActive	0%	>60"	Pedisediment Over Till	Outsloped	Natural Surface
		29	5%	51	287	30	77	Shoulder	Linear	Linear	CL/Loam	4"	N/A	9"	SuperActive	0%	>60"	Pedisediment Over Till	Inslope	Natural Surface
		30	16%	63	130	0	50	Shoulder	Convex	Concave	CL/Loam	4"	N/A	6"	SuperActive	15%	>60"	Pedisediment Over Till	Outsloped	Natural Surface
		31	6%	92	41	335	66	Shoulder	Concave	Concave	CL/Loam	1.5"	N/A	5"	SuperActive	15%	>60"	Pedisediment Over Till	Outsloped	Natural Surface
		32	11%	100	38	65	27	Shoulder	Linear	Concave	CL/Loam	2"	N/A	8"	SuperActive	20%	>60"	Pedisediment Over Till	Outsloped	Natural Surface
		33	4%	43	345	50	64	Shoulder	Convex	Linear	CL/Loam	4"	N/A	11"	SuperActive	15%	<48"	Pedisediment Over Till	Outsloped	Natural Surface
		34	18%	145	315	20	64	Shoulder	Linear	Concave	CL/Loam	1.5"	N/A	1.5"	SuperActive	20%	<48"	Till Over Residuum	Outsloped	Natural Surface
		35	17%	140	37	45	8	Backslope	Convex	Concave	Sil	1.5	N/A	14"	SuperActive	50%	<24"	TIll Over Residuum	Insloped	4" GeoCell
		36	2%	54	349	Neutral	N/A	Footslope	Linear	Linear	Loam	5"	N/A	N/A	SuperActive	35%	<36"	Alluvium	Crowned	Wrapped GT
		37	0%	60	349	Neutral	N/A	Footslope	Linear	Linear	N/A	N/A	N/A	N/A	SuperActive	0%	0"	Alluvium	N/A	Stream Crossing - 8" Geocell
		38	1%	106	29.3	Neutral	N/A	Footslope	Linear	Linear	Loam	5"	N/A	N/A	SuperActive	35%	<36"	Alluvium	Crowned	Surface Agg.
			0%																	
Rudolf Bennitt	Section 2	1	11%	20	80	-	-	Dam Crest	-	-	-	-	-	-	-	-	-	Earthen Dam	Crowned	4" Geocell
		2	0%	37	80	-	-	Dam Crest	-	-	-	-	-	-	-	-	-	Earthen Dam	Crowned	Wrapped GT
		3	11%	20	80	-	-	Dam Crest	-	-	-	-	-	-	-	-	-	Earthen Dam	Crowned	4" Geocell
		4	0%	12	80	-	-	Dam Crest	-	-	-	-	-	-	-	-	-	Earthen Dam	Crowned	No-Wrap GT
		5	0%	130	80	-	-	Dam Crest	-	-	-	-	-	-	-	-	-	Earthen Dam	Crowned	No-Wrap GT
		6	0%	220	80	-	-	Dam Crest	-	-	-	-	-	-	-	-	-	Earthen Dam	Crowned	Wrapped GT
		7	0%	150	80	-	-	Dam Crest	-	-	-	-	-	-	-	-	-	Earthen Dam	Crowned	No-Wrap GT
		8	0%	20	80	-	-	Dam Crest	-	-	-	-	-	-	-	-	-	Earthen Dam	Crowned	No-Wrap GT
		9	0%	54	80	-	-	Dam Crest	-	-	-	-	-	-	-	-	-	Earthen Dam	Crowned	No-Wrap GT
		10	5%	32	80	-	-	Dam Crest	-	-	-	-	-	-	-	-	-	Earthen Dam	Crowned	No-Wrap GT
		11	10%	25	15	-	-	Dam Crest	-	-	-	-	-	-	-	-	-	Earthen Dam	Crowned	4" Geocell
		12	0%	42	15	-	-	Dam Crest	-	-	-	-	-	-	-	-	-	Earthen Dam	Crowned	No-Wrap GT
			0%																	
Rudolf Bennitt	Section 3	1	14%	134	211	80	49	Backslope	Linear	Convex	SIL	3"	21"	8"	Superactive	0%	>60"	Pedisediment Over Till	Outsloped	Natural Surface
		2	3%	70	290	175	65	Backslope	Convex	Convex	Loam	3"	3"	3"	Superactive	0%	>60"	Till	Outsloped	Natural Surface
		3	7%	74	230	135	85	Backslope	Convex	Convex	Sil	4"	4"	4"	Superactive	0%	>60"	Till	Outsloped	Natural Surface
		4	1%	45	244	165	79	Backslope	Convex	Convex	Sil	3"	3"	3"	Superactive	0%	>60"	Till	Outsloped	Natural Surface
		5	8%	45	270	315	45	Backslope	Linear	Convex	Sil	2"	2"	2"	Superactive	0%	>60"	Till	Outsloped	Natural Surface
		6	2%	59	300	205	85	Backslope	Convex	Convex	Loam	5"	5"	5"	Superactive	0%	>60"	Till	Outsloped	Natural Surface
		7	5%	60	295	190	75	Backslope	Linear	Convex	Sil	4"	8"	8"	Superactive	0%	>60"	Till	Outsloped	Natural Surface
		8	5%	42	291	180	69	Backslope	Convex	Convex	Sil	1.5"	4"	4"	Superactive	0%	>60"	Till	Outsloped	Natural Surface
		9	5%	88	291	180	69	Backslope	Convex	Convex	Sil	1.5"	4"	4"	Superactive	0%	>60"	Till	Outsloped	Natural Surface
		10	1%	60	260	135	55	Backslope	Convex	Convex	Sil	1"	N/A	1"	Superactive	0%	>60"	Till	Outsloped	Natural Surface
		11	4%	89	312	245	67	Backslope	Linear	Lin	Sil	4"	5"	5"	Superactive	0%	>60"	Till	Outsloped	Natural Surface
		12	4%	80	320	245	75	Backslope	Convex	Convex	Sil	1"	2"	2"	Superactive	0%	>60"	Till	Outsloped	Natural Surface
		13	15%	70	230	165	65	Backslope	Concave	Linear	Sil	3"	3"	3"	Superactive	0%	>60"	Till	Outsloped	Natural Surface
		14	1%	100	180	90	90	Backslope	Concave	Linear	Sil	2"	4"	4"	Superactive	0%	>60"	Till	Outsloped	Natural Surface
		15	0%	30	250	300	50	Backslope	concave	Linear	Loam	3"	4"	4"	Superactive	0%	>60"	Till	Outsloped	Natural Surface
		16	0%	91	160	230	70	Backslope	Concave	Linear	Loam	2"	4"	4"	Superactive	0%	>60"	Till	Outsloped	Natural Surface
		17	13%	113	242	340	82	Backslope	Convex	Convex	Loam	3"	6"	6"	Superactive	0%	>60"	Till	Outsloped	Natural Surface
		18	9%	200	194	240	46	Backslope	Convex	Linear	Loam	3"	12"	12"	Superactive	0%	>60"	Pedisediment Over Till	Outsloped	Natural Surface

Table A-2. Rudolf Bennitt CA - Section 1 Observation Data.



