BACKCOUNTRY TRAILS NEAR STREAM CORRIDORS: AN ECOLOGICAL APPROACH TO DESIGN

by

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(ABSTRACT)

Traditional trails near backcountry stream corridors are often designed with disregard to their potential ecological impact. Ecological and trail related literature show that riparian landscapes are sensitive to recreation impacts. This thesis examines concepts for designing trails in ecologically compatible ways near backcountry stream corridors.

The synthesis of the literature regarding the biophysical processes of stream corridors and the effects of trails on the environment is used to help develop principles and guidelines for locating trails near backcountry stream corridors. In turn, these principles and guidelines assisted in the development of a trail assessment manual useful to scientists, planners, and designers. Seven trail impacts are assessed: excessive soil erosion, wet trails, water on trails, excessive trail widths, multiple trails, root exposure, and stream sedimentation. Three backcountry study sites from the Appalachian Ridge and Valley Province of Virginia are evaluated. A ranking and measurement procedure is developed to characterize environmental, use, design/siting, construction, and maintenance factors because each of these influence the degree of impacts along studied trails.

Results show that many steep trail segments, especially those without proper drainage features have incised or eroded trail treads. Likewise, many trail segments without drainage features located along flat adjacent landforms have wet soil and water on trail impacts. Overall results show that as use amount or type increase there is a parallel in trail and environmental degradation. Finally, a stream crossing and trail drainage concept is developed illustrating ways to reduce sediment inputs into nearby streams.

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TABLE OF CONTENTS

Chapter 1 Thesis Introduction **1**

Problem Statement **3**

Thesis Questions **4**

Chapter 2 Literature Review **5**

Characteristics of Backcountry and Frontcountry Recreation Areas **6**

Geomorphology of Stream Corridors **9**

- Introduction **9**
- Processes **10**
- Drainage Basin **12**
- Channel Form **14**
- Topography **15**
- Aspect and Elevation **20**
- Land Cover **22**
- Land Use **24**
- Habitat Structure **25**

Environmental Impacts Near Stream Corridors as Clues for Ecological Trail Design. **28**
A Review of Four Components for Areas Within or Near Stream Corridors:
Vegetation, Soils, Water Quality, and Wildlife

- Vegetation and Vegetation-Soils Relationships **28**
  - Vegetation **30**

        Trail Impacts **30**
        Factors That Influence Extent of Impact **31**
    Soils and Soil-Water Quality Relationships **33**
        Soils and Trail Impacts **33**
        Factors That Influence Extent of Impact **34**
        Soil-Water Quality Relationships **36**
        Stream Impacts from Trails **36**
        Factors That Influence Extent Of Impacts **37**
    Wildlife **39**
        Trail Impacts **39**
        Factors Influencing Extent of Impacts **41**

Chapter 3 Synthesis and Implications of the Literature Review **43**
Addition to Mannings' Trampling Diagram **43**
Summary of Ecological Trail Design Research **44**
Principles/Guidelines **48**

Chapter 4 Trail Study Sites and Case Study Methodology **52**
Trail Descriptions **52**

Chapter 5 Results/Discussion **61**

Chapter 6 Conclusion **84**

Bibliography **91**

Appendix A Trail Assessment Manual **95**

Appendix B Tables for Field Data **109**

Appendix C Maintenance/Construction Figures **113**

Vita **117**

List of Figures

Figure 2.1 Typical Drainage Basin: Form and Stream Orders **13**

Figure 2.2 Trail Alignment **16**

Figure 2.3 Out-Slopping Trail Tread and Relationship to the Landform **19**

Figure 2.4 Matrix Vegetation of Backcountry and Frontcountry Stream Corridors **26**

Figure 2.5 Four Different Lineal Habitats of Stream Corridors **27**

Figure 2.6 Trampling Impacts on Vegetation and Soils **29**

Figure 3.1 Mannings' Diagram Expanded **43**

Figure 4.1 Trail 1: Appalachian Trail at Peters Mountain Wilderness **53**
along the Pine Swamp Branch

Figure 4.2 Trail 2: Cascades Trail along Little Stony Creek **55**

Figure 4.3 Trail 3: Pandapas Pond Trail along Poverty Creek **57**

Figure 5.6 Stream Crossing Design Concept **78**

Figure C.1 Corduroy **113**

Figure C.2 Puncheon **113**

Figure C.3 Turnpike **114**

Figure C.4 Waterbar: Function and Maintenance **114**

Figure C.5 Geonet **115**

Figure C.6 Geogrids **115**

Figure C.7 Geotextile Placement **116**

Figure C.8 Geotextile Placement **116**

List of Tables

Table 3.1 Environmental, Use, Siting, and Maintenance Factors Causing Trail Degradation **47**