Conservation Area	Section #	Segement #	Slope (%)	Length (ft)	Slope Alignment (°)	Topography Location	Surface Texture	Clay Depth (in)	% Rock Fragments	Bedrock Depth (in)	Geology	Tread Shape	Surface Application	Performance Obserations
Rudolf Bennitt	Section 1	1	4%	50	53	Ridgetop	Sil	14"	0%	>60"	Loess Over Pedisediment	Outsloped	Natural Surface	Rills 2" deep and hoof prints observed after rain events; Surface dried within 3 days after rain event. Surface loosened by hooves when dry.
		2	5%	59	9	Ridgetop	Sil	14"	0%	>60"	Loess Over Pedisediment	Outsloped	Natural Surface	Rills 2" deep and hoof prints observed after rain events; Surface dried within 3 days after rain event. Surface loosened by hooves when dry.
		3	5%	117	9	Ridgetop	Sil	14"	0%	>60"	Loess Over Pedisediment	Outsloped	Natural Surface	Rills 2" deep and hoof prints observed after rain events; Surface dried within 3 days after rain event. Surface loosened by hooves when dry.
		4	5%	77	9	Ridgetop	Sil	14"	0%	>60"	Loess Over Pedisediment	Outsloped	Natural Surface	Rills 2" deep and hoof prints observed after rain events; Surface dried within 3 days after rain event. Surface loosened by hooves when dry.
		5	3%	62	73	Ridgetop	Sil	13"	0%	>60"	Loess Over Pedisediment	Outsloped	Natural Surface	Rills 2" deep and hoof prints observed after rain events; Surface dried within 3 days after rain event. Surface loosened by hooves when dry.
		6	3%	142	73	Ridgetop	Sil	13"	0%	>60"	Loess Over Pedisediment	Outsloped	Lime Admixture	No hoof prints observed before winter; After winter surface was loose and hoof prints observed.
		7	4%	70	85	Ridgetop	Sil	14"	0%	>60"	Loess Over Pedisediment	Outsloped	Natural Surface	Rills 2" deep and hoof prints observed after rain events; Surface dried within 3 days after rain event. Surface loosened by hooves when dry.
		8	2%	156	75	Ridgetop	Sil	14"	0%	>60"	Loess Over Pedisediment	Outsloped	Natural Surface	Rills 2" deep and hoof prints observed after rain events; Surface dried within 3 days after rain event. Surface loosened by hooves when dry.
		9	3%	103	40	Ridgetop	Sil	13"	0%	>60"	Loess Over Pedisediment	Outsloped	Natural Surface	Rills 2" deep and hoof prints observed after rain events; Surface dried within 3 days after rain event. Surface loosened by hooves when dry.
		10	2%	137	55	Ridgetop	Sil	14"	0%	>60"	Loess Over Pedisediment	Outsloped	Natural Surface	Rills 2" deep and hoof prints observed after rain events; Surface dried within 3 days after rain event. Surface loosened by hooves when dry.
		11	5%	76	55	Ridgetop	Sil	13"	0%	>60"	Loess Over Pedisediment	Outsloped	Natural Surface	Rills 2" deep and hoof prints observed after rain events; Surface dried within 3 days after rain event. Surface loosened by hooves when dry.
		12	1%	156	N/A	Ridgetop	Sil	14"	0%	>60"	Loess Over Pedisediment	Outsloped	Natural Surface	Rills 2" deep and hoof prints observed after rain events; Surface dried within 3 days after rain event. Surface loosened by hooves when dry.
		13	1%	49	N/A	Ridgetop	Sil	5"	0%	>60"	Loess Over Pedisediment	Outsloped	Natural Surface	Rills 2" deep and hoof prints observed after rain events; Surface dried within 3 days after rain event. Surface loosened by hooves when dry.
		14	1%	95	N/A	Ridgetop	Sil	5"	0%	>60"	Loess Over Pedisediment	Outsloped	Natural Surface	Rills 2" deep and hoof prints observed after rain events; Surface dried within 3 days after rain event. Surface loosened by hooves when dry.
		15	1%	49	N/A	Ridgetop	Sil	6"	0%	>60"	Loess Over Pedisediment	Outsloped	Natural Surface	Rills 2" deep and hoof prints observed after rain events; Surface dried within 3 days after rain event. Surface loosened by hooves when dry.
		16	1%	53	N/A	Ridgetop	Sil	6"	0%	>60"	Loess Over Pedisediment	Outsloped	Natural Surface	Rills 2" deep and hoof prints observed after rain events; Surface dried within 3 days after rain event. Surface loosened by hooves when dry.
		17	1%	53	N/A	Ridgetop	Sil	6"	0%	>60"	Loess Over Pedisediment	Outsloped	Natural Surface	Rills 2" deep and hoof prints observed after rain events; Surface dried within 3 days after rain event. Surface loosened by hooves when dry.
		18	1%	104	N/A	Ridgetop	Sil	6"	0%	>60"	Loess Over Pedisediment	Outsloped	Natural Surface	Rills 2" deep and hoof prints observed after rain events; Surface dried within 3 days after rain event. Surface loosened by hooves when dry.
		19	4%	93	67	Ridgetop	Sil/SICL	6"	0%	>60"	Loess Over Pedisediment	Outsloped	Natural Surface	Clay surface often muddy and unstable; 2" deep hoof prints observed. When dry, surface stable.
		20	4%	197	67	Ridgetop	Sil/SICL	6"	0%	>60"	Loess Over Pedisediment	Outsloped	Natural Surface	Clay surface often muddy and unstable; 2" deep hoof prints observed. When dry, surface stable.
		21	3%	70	18	Ridgetop	Sil/SICL	19"	0%	>60"	Loess Over Pedisediment	Outsloped	Natural Surface	Clay surface often muddy and unstable; 2" deep hoof prints observed. When dry, surface stable.
		22	3%	76	18	Ridgetop	Sil/SICL	19"	0%	>60"	Loess Over Pedisediment	Outsloped	Natural Surface	Clay surface often muddy and unstable; 2" deep hoof prints observed. When dry, surface stable.
		23	6%	90	78	Shoulder	Sil/SICL	8"	0%	>60"	Loess Over Pedisediment	Outsloped	Natural Surface	Clay surface often muddy and unstable; 4" deep hoof prints observed.
		24	6%	39	78	Shoulder	Sil/SICL	8"	0%	>60"	Loess Over Pedisediment	Outsloped	Natural Surface	Clay surface often muddy and unstable; 4" deep hoof prints observed.
		25	6%	30	78	Shoulder	Sil/SICL	8"	0%	>60"	Loess Over Pedisediment	Outsloped	Natural Surface	Clay surface often muddy and unstable; 4" deep hoof prints observed.
		26	16%	46	1	Shoulder	Sil/SICL	23"	0%	>60"	Pedisediment Over Till	Outsloped	Natural Surface	Clay surface often muddy and unstable; 4" deep hoof prints observed.
		27	16%	24	90	Shoulder	Sil/SICL	23"	0%	>60"	Pedisediment Over Till	Outsloped	Natural Surface	Clay surface often muddy and unstable; 4" deep hoof prints observed.
		28	5%	26	77	Shoulder	CL/Loam	9"	0%	>60"	Pedisediment Over Till	Outsloped	Natural Surface	Clay surface often muddy and unstable; 4" deep hoof prints observed.
		29	5%	51	77	Shoulder	CL/Loam	9"	0%	>60"	Pedisediment Over Till	Inslope	Natural Surface	Clay surface observed to always be muddy and unstable; Intercepted run off from old trail.
		30	16%	63	50	Shoulder	CL/Loam	6"	15%	>60"	Pedisediment Over Till	Outsloped	Natural Surface	Clay surface often muddy and unstable; 2"-4" deep hoof prints observed.
		31	6%	92	66	Shoulder	CL/Loam	5"	15%	>60"	Pedisediment Over Till	Outsloped	Natural Surface	Clay surface often muddy and unstable; 2"-4" deep hoof prints observed.
		32	11%	100	27	Shoulder	CL/Loam	8"	20%	>60"	Pedisediment Over Till	Outsloped	Natural Surface	Clay surface often muddy and unstable; 2"-4" deep hoof prints observed.
		33	4%	43	64	Shoulder	CL/Loam	11"	15%	<48"	Pedisediment Over Till	Outsloped	Natural Surface	Clay Surface sometimes muddy; 1" deep hoof prints observed.
		34	18%	145	64	Shoulder	CL/Loam	1.5"	20%	<48"	Till Over Residuum	Outsloped	Natural Surface	Clay Surface sometimes muddy; 1" deep hoof prints observed.
		35	17%	140	8	Backslope	Sil	14"	50%	<24"	TIll Over Residuum	Insloped	4" GeoCell	Aggregate surface stable; No hoof prints observed.
		36	2%	54	N/A	Footslope	Loam	N/A	35%	<36"	Alluvium	Crowned	Wrapped GT	Aggregate surface stable; No hoof prints observed.
		37	0%	60	N/A	Footslope	N/A	N/A	0%	0"	Alluvium	N/A	Stream Crossing - 8" Geocell	Aggregate surface stable; Stream bottom silting in with sediment.
		38	1%	106	N/A	Footslope	Loam	N/A	35%	<36"	Alluvium	Crowned	Surface Agg	Aggregate surface stable; No hoof prints observed.

Table A-3. Rudolf Bennitt CA - Sections 2 and 3 Observation Data

Conservation Area	Section #	Segement #	Slope (%)	Length (ft)	Slope Alignment (°)	Topography Location	Surface Texture	Clay Depth (in)	% Rock Fragments	Bedrock Depth (in)	Geology	Tread Shape	Surface Application	Performance Obserations
Rudolf Bennitt	Section 2	1	11%	20	-	Dam Crest	-	-	-	-	Earthen Dam	Crowned	4" Geocell	Surface stable; Hooves causing sliding of aggregate due to too much aggregate applied (>4" above cells)
		2	0%	37	-	Dam Crest	-	-	-	-	Earthen Dam	Crowned	Wrapped GT	Aggregate Surface Stable. No prints observed.
		3	11%	20	-	Dam Crest	-	-	-	-	Earthen Dam	Crowned	4" Geocell	Surface stable; Hooves causing sliding of aggregate due to too much aggregate applied (>4" above cells)
		4	0%	12	-	Dam Crest	-	-	-	-	Earthen Dam	Crowned	Non-Wrap GT	Aggregate Surface Stable; No hoof prints observed.
		5	0%	130	-	Dam Crest	-	-	-	-	Earthen Dam	Crowned	Non-Wrap GT	Aggregate Surface Stable; No hoof prints observed.
		6	0%	220	-	Dam Crest	-	-	-	-	Earthen Dam	Crowned	Wrapped GT	Aggregate Surface Stable; No hoof prints observed.
		7	0%	150	-	Dam Crest	-	-	-	-	Earthen Dam	Crowned	Non-Wrap GT	Aggregate Surface Stable; No hoof prints observed.
		8	0%	20	-	Dam Crest	-	-	-	-	Earthen Dam	Crowned	Non-Wrap GT	Aggregate Surface Stable; No hoof prints observed.
		9	0%	54	-	Dam Crest	-	-	-	-	Earthen Dam	Crowned	Non-Wrap GT	Aggregate Surface Stable; No hoof prints observed.
		10	5%	32	-	Dam Crest	-	-	-	-	Earthen Dam	Crowned	Non-Wrap GT	Aggregate Surface Stable; No hoof prints observed.
		11	10%	25	-	Dam Crest	-	-	-	-	Earthen Dam	Crowned	4" Geocell	Aggregate Surface Stable; No hoof prints observed.
		12	0%	42	-	Dam Crest	-	-	-	-	Earthen Dam	Crowned	Non-Wrap GT	Aggregate Surface Stable; No hoof prints observed.
Rudolf Bennitt	Section 3	1	14%	134	49	Backslope	SIL	8"	0%	>60"	Pedisediment Over Till	Outsloped	Natural Surface	4" deep hoof prints observed after winter; Surface muddy and unstable.
		2	3%	70	65	Backslope	Loam	3"	0%	>60"	Till	Outsloped	Natural Surface	4" deep hoof prints observed after winter; Surface muddy and unstable.
		3	7%	74	85	Backslope	Sil	4"	0%	>60"	Till	Outsloped	Natural Surface	4" deep hoof prints observed after winter; Surface muddy and unstable.
		4	1%	45	79	Backslope	Sil	3"	0%	>60"	Till	Outsloped	Natural Surface	4" deep hoof prints observed after winter; Surface muddy and unstable.
		5	8%	45	45	Backslope	Sil	2"	0%	>60"	Till	Outsloped	Natural Surface	4" deep hoof prints observed after winter; Surface muddy and unstable.
		6	2%	59	85	Backslope	Loam	5"	0%	>60"	Till	Outsloped	Natural Surface	4" deep hoof prints observed after winter; Surface muddy and unstable.
		7	5%	60	75	Backslope	Sil	8"	0%	>60"	Till	Outsloped	Natural Surface	4" deep hoof prints observed after winter; Surface muddy and unstable.
		8	5%	42	69	Backslope	Sil	4"	0%	>60"	Till	Outsloped	Natural Surface	4" deep hoof prints observed after winter; Surface muddy and unstable.
		9	5%	88	69	Backslope	Sil	4"	0%	>60"	Till	Outsloped	Natural Surface	4" deep hoof prints observed after winter; Surface muddy and unstable.
		10	1%	60	55	Backslope	Sil	1"	0%	>60"	Till	Outsloped	Natural Surface	4" deep hoof prints observed after winter; Surface muddy and unstable.
		11	4%	89	67	Backslope	Sil	5"	0%	>60"	Till	Outsloped	Natural Surface	4" deep hoof prints observed after winter; Surface muddy and unstable.
		12	4%	80	75	Backslope	Sil	2"	0%	>60"	Till	Outsloped	Natural Surface	4" deep hoof prints observed after winter; Surface muddy and unstable.
		13	15%	70	65	Backslope	Sil	3"	0%	>60"	Till	Outsloped	Natural Surface	4" deep hoof prints observed after winter; Surface muddy and unstable.
		14	1%	100	90	Backslope	Sil	4"	0%	>60"	Till	Outsloped	Natural Surface	4" deep hoof prints observed after winter; Surface muddy and unstable.
		15	0%	30	50	Backslope	Loam	4"	0%	>60"	Till	Outsloped	Natural Surface	4" deep hoof prints observed after winter; Surface muddy and unstable.
		16	0%	91	70	Backslope	Loam	4"	0%	>60"	Till	Outsloped	Natural Surface	4" deep hoof prints observed after winter; Surface muddy and unstable.
		17	13%	113	82	Backslope	Loam	6"	0%	>60"	Till	Outsloped	Natural Surface	4" deep hoof prints observed after winter; Surface muddy and unstable.
		18	9%	200	46	Backslope	Loam	12"	0%	>60"	Pedisediment Over Till	Outsloped	Natural Surface	4" deep hoof prints observed after winter; Surface muddy and unstable.

Table A-4. Forest 44 CA - Trail Measurement Data.