Table 3.2 Environmental, and Trail Use, Siting, and Maintenance Factors Causing Stream Sedimentation **48**

Table 5.1 Trail 1, Pine Swamp Branch segment of the Appalachian Trail. Means, minimum, and maximum measurements for trail resource impact segments **61**

Table 5.2 Total lineal distances of resource impacts for The Appalachian Trail along the Pine Swamp Branch Creek **62**

Table 5.3 Contributions of Individual Factors of Use, Siting, and Construction/Maintenance to Soil Erosion (SE) on Trail 1 **63**

Table 5.4 Trail 2, Cascades Trail along Little Stony Creek. Means, minimum, and maximum measurements for trail resource impact segments **65**

Table 5.5 Summary of number of occurrences and total lineal distance of trail attributes for The Cascades Trail along Little Stony Creek **66**

Table 5.6 Contributions of Individual Factors of Use, Siting, and Construction/Maintenance to Soil Erosion (SE) on Trail 2 **68**

Table 5.7 Contributions of Individual Factors for Use, Siting, and Construction/Maintenance for Wet Soil (WS) and Water on Trails (WT) on Trail 2 **69**

Table 5.8 Trail 3, Pandapas Pond Trail along Poverty Creek. Means, minimum, and maximum measurements for trail resource impact segments **72**

Table 5.9 Summary of number of occurrences and total lineal distance of trail attributes for The Pandapas Pond Trail along Poverty Creek **72**

Table 5.10 Contributions of Individual Factors of Use, Siting, and Construction/Maintenance for Soil Erosion along Trail 3 **73**

Table 5.11 Contributions of Individual Factors of Use, Siting, and Construction/Maintenance for Wet Soils on Trail 3 **75**

Table 5.12 Occurrences and Types of Related Stream Sedimentation along all Studied Trails **77**

Table B.1 Resource Condition Field Data for Trail1 **109**

Table B. 2 Resource Condition Field Data for Trail 2 **110**

Table B. 3 Resource Condition Field Data for Trail 3 **111**

Chapter 1 Introduction

Why is it important to study trail impacts near stream corridors? First, stream corridors are valuable and vulnerable natural resource settings. Placing a recreational trail near this natural resource creates tension between conservation and recreation related goals. People enjoy hiking near water. Encouraging recreation within or near a stream corridor may compromise the corridors' natural functions. Therefore studying and understanding visitor related impacts and ways to reduce these impacts is necessary if we are to accommodate recreational use while preserving natural resources.

Similarly, protecting stream corridors from trail impacts is beneficial to preserving natural hydrologic processes of the corridor and helps to protect the larger drainage basins to which stream corridors are linked. A naturally functioning stream corridor (without trails or human activities) typically provides clean water to downstream areas. Clean water is the result of a complex interaction between geomorphology, landform, soils and riparian flora and fauna. Trail and other human impacts can disrupt the interactions between these components in various ways thus impairing the corridor's ability to produce clean water.

A third reason to study this topic is to provide a more comprehensive understanding of appropriate ways to design trails in riparian habitats. Current trail maintenance and design manuals are primarily derived from management experience and are chiefly based on recreation needs and objectives. The focus of this thesis is to study the structure, function, and dynamics of stream corridors and their associated watersheds, and to evaluate the impacts that trails have on stream corridor function and dynamics. This type of investigation will provide information essential to design, construct, and maintain riparian trails that avoid or minimize riparian corridor resource impacts while still providing for recreation needs and desires.

Due to the large number of possible interactions of trails to areas within or near stream corridors, the scope of this thesis is limited to backcountry trail design in rural, mountainous areas. The findings of this thesis are expected to be generally applicable to frontcountry trail design. The thesis has two sets of goals:

General goals specific to trails within or near stream corridors:

1. To understand five stream corridor attributes: geomorphology, vegetation, soils, water quality, and wildlife.
2. To understand the appropriate relationship between a trail and areas within or near a stream corridor.
3. To understand the primary impacts that recreational trails have on areas within or near stream corridors and describe practices that can be used to reduce these impacts.
4. To develop principles and guidelines for designing a ecologically sensitive trail within or near a stream corridor so that trail designers and trail managers can improve how trails are located, maintained, and managed.