Conservation Area	Section #	Segement #	Slope (%)	Length (ft)	Bearing (°)	Surface Aspect (°)	Slope Alignment (°)	Topography Location	Surface Shape Across	Surface Shape Down	Surface Texture	Surface Thickness (in)	Sediment Thickness (in)	Clay Depth (in)	Clay Activity	% Rock Fragments	Bedrock Depth (in)	Geology	Tread Shape	Surface Application	Notes
Forest 44	Section 1	1	14%	35	65	131	66	Backslope	Linear	Linear	Sil	12"	-	-	Active	25%	>60"	Pedisediment	Outsloped	Surface Aggregate	
		2	14%	37	65	131	66	Backslope	Linear	Linear	Sil	12"	-	-	Active	25%	<48"	Pedisediment	Outsloped	Surface Aggregate	
		3	13%	34	74	145	71	Backslope	Corrigated	Linear	Sil	6"	-	-	Active	30%	>60"	Pedisediment	Outsloped	Surface Aggregate	
		4	16%	20	74	145	71	Backslope	Corrigated	Linear	Sil	6"	-	-	Active	31%	>60"	Pedisediment	Outsloped	Surface Aggregate	
		5	4%	87	74	145	71	Backslope	Corrigated	Linear	Sil	6"	-	-	Active	32%	>60"	Pedisediment	Outsloped	Natural Soil	
		6	8%	40	83	155	72	Backslope	Linear	Convex	Sil	2"	-	-	Active	45%	>60"	Pedisediment	Outsloped	Grade Dip-4" Geocell	Ephimeral Drainage
		7	15%	50	55	150	85	Backslope	Corrigated	Convex	Sil	3"	-	-	Active	35%	>60"	Pedisediment	Outsloped	Natural Soil	
		8	1%	38	55	150	85	Backslope	Corrigated	Convex	Sil	3"	-	-	Active	35%	>60"	Pedisediment	Outsloped	No-Wrap GT	
		9	3%	39	59	155	84	Backslope	Linear	Linear	Sil	4"	-	-	Active	25%	>60"	Pedisediment	Outsloped	Surface Aggregate	
		10	13%	31	109	170	61	Backslope	Convex	Convex	Sil	4"	-	-	Active	40%	>60"	Pedisediment	Outsloped	Natural Soil	
		11	8%	25	70	163	87	Backslope	Linear	Linear	Sil	4"	-	-	Active	40%	>60"	Pedisediment	Outsloped	Surface Aggregate	
		12	16%	23	109	170	61	Backslope	Convex	Convex	Sil	4"	-	-	Active	40%	>60"	Pedisediment	Outsloped	Surface Aggregate	
		13	15%	26	90	163	73	Backslope	Convex	Convex	Sil	3"	-	-	Active	55%	>60"	Pedisediment	Outsloped	Natural Soil	
		14	7%	36	74	155	81	Backslope	Convex	Convex	Sil	3"	-	-	Active	55%	>60"	Pedisediment	Outsloped	Natural Soil	
		15	13%	42	52	175	57	Backslope	Convex	Convex	Sil	3"	-	-	Active	45%	>60"	Pedisediment	Outsloped	Natural Soil	
		16	14%	34	30	180	30	Backslope	Convex	Linear	Sil	2"	-	-	Active	65%	>60"	Pedisediment	Crowned	Wrapped GT	
		17	15%	13	22	185	17	Backslope	Convex	Linear	Sil	3"	-	-	Active	45%	>60"	Pedisediment	Crowned	No-Wrap GT	
		18	17%	43	22	185	17	Backslope	Convex	Linear	Sil	3"	-	-	Active	45%	>60"	Pedisediment	Crowned	4" Geocell	
		19	18%	22	65	95	30	Backslope	Convex	Linear	Sil	4"	-	-	Active	45%	>60"	Pedisediment	Crowned	4" Geocell	
		20	0%	25	65	0	65	Footslope	Concave	Linear	-	-	-	-	Active	N/A	>60"	Pedisediment	Outsloped	4" Geocell	Ephimeral Drainage
Forest 44	Section 2	1	1%	550	249	5	64	Footslope	Linear	Linear	Sil	6"	-	-	Superactive	0%	>60"	Alluvium	Linear	Natural Soil	
		2	2%	104	264	305	41	Footslope	Linear	Linear	Sil	6"	-	-	Superactive	0%	>60"	Alluvium	Crowned	Wrapped GT	
		3	0%	60	236	20	36	Footslope	Convex	Convex	Sil	6"	-	-	Superactive	N/A	>60"	Alluvium	Crowned	Stream Crossing - 8" Cells	Stream Crossing
		4	3%	140	234	60	6	Footslope	Linear	Linear	Sil	5"	-	-	Superactive	0%	>60"	Alluvium	Crowned	Wrapped GT	
Forest 44	Section 3	1	18%	57	47	40	7	Backslope	Convex	Linear	Sil	4"	-	-	Superactive	0%	>60"	Loess	Crowned	4" Geocells	
		2	9%	71	71	10	61	Backslope	Convex	Linear	Sil	5"	-	-	Superactive	0%	>60"	Loess	Outsloped	Wrapped GT	
		3	12%	46	61	0	61	Backslope	Linear	Linear	Sil	4"	-	-	Superactive	0%	>60"	Loess	Outsloped	Wrapped GT	
		4	10%	70	61	0	61	Backslope	Linear	Linear	Sil	4"	-	-	Superactive	0%	>60"	Loess	Outsloped	No-Wrap GT	

Table A-5. Forest 44 CA - Observation Data

Conservation Area	Section #	Segement #	Slope (%)	Length (ft)	Slope Alignment (°)	Topography Location	Surface Texture	% Rock Fragments	Geology	Tread Shape	Surface Application	Performance Observations
Forest 44	Section 1	1	14%	35	66	Backslope	Sil	25%	Pedisediment	Outsloped	Surface Aggregate	Surface always stable; Trail surface compacted, 1" deep rut; Water Bar Compacted 2"
		2	14%	37	66	Backslope	Sil	25%	Pedisediment	Outsloped	Surface Aggregate	Surface always stable; Trail surface compacted, 1" deep rut; Water Bar Compacted 2"
		3	13%	34	71	Backslope	Sil	30%	Pedisediment	Outsloped	Surface Aggregate	Surface always stable; Trail surface compacted, 1" deep rut; Water Bar Compacted 1"
		4	16%	20	71	Backslope	Sil	31%	Pedisediment	Outsloped	Surface Aggregate	Surface always stable; Trail surface compacted, 1" deep rut; Water Bar Compacted 1"
		5	4%	87	71	Backslope	Sil	32%	Pedisediment	Outsloped	Natural Soil	Surface always stable; Rut compacted 2" deep; rocks left in rut.
		6	8%	40	72	Backslope	Sil	45%	Pedisediment	Outsloped	Grade Dip-4" Geocell	Ephimeral Drainage - Surface Stable; No rutting observed
		7	15%	50	85	Backslope	Sil	35%	Pedisediment	Outsloped	Natural Soil	Surface always stable; Rut compacted 2" deep; rocks left in rut.
		8	1%	38	85	Backslope	Sil	35%	Pedisediment	Outsloped	No-Wrap GT	Surface always Stable; No rutting observed.
		9	3%	39	84	Backslope	Sil	25%	Pedisediment	Outsloped	Surface Aggregate	Surface always stable; Trail surface compacted, 1" deep rut.
		10	13%	31	61	Backslope	Sil	40%	Pedisediment	Outsloped	Natural Soil	Surface always stable; Trail surface compacted, 1" deep rut.
		11	8%	25	87	Backslope	Sil	40%	Pedisediment	Outsloped	Surface Aggregate	Surface always stable; Trail surface compacted, 1" deep rut.
		12	16%	23	61	Backslope	Sil	40%	Pedisediment	Outsloped	Surface Aggregate	Surface always stable; Trail surface compacted, 1" deep rut.
		13	15%	26	73	Backslope	Sil	55%	Pedisediment	Outsloped	Natural Soil	Surface always stable; Trail surface compacted, 2" deep rut.
		14	7%	36	81	Backslope	Sil	55%	Pedisediment	Outsloped	Natural Soil	Surface always stable; Trail surface compacted, 2" deep rut.
		15	13%	42	57	Backslope	Sil	45%	Pedisediment	Outsloped	Natural Soil	Surface always stable; Trail surface compacted, 2" deep rut.
		16	14%	34	30	Backslope	Sil	65%	Pedisediment	Crowned	Wrapped GT	Surface always Stable; No rutting observed.
		17	15%	13	17	Backslope	Sil	45%	Pedisediment	Crowned	No-Wrap GT	Surface always Stable; No rutting observed.
		18	17%	43	17	Backslope	Sil	45%	Pedisediment	Crowned	4" Geocell	Surface always Stable; No rutting observed.
		19	18%	22	30	Backslope	Sil	45%	Pedisediment	Crowned	4" Geocell	Surface always Stable; No rutting observed.
		20	0%	25	65	Footslope	-	N/A	Pedisediment	Outsloped	4" Geocell	Ephimeral Drainage - Surface Stable; No rutting observed
Forest 44	Section 2	1	1%	550	64	Footslope	Sil	0%	Alluvium	Linear	Natural Soil	Surface often muddy and unstable; Surface stable, but broken up and loose when dry
		2	2%	104	41	Footslope	Sil	0%	Alluvium	Crowned	Wrapped GT	Surface always stable; No prints observed.
		3	0%	60	36	Footslope	Sil	N/A	Alluvium	Crowned	Stream Crossing - 8" Cells	Stream Crossing - Surface stable; No prints observed.
		4	3%	140	6	Footslope	Sil	0%	Alluvium	Crowned	Wrapped GT	Surface always stable; No prints observed.
Forest 44	Section 3	1	18%	57	7	Backslope	Sil	0%	Loess	Crowned	4" Geocells	Surface always stable; No prints observed.
		2	9%	71	61	Backslope	Sil	0%	Loess	Outsloped	Wrapped GT	Surface always stable; No prints observed.
		3	12%	46	61	Backslope	Sil	0%	Loess	Outsloped	Wrapped GT	Surface always stable; No prints observed.
		4	10%	70	61	Backslope	Sil	0%	Loess	Outsloped	No-Wrap GT	Surface always stable; No prints observed.

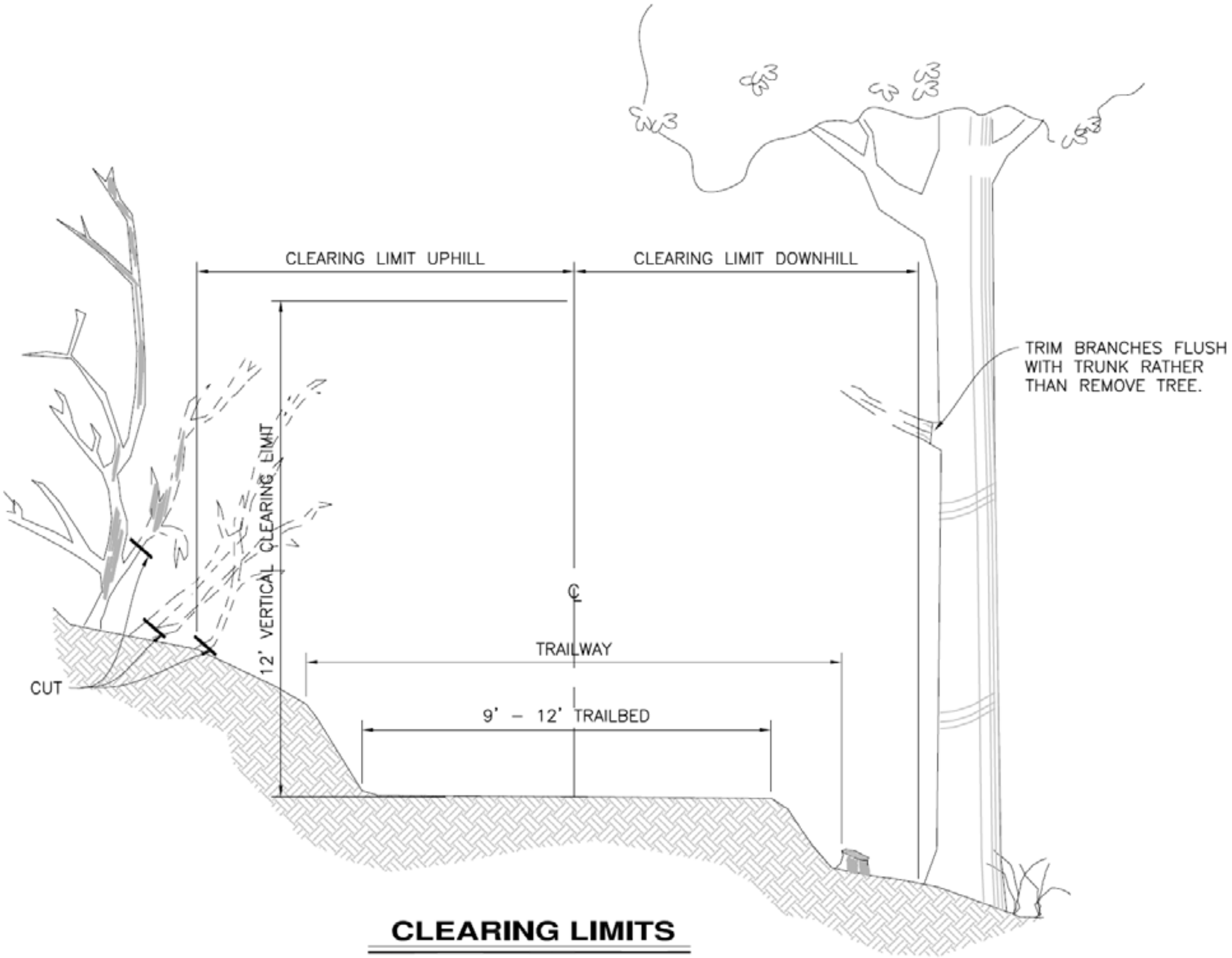
Table A-6. Angeline CA - Trail Measurement Data.