Site specific goals:

1. To provide a description of site conditions for typical areas within backcountry stream corridors and their associated drainage basins in the Appalachian Ridge and Valley Province (ARVP) of Virginia.
2. To understand the important relationships between specific trails and trail related environmental impacts on natural structure and function for areas within or near stream corridors of the ARVP.

Problem Statement

Very few trail impact studies of stream corridors within the Appalachian Ridge and Valley Province exist. Since recreation trails are in high demand in this phsysiographic province and stream corridors are desirable places for trails, a study of selected trails within ARVP stream corridors is important. This study evaluates resource conditions on these riparian trails and will shed light on new design concepts allowing trail designers and managers to upgrade traditional design concepts.

Traditional methods of locating trails have not specifically accounted for riparian habitats and drainage basin functions and attributes. The combined literature found in the fields of Landscape Architecture and Recreational Ecology offer limited, nevertheless useful ecological design concepts for this thesis. Existing literature is somewhat limiting due to the complex processes associated with mountainous stream corridors and their relationships to recreational trails. This research offers insights and applied knowledge to ecological trail design near stream corridors of the ARVP. Study sites are specifically chosen to facilitate applied research of the subject.

A principal hypothesis of this thesis is that the application of trail design guidelines informed by recreation and riparian ecology literature research can substantially improve the siting and/or design of trails. These guidelines will help trail designers avoid or minimize impacts to riparian natural resources and trails. This thesis asks three important questions:

- What are the essential issues to consider in the layout and construction of trails within or near backcountry stream corridors and what issues of trail design are most and least understood as noted within the literature?

- What can we do to avoid trail degradation and associated natural resource impacts when we design and construct a low impact, backcountry trail?

- What types of trail degradation occur on backcountry trails within or near stream corridors? Also, given that these problems exist, why do they occur and how are they affected by various environmental and managerial factors?

Given the complexity of riparian habitats, specific aspects of stream corridors will be assessed and analyzed. These aspects are geomorphology, vegetation and soils, water quality, and wildlife. This discussion of explicit stream corridor attributes, essential in the study and understanding of trail impacts on riparian systems, is discussed as part of the literature review.

Chapter 2 Literature Review

The literature review discusses specific characteristics of areas within or near stream corridors (riparian landscapes) in order to determine the sensitivities of these areas to existing or proposed recreational trails. Literature from the fields of Landscape Architecture and Recreational Ecology and Geomorphology are used to understand ways to design and manage trails within riparian landscapes in an ecologically sensitive manner. The combined literature provides principles and guidelines that designers and managers can use to avoid or minimize trail and environmental degradation. Backcountry, mountainous stream corridors are emphasized to relate to thesis goals and case study objectives.

The literature review emphasizes certain characteristics of riparian landscapes with less emphasis for other characteristics. Emphasis is placed on geomorphology, vegetation, and soil characteristics. Information of these characteristics is plentiful in the literature. Water quality issues are described as part of the soils discussion since there is very little literature related to trail impacts and water quality issues. Wildlife issues are less emphasized due to lack of trail-related wildlife impact literature and the complexity which wildlife considerations present. However, wildlife issues must not be discounted when considering trail design.

Many characteristics of stream corridors are interrelated. Knowledge of these interrelationships is needed for properly designing an ecologically sensitive trail. For instance, vegetation differences in mountain valleys are a result of flooding, topography, and land use. This is the nature of ecology where environmental aspects and landscape factors interrelate to form mosaic landscapes and ecosystems. Ecological trail designs in riparian landscapes rely on an adequate understanding of the interrelationships within riparian landscapes and between stream corridors and trails.

When appropriate, the literature review describes trail design and construction considerations that have been shown to help avoid or reduce trail degradation. This information is provided in association with the discussion of environmental factors and ecological processes of riparian landscapes. This mode of discussion aids in the development of principles and guidelines that minimize degradation to both trails and riparian landscapes.

The literature review first addresses the characteristics of backcountry versus frontcountry settings as determined by the Recreational Opportunity Spectrum. This is followed by a discussion of riparian geomorphology and discussions of riparian land cover and land use. The intimate relationship between vegetation and soils is noted under the vegetation section. Soils and their influence on water quality are examined next followed by a look at water quality issues. The last section contains a discussion of wildlife considerations in relation to trail impacts.