Conservation Area	Section #	Segement #	Slope (%)	Length (ft)	Bearing (°)	Surface Aspect (°)	Slope Alignment (°)	Topography Location	Surface Shape Across	Surface Shape Down	Surface Texture	Surface Thickness (in)	Sediment Thickness (in)	Clay Depth (in)	Clay Activity	% Rock Fragments	Bedrock Depth (in)	Geology	Tread Shape	Surface Application	Notes Taken During Initial Measurements
Angeline Conservation Area	Segment 1	1	14%	159	90	60	30	Shoulder	Convex	Convex	-	-	>48"	>48"	Semi-Active	-	>48"	Gasconade	Outsloped	Surface Aggregate	
		2	10%	172	320	35	75	Shoulder	Convex	Convex	-	-	48"	48"	Semi-Active	-	>48"	Gasconade	Outsloped	Surface Aggregate	
		3	20%	157	55	35	20	Shoulder	Convex	Convex	-	-	18"-36"	18"-36"	Semi-Active	-	>48"	Gasconade	Outsloped	Surface Aggregate	
		4	12%	69	340	41	61	Shoulder	Convex	Convex	-	-	24"	24"	Semi-Active	-	>48"	Gasconade	Outsloped	No-Wrap GT	
		5	11%	131	45	55	10	Backslope	Convex	Convex	-	-	12"-24"	12"-24"	Semi-Active	-	>48"	Gasconade	Outsloped	No-Wrap GT	
		6	11%	78	94	55	39	Backslope	Linear	Convex	-	-	12"-24"	12"-24"	Semi-Active	-	>48"	Gasconade	Outsloped	No-Wrap GT	Water Seeps on Trail
		7	19%	88	23	11	12	Backslope	Convex	Convex	-	-	18"-24"	18"-24"	Semi-Active	-	>48"	Gasconade	Insloped	No-Wrap GT	
		8	19%	72	23	11	12	Backslope	Convex	Convex	-	-	18"-24"	18"-24"	Semi-Active	-	>48"	Gasconade	Insloped	No-Wrap GT	
		9	15%	48	91	49	42	Backslope	Convex	Convex	-	-	12"-18"	12"-18"	Semi-Active	-	0"-36"	Gasconade	Outsloped	No-Wrap GT	Rock Outcrop - Water Seeps on Trail
		10	15%	45	91	49	42	Backslope	Convex	Convex	-	-	12"-18"	12"-18"	Active	-	0"-36"	Gasconade	Outsloped	No-Wrap GT	Rock Outcrop - Water Seeps on Trail
		11	16%	126	47	62	15	Backslope	Convex	Convex	-	-	24"	24"	Superactive	-	>48"	Gasconade	Outsloped	No-Wrap GT	
		12	8%	210	48	3	45	Bench	Linear	Linear	-	-	15"	15"	Semi-Active	-	>48"	Gasconade	Crowned	Wrapped GT	
		13	1%	221	99	184	85	Bench	Concave	Convcave	-	-	18"-36"	18"-36"	Semi-Active	-	>48"	Gasconade	Crowned	No-Wrap GT	
		14	10%	93	77	20	57	Ridgetop	Concave	Convex	-	-	30"-48"	30"-48"	Semi-Active	-	>48"	Gasconade	Crowned	No-Wrap GT	
		15	10%	62	7	7	0	Shoulder	Linear	Linear	-	-	30"-48"	30"-48"	Semi-Active	-	>48"	Eminence	Outsloped	No-Wrap GT	
		16	10%	87	352	7	15	Shoulder	Linear	Linear	-	-	30"-48"	30"-48"	Semi-Active	-	>48"	Eminence	Outsloped	No-Wrap GT	
		17	7%	51	78	0	78	Backslope	Linear	Convex	-	-	18"-36"	18"-36"	Semi-Active	-	>48"	Eminence	Outsloped	No-Wrap GT	Water Seeps on Trail
		18	7%	70	78	0	78	Backslope	Linear	Convex	-	-	18"-36"	18"-36"	Semi-Active	-	>48"	Eminence	Outsloped	Surface Aggregate	Water Seeps on Trail
		19	7%	103	78	0	78	Backslope	Linear	Convex	-	-	18"-36"	18"-36"	Semi-Active	-	>48"	Eminence	Outsloped	Surface Aggregate	Water Seeps on Trail
		20	20%	286	15	10	5	Backslope	Convex	Convex	-	-	24"-36"	24"-36"	Semi-Active	-	>48"	Eminence	Outsloped	Surface Aggregate	
		21	45%	146	15	15	0	Backslope	Concave	Concave	-	-	18"	18"	Superactive	-	0"-22"	Eminence	Outsloped	Surface Aggregate	Dolomite Rock Outcrop, Water Seeps on Trail
		22	12%	80	69	17	52	Footslope	Concave	Concave	-	-	6"-12"	6"-12"	Superactive	-	0"-36"	Eminence	Outsloped	Surface Aggregate	Dolomite Rock Outcrop, Water Seeps on Trail

Table A-7. Angeline CA - Observation Data

Conservation Area	Section #	Segement #	Slope (%)	Length (ft)	Slope Alignment (°)	Topography Location	Bedrock Depth (in)	Geology	Tread Shape	Surface Application	Notes Before Construction	Performance Observations
Angeline Conservation Area	Segment 1	1	14%	159	30	Shoulder	>48"	Gasconade	Outsloped	Surface Aggregate		Ruts created by vehicles; 2" deep ruts caused by water crossing trail surface
		2	10%	172	75	Shoulder	>48"	Gasconade	Outsloped	Surface Aggregate		Ruts created by vehicles; 4" deep ruts caused by water crossing trail surface
		3	20%	157	20	Shoulder	>48"	Gasconade	Outsloped	Surface Aggregate		Ruts created by vehicles; 3" deep ruts caused by water crossing trail surface
		4	12%	69	61	Shoulder	>48"	Gasconade	Outsloped	Non-Wrap GT		Surface always stable; no ruts
		5	11%	131	10	Backslope	>48"	Gasconade	Outsloped	Non-Wrap GT		6" deep ruts created by water crossing trail surface
		6	11%	78	39	Backslope	>48"	Gasconade	Outsloped	Non-Wrap GT	Water Seeps on Trail	Surface always stable; no ruts
		7	19%	88	12	Backslope	>48"	Gasconade	Insloped	Non-Wrap GT		Surface always stable; no ruts
		8	19%	72	12	Backslope	>48"	Gasconade	Insloped	Non-Wrap GT		6" deep ruts created by water crossing trail surface
		9	15%	48	42	Backslope	0"-36"	Gasconade	Outsloped	Non-Wrap GT	Rock Outcrop - Water Seeps on Trail	6" deep ruts created by water crossing trail surface
		10	15%	45	42	Backslope	0"-36"	Gasconade	Outsloped	Non-Wrap GT	Rock Outcrop - Water Seeps on Trail	Surface always stable; no ruts
		11	16%	126	15	Backslope	>48"	Gasconade	Outsloped	Non-Wrap GT		Surface always stable; no ruts
		12	8%	210	45	Bench	>48"	Gasconade	Crowned	Wrapped GT		Surface always stable; no ruts
		13	1%	221	85	Bench	>48"	Gasconade	Crowned	Non-Wrap GT		Surface always stable; no ruts
		14	10%	93	57	Ridgetop	>48"	Gasconade	Crowned	Non-Wrap GT		Surface always stable; no ruts
		15	10%	62	0	Shoulder	>48"	Eminence	Outsloped	Non-Wrap GT		Surface always stable; no ruts
		16	10%	87	15	Shoulder	>48"	Eminence	Outsloped	Non-Wrap GT		Surface always stable; no ruts
		17	7%	51	78	Backslope	>48"	Eminence	Outsloped	Non-Wrap GT	Water Seeps on Trail	Surface always stable; no ruts
		18	7%	70	78	Backslope	>48"	Eminence	Outsloped	Surface Aggregate	Water Seeps on Trail	Ruts Created by vehicles.
		19	7%	103	78	Backslope	>48"	Eminence	Outsloped	Surface Aggregate	Water Seeps on Trail	Ruts Created by vehicles.
		20	20%	286	5	Backslope	>48"	Eminence	Outsloped	Surface Aggregate		Surface stable; No rutting observed.
		21	40%	146	0	Backslope	0"-22"	Eminence	Outsloped	Surface Aggregate	Dolomite Rock Outcrop, Water Seeps on Trail	Ruts 6" deep created by wheeled vehicles; Surface always muddy.
		22	12%	80	52	Footslope	0"-36"	Eminence	Outsloped	Surface Aggregate	Dolomite Rock Outcrop, Water Seeps on Trail	Ruts 6" deep created by wheeled vehicles; Surface always muddy.

B. APPENDIX B: TRAIL CONSTRUCTION DRAWINGS



CLEARING LIMITS

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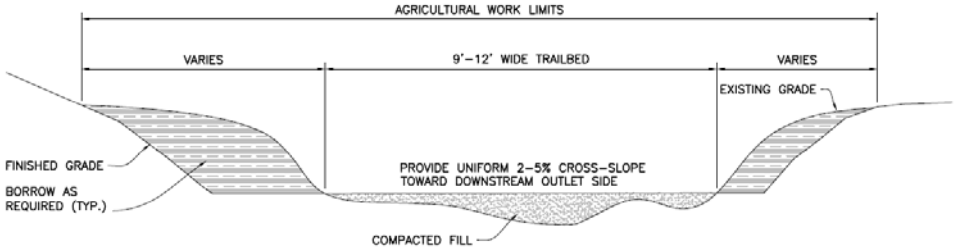
EQUESTRIAN TRAIL - DETAILS

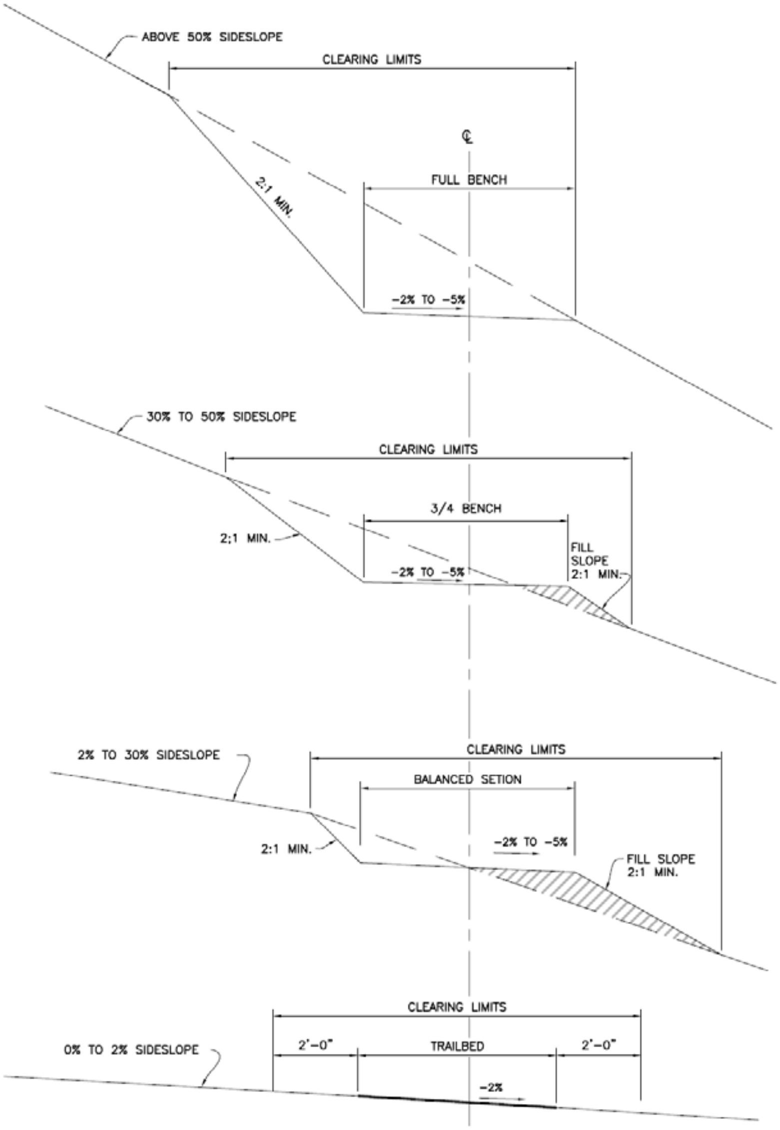
CLEARING LIMITS

SHEET 1 of 1



TRAIL "A" - TYPICAL ROAD RENOVATION

NTS



TYPICAL TRAIL CROSS SECTIONS

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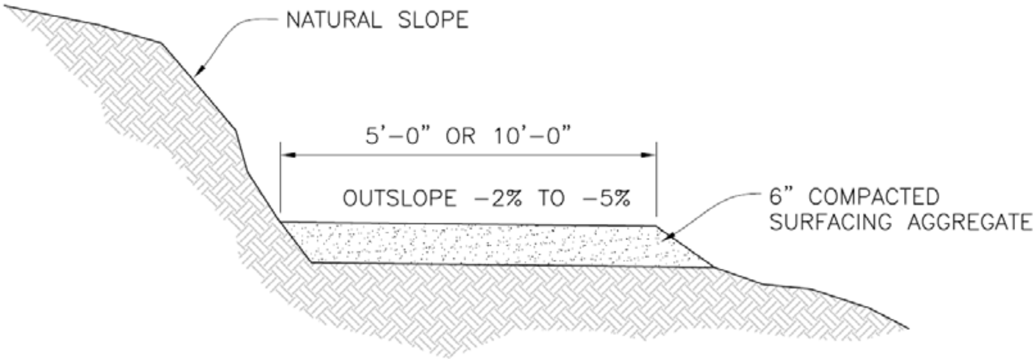
TYPICAL ROAD AND TRAIL SECTIONS

SHEET 1 of 1



1/1

OUTSLOPED AGGREGATE SURFACING

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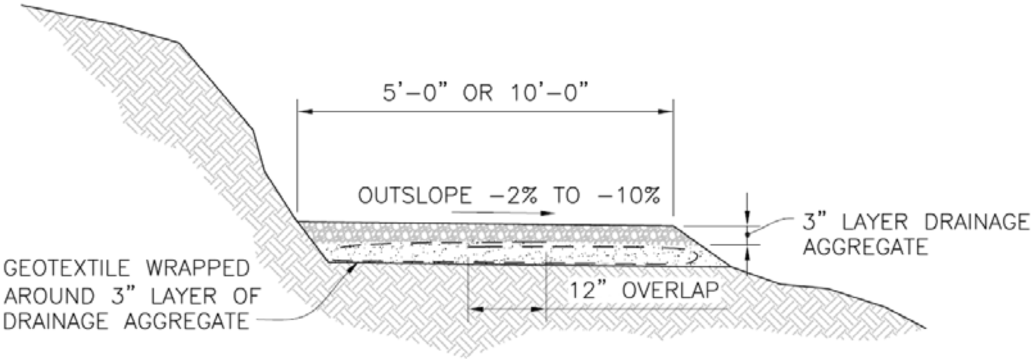

2/1

OUTSLOPED ENCAPSULATED AGGREGATE SURFACING

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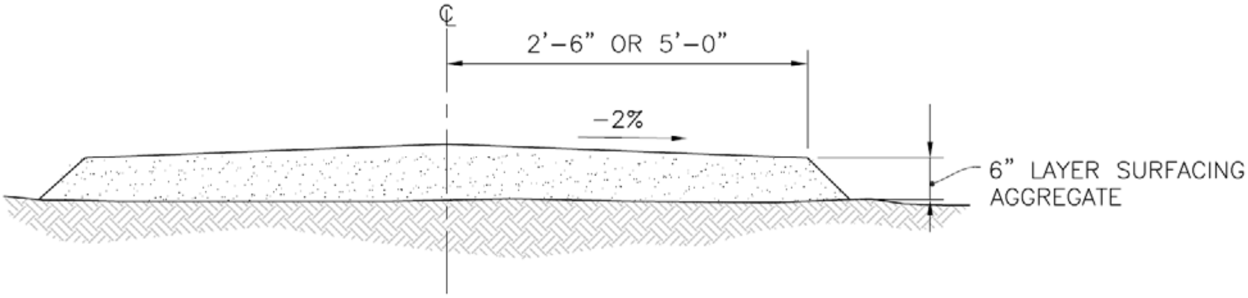
EQUESTRIAN TRAIL - DETAILS
AGGREGATE SURFACING SECTIONS
SHEET 1 of 2



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CROWNED AGGREGATE SURFACING

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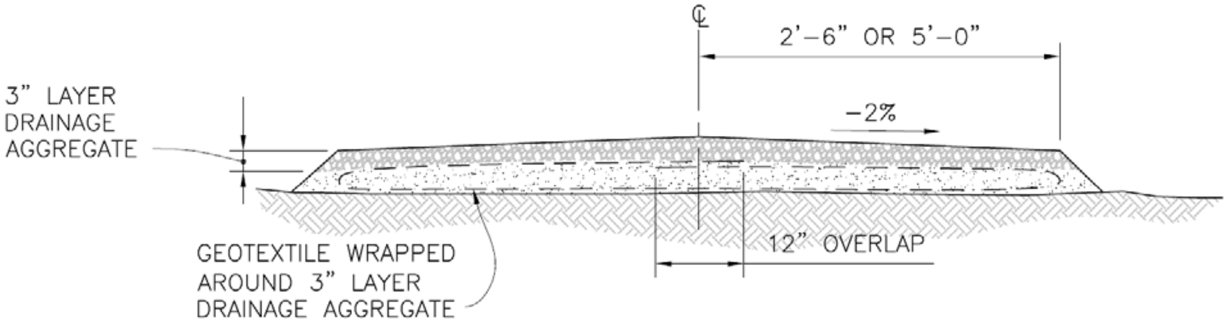

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CROWNED ENCAPSULATED AGGREGATE SURFACING

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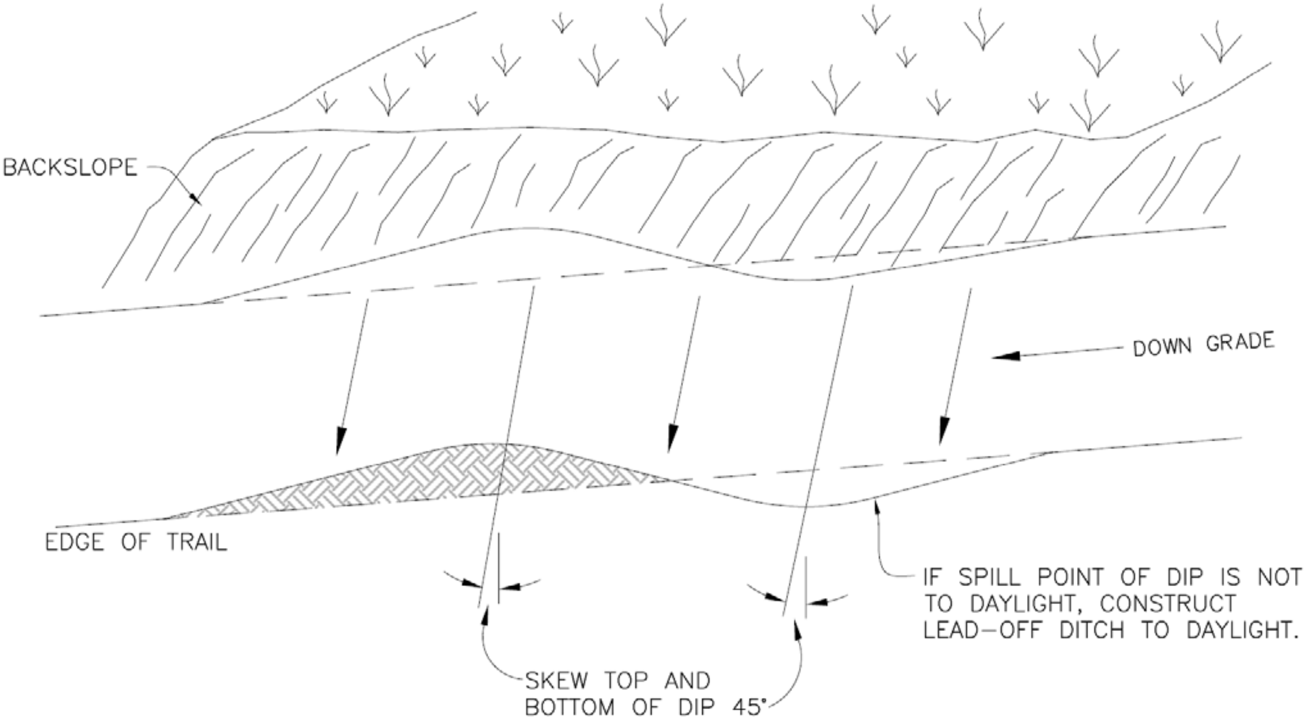
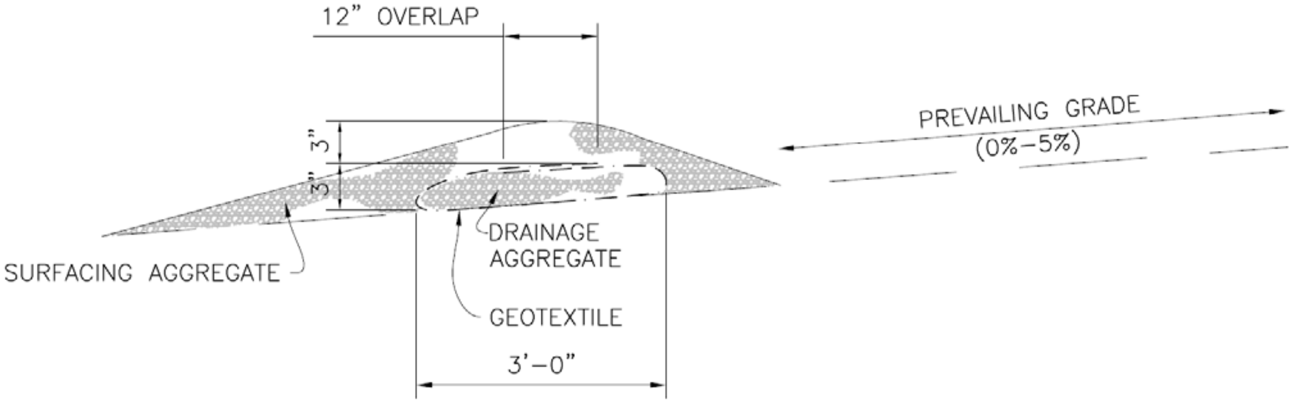
AGGREGATE SURFACING SECTION CONTINUED