Characteristics of Backcountry to Frontcountry Recreation Areas

The Recreational Opportunity Spectrum (ROS) is a framework designed to zone federal lands for management of recreational uses (1998, Marion, Personal Communication, Hammit and Cole 1987). It was developed and is used by the U.S. Forest Service and the Bureau of Land Management. The National Park Service has also applied ROS and uses similar zoning classifications. Public land management agencies apply ROS to define land management zones to reduce undesirable impacts to resources, promote recreational diversity, and provide backcountry and frontcountry settings (Hammitt and Cole 1987, Brown et al. 1979). Different recreational experiences are part of the development process, including places to contemplate nature and urban parks for sports. ROS management and experience standards of backcountry settings for primitive, semi-primitive, and rural areas pertain to thesis goals.

The ROS spectrum consists of six settings: primitive, semi-primitive/non-motorized, semi-primitive/motorized, roaded natural, semi-urban, and urban. Each setting has specific standards based on physical, social and managerial requirements. The first three settings are typically considered backcountry and the last three frontcountry. The primitive to urban continuum produces a diverse array of natural conditions, providing different experiences for visitors even though similar recreational activities may occur in each zone.

Primitive and semi-primitive non-motorized settings characterize the case study trails in this thesis. Two of these areas were accessible by motorized vehicles in the past and are thus more accessible by motorized (maintenance) vehicles than the third trail selected for study.

Primitive settings require the most limited facility and site management presence. These criteria only allow subtle drainage practices to control erosion, primitive log bridges, and no site development. Facilities are designed to protect resources and provide visitor safety. Native on-site materials are most appropriate for trail construction and maintenance. Only low to moderate levels of visitor use are appropriate and evidence of that use should be minimal.

Semi-primitive non-motorized settings are similar to primitive settings, however there is a increase in the amount of use allowed. This increase in use requires a minor increase in construction and maintenance for resource management and visitor safety. Therefore, the densities (or amount) of constructed drainage features and the amount of site development can increase. Only native on-site materials are allowed for site management.

Marion, (1998, Personal Communication) indicates that even in these mentioned settings, ROS rules may be superseded when trails or resources (along trail corridors) require protective site construction or management. It is not uncommon for these settings to have a pre-fabricated bridge air lifted in and constructed to cross a wide stream. A trail may require the addition of a culvert to allow the passage of a seep or stream under a trail. In some instances, superseding ROS regulations may be the only way to protect trails and site resources or provide visitor safety.

Conversely, in motorized frontcountry environments recreational designs may incorporate the use of non-native materials like pavements, treated lumber, and vegetative plantings with non-native species to protect resources. Such “site development” options offer managers considerably more control over resource impacts in frontcountry settings. For example, managers can effectively resolve trail erosion by applying gravel or pavement, options that would be inappropriate in most primitive and semi-primitive backcountry settings. For these reasons, Marion (1998, Personal Communication) indicates that locating and maintaining trails to avoid or minimize impacts is more critical in backcountry environments than in frontcountry environments for this reason.

Geomorphology of Stream Corridors

Introduction

This section examines the development and characteristics of existing topography typical of mountainous areas and associated stream corridors. A stream corridor is a linear area of riparian and other vegetation that differs from the surrounding matrix (Forman 1995, Forman and Gordon 1986). This area of riparian and other vegetation varies in width and encloses a channel of actively flowing water (Forman 1995, Forman and Gordon 1986). The corridor typically includes the channel and floodplain, the two adjacent banks above the floodplain, and part of the upland above the banks (Forman 1995, Forman and Gordon 1986).

This analysis concentrates on geomorphic aspects that are important for us to understand so we may sensitively locate trails within or near mountainous stream corridors. The analysis uses a geomorphic lens to examine the origins, development, classification, and description of the landforms and landscapes that shape and encompass stream corridors (Tuttle 1975). Pertinent developmental and descriptive characteristics of mountainous stream corridors are analyzed. Information specific to the Appalachian Ridge and Valley (ARVP) is included to develop an appreciation for the types of stream corridors to be highlighted in the case studies.

Processes

Geomorphic processes, which constantly shape and create new terrain, ultimately determine a trails susceptibility to environmental degradation. Two important processes important in shaping mountainous stream corridors and important to trail design are physical weathering and the erosive properties of running water.

Physical weathering slowly disintegrates parent material by thermal expansion, hydration or swelling, frost-heaving, and mass wasting (Tuttle 1975, Ritter 1995). Frost-heaving causes surface rocks to become brittle and can completely bury upper