SHEET 2 of 2



PLAN



PROFILE

TYPICAL WATER BAR

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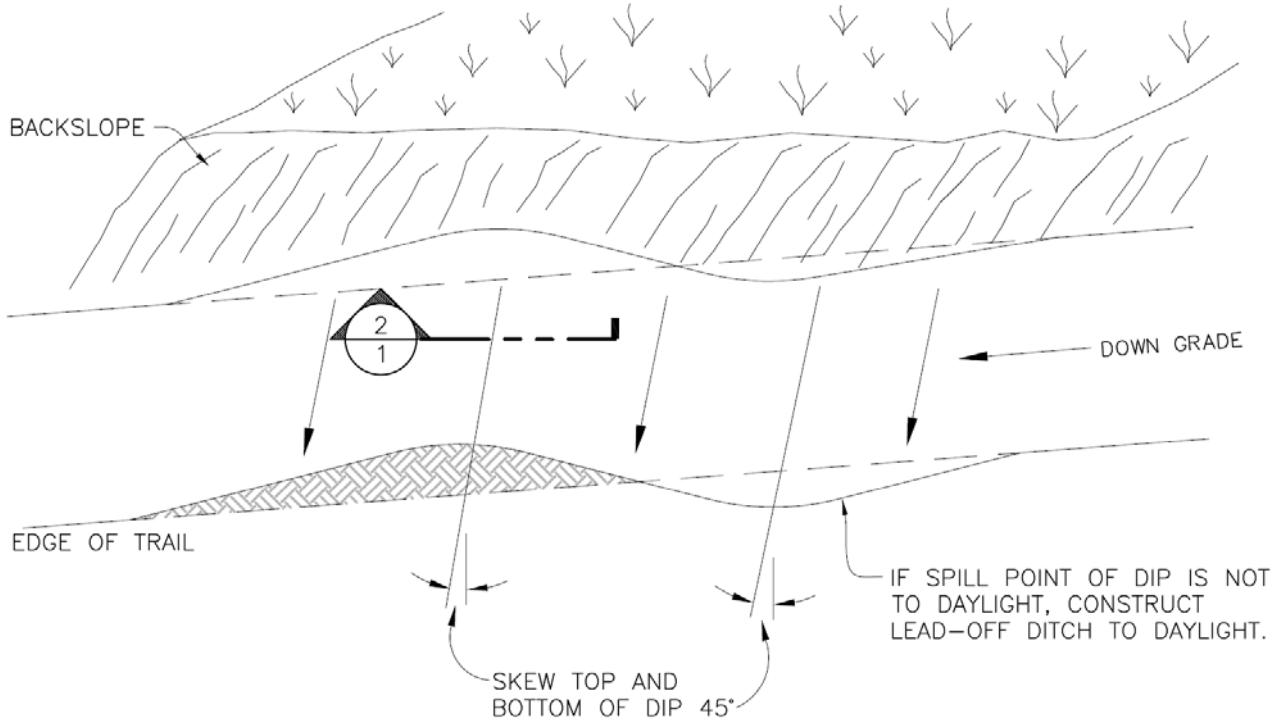
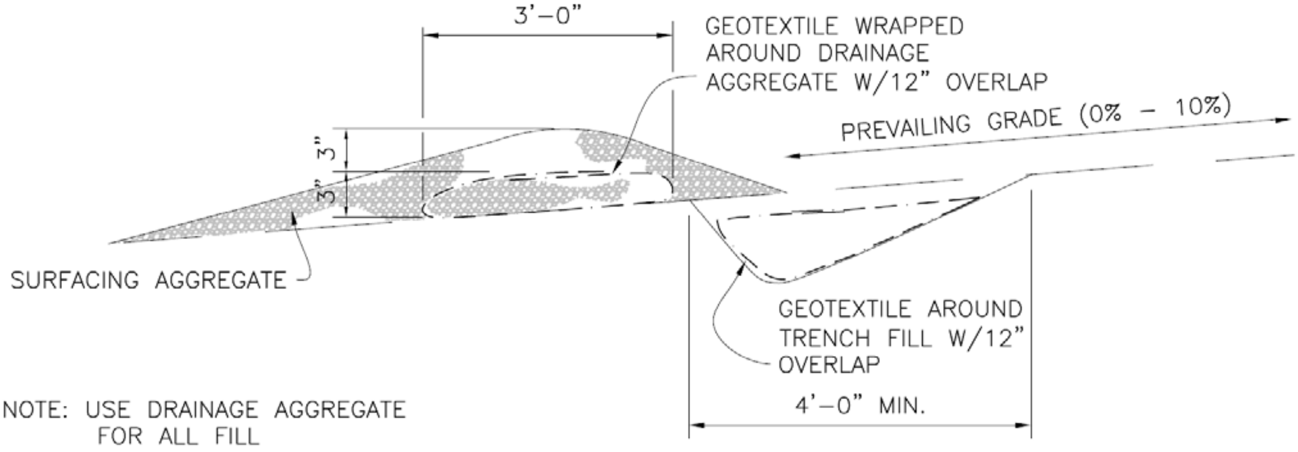
TYPICAL WATER BAR

SHEET 1 of 1



1/1 INFILTRATION BAR PLAN

NTS



NOTE: USE DRAINAGE AGGREGATE
FOR ALL FILL

2/1 INFILTRATION BAR SECTION

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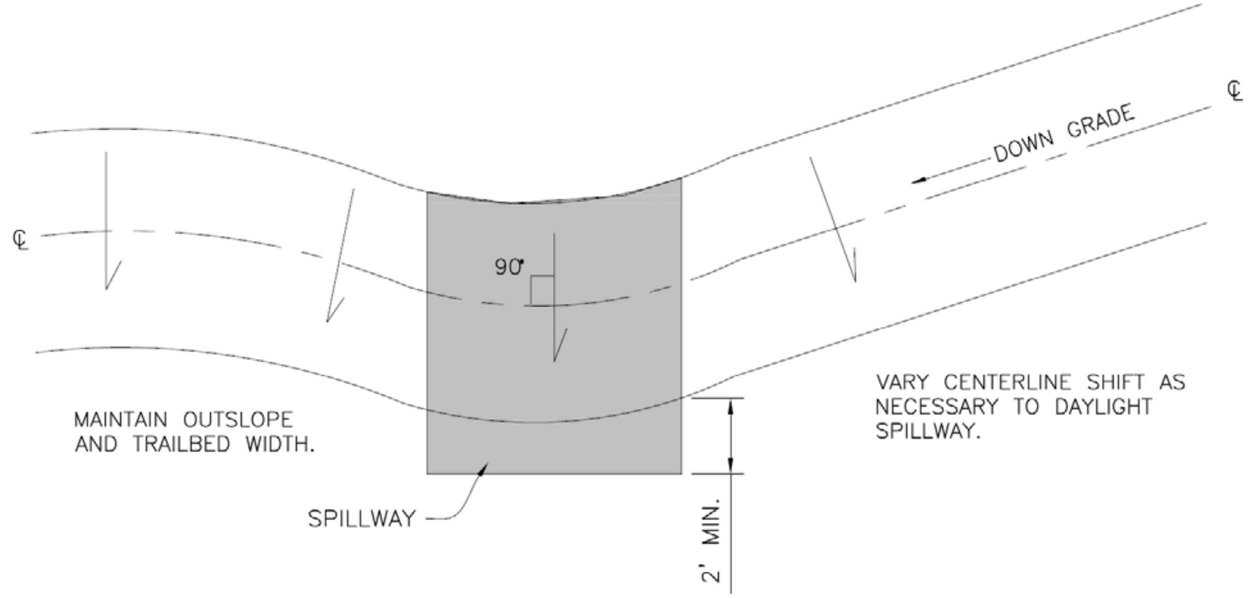
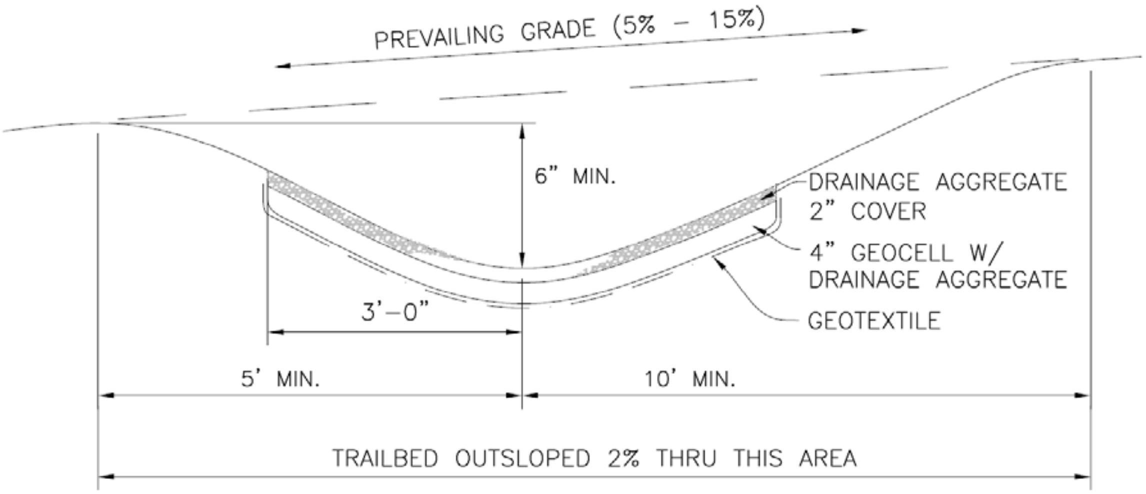
EQUESTRIAN TRAIL - DETAILS

INFILTRATION BAR

SHEET 1 of 1



PLAN



PROFILE

TYPICAL GRADE REVERSAL

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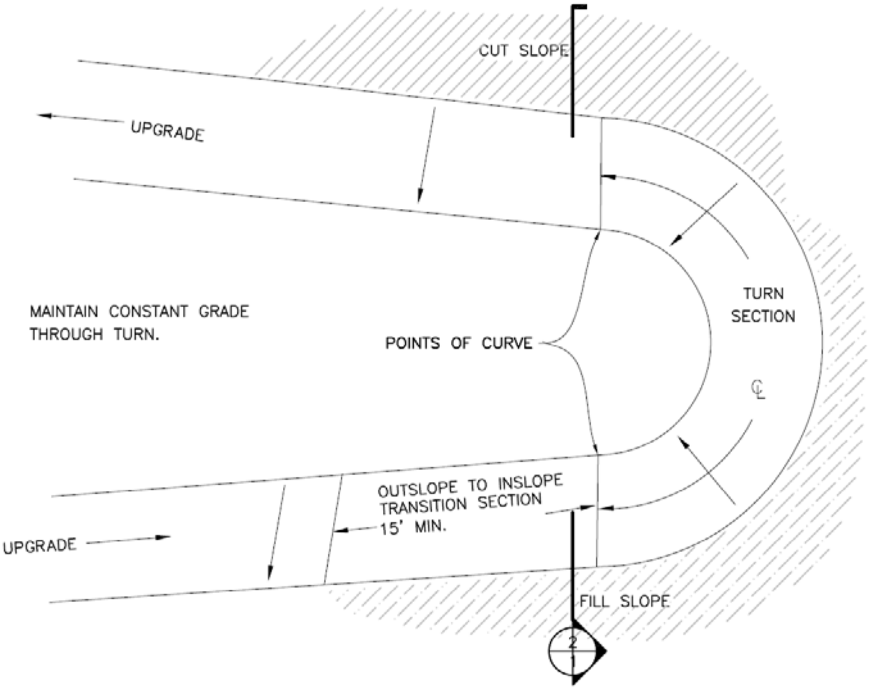
EQUESTRIAN TRAIL - DETAILS

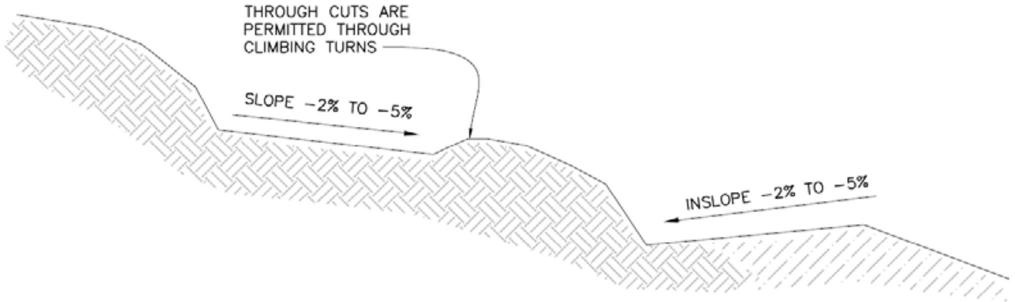
TYPICAL GRADE REVERSAL

SHEET 1 of 1



1/1 **INSLOPED CLIMBING TURN PLAN**

NTS



2/1 **INSLOPED CLIMBING TURN SECTION**

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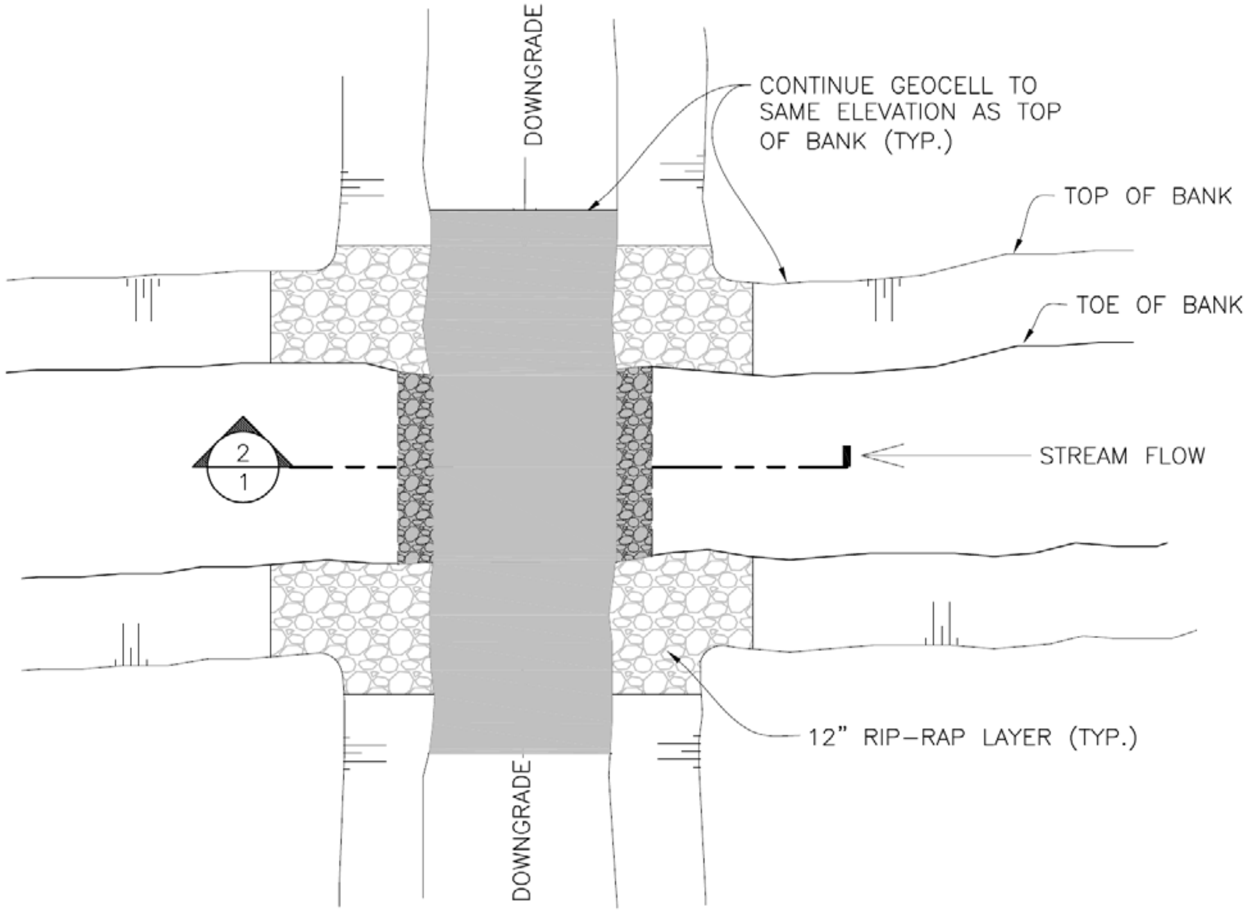
DESIGN & DEVELOPMENT

EQUESTRIAN TRAIL - DETAILS

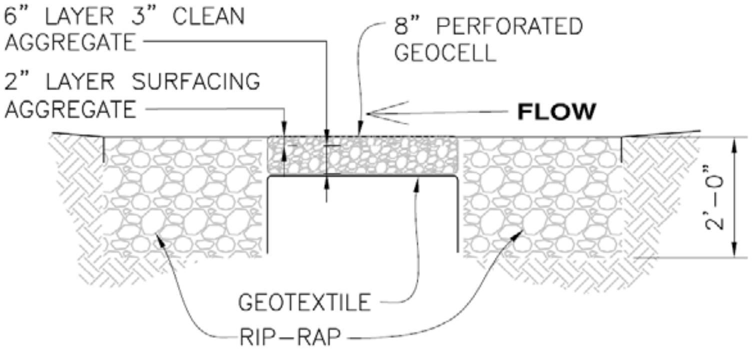
INSLOPED CLIMBING TURN

SHEET 1 of 1



1/1 STREAM CROSSING DETAIL

NTS



2/1 STREAM CROSSING SECTION

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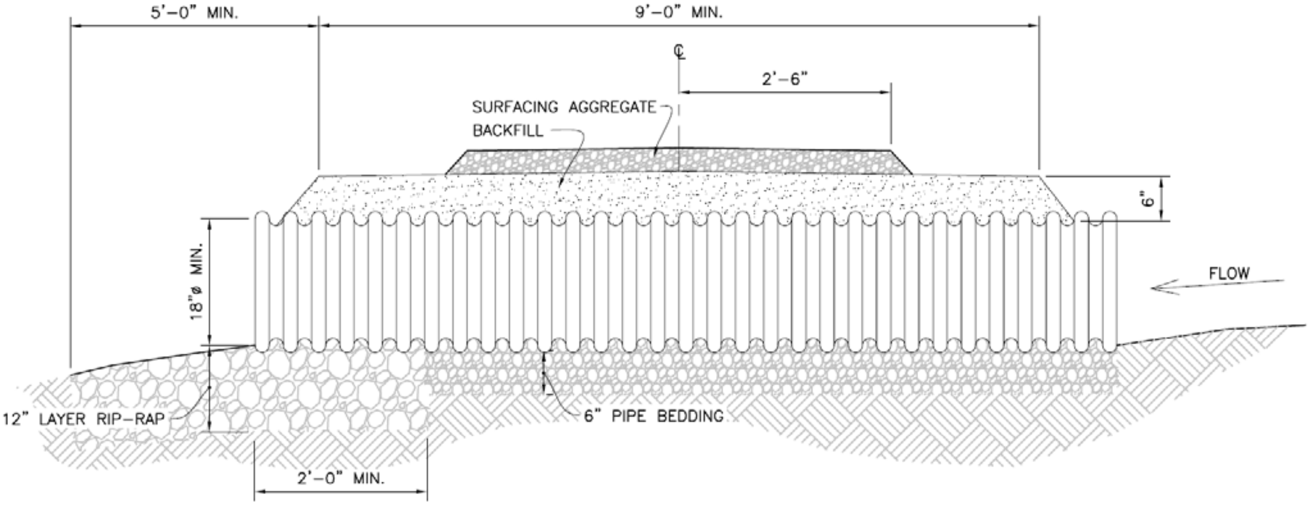
EQUESTRIAN TRAIL - DETAIL

STREAM CROSSING

SHEET 1 of 1



CULVERT DETAIL

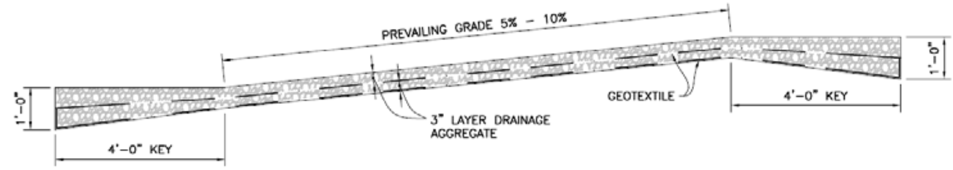
NTS

MISSOURI DEPARTMENT OF CONSERVATION
DESIGN & DEVELOPMENT

EQUESTRIAN TRAIL - DETAILS

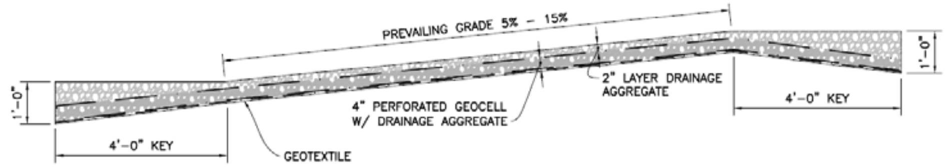
CULVERT DETAILS

SHEET 1 of 1



LONGITUDINAL ENCAPSULATED AGGREGATE PROTECTION

NTS



LONGITUDINAL GEOCELL PROTECTION

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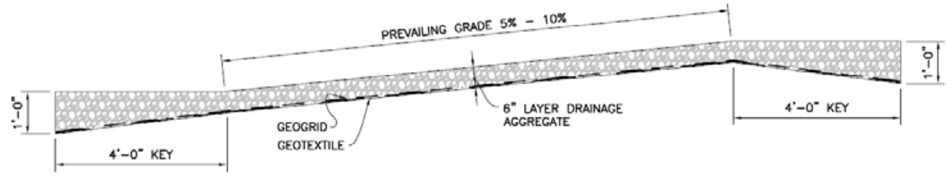
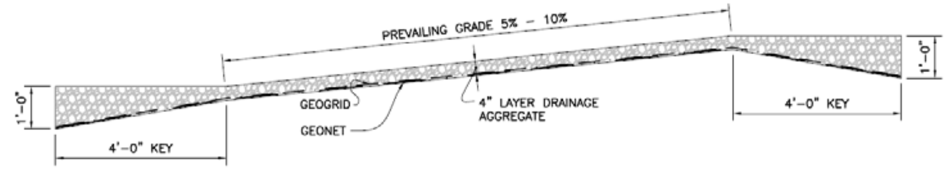


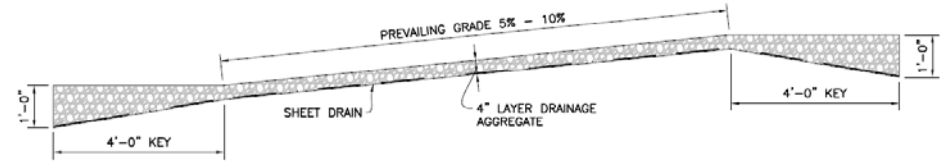
LONGITUDINAL GEOGRID & GEOTEXTILE PROTECTION

NTS



LONGITUDINAL GEOGRID & GEONET PROTECTION

NTS



LONGITUDINAL SHEET DRAIN PROTECTION

NTS

MISSOURI DEPARTMENT OF CONSERVATION
DESIGN & DEVELOPMENT

EQUESTRIAN TRAIL - DETAILS
LONGITUDINAL PROTECTION DETAILS
SHEET 1 of 1

C. APPENDIX B: PRELIMINARY GUIDELINES FOR EQUESTRIAN TRAIL MANAGEMENT.

A preliminary version of the tables and figures for the guidelines are included in this section. The guidelines include the basic thought process for the design and layout of equestrian trails.

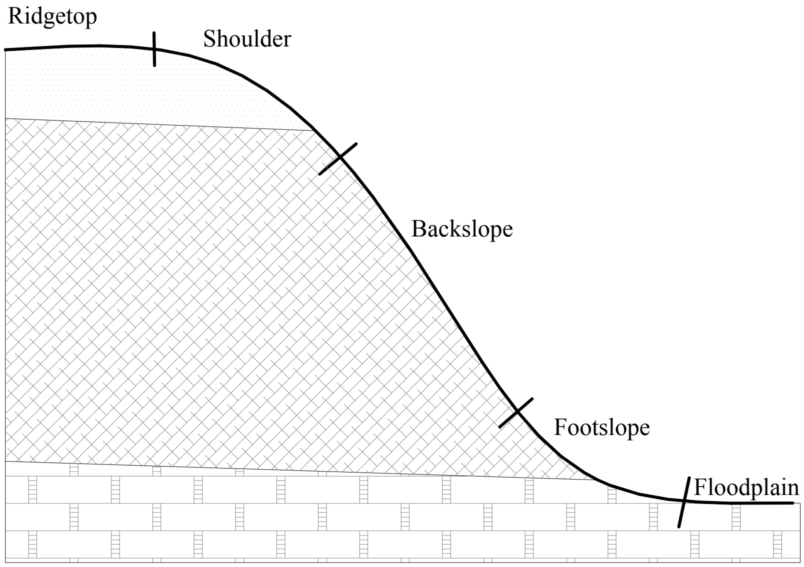
Table C-1. Important Factors for Trail Design.

Soil types and Associated Problems

Soil Type	Erosion Resistance	Trampling/Wearing Resistance	Problems
Clay	High	High (when dry)	Muddy and slippery when wet. High runoff potential.
Silt	Low	Moderate (when dry)	Highly Erosive; Muddy when wet.
Loam	Moderate	Moderate	Possibly muddy when wet.
Sand	Moderate	Low	Loose Particles can be highly erosive.
Gravely Clay	High	High	High runoff potential.
Gravel	Moderately High	High	Potential erosion with intense flows.

Landscape Position Factors

Landscape Location	Watershed Size	Contributing Water Potential	Water Diversion Potential
Ridgetop	Low	Low	Low
Shoulder	Low	Low	Moderate
Backslope	Moderate	Moderate	High
Footslope	High	High	Low
Floodplain	Very High	Very High	Very Low



Trail Alignment Angles Factors

Alignment Angle	Water Diversion Potential	Erosion Potential
68-90°	High	Low
46-67°	Moderate	Moderate
23-45°	Low	High
0-22°	Very Low	Very High

Problem Solving Flow Chart for Old Trail Segments

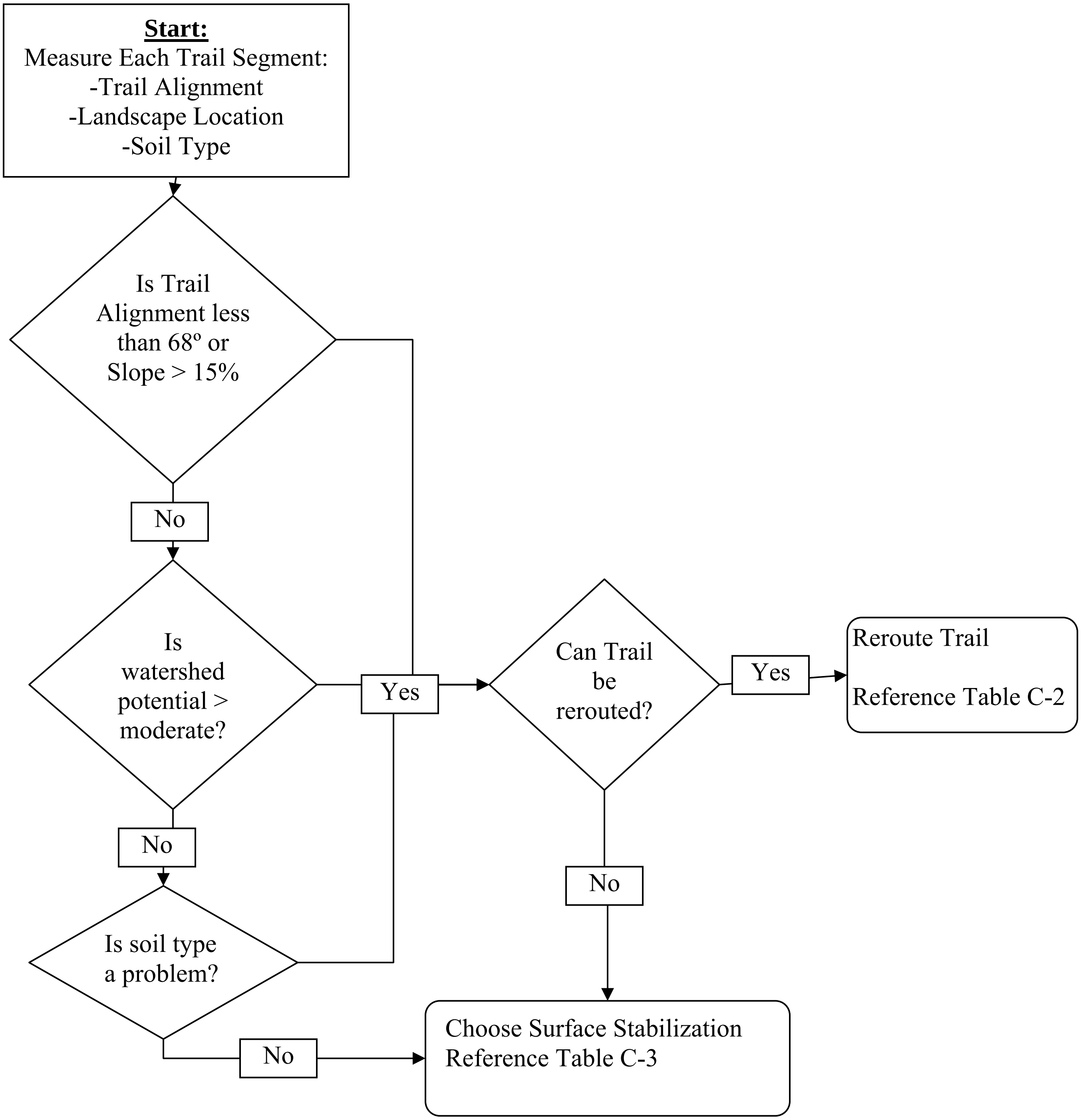


Table C-2. Design Steps for Rerouting/New Trail Construction.

1. Obtain Soil and Landscape Data.
    a. Soil Texture
    b. Restrictive Soil/Geology Layers
    c. Topography and Soil Maps
2. Using a topographic map, layout the new trail on paper.
    a. Avoid concave and low areas
    b. Keep trail steepness below 15%
    c. Keep Trail Alignment above 68º
3. Visit the site and layout trail.
4. Choose Surface Stabilization
    a. Reference Table C-3.
5. Locate water control structures.
6. Construct Trail.
7. Monitor Performance.

Table C-3. Surface Stabilization Selection Chart.

			Water Potential											
			Low				Med				High			
Trail Alignment	Trail Steepness	**Soil Type**	None	Gravel	GT	GC	None	Gravel	GT	GC	None	Gravel	GT	GC
69-90°	0-7%	Silt/Sand	x					x					x	
		Loam	x					x					x	
		Clay		x					x				x	
		Gravel Loam	x				x					x		
		Gravelly Clay	x				x					x		
	8-15%	Silt/Sand		x				x					x	
		Loam		x				x					x	
		Clay			x				x				x	
		Gravel Loam	x					x					x	
		Gravelly Clay	x					x					x	
	15-25%	Silt/Sand			x				x					x
		Loam		x					x					x
		Clay			x				x					x
		Gravel Loam		x				x						x
		Gravelly Clay		x				x						x
23-68°	0-7%	Silt/Sand		x				x					x	
		Loam	x					x					x	
		Clay			x				x				x	
		Gravel Loam	x				x					x		
		Gravelly Clay	x				x					x		
	8-15%	Silt/Sand		x				x					x	
		Loam		x				x					x	
		Clay			x				x				x	
		Gravel Loam	x				x						x	
		Gravelly Clay	x				x						x	
	15-25%	Silt/Sand		x					x					x
		Loam		x					x					x
		Clay			x				x					x
		Gravel Loam		x				x						x
		Gravelly Clay		x				x						x
0-22°	0-7%	Silt/Sand		x				x					x	
		Loam		x				x					x	
		Clay			x				x				x	
		Gravel Loam	x				x						x	
		Gravelly Clay	x				x						x	
	8-15%	Silt/Sand		x				x					x	
		Loam			x			x					x	
		Clay			x				x				x	
		Gravel Loam	x					x					x	
		Gravelly Clay	x					x					x	
	15-25%	Silt/Sand			x					x				x
		Loam			x					x				x
		Clay			x					x				x
		Gravel Loam		x				x						x
		Gravelly Clay		x				x						x
			Solutions											

None – Surface stabilization not required; requires more maintenance.
Gravel – Requires least 4” of surface aggregate.
GT – Gravel with Geotextile (wrapped or non-wrapped; depends on situation).
GC – 4” Geocells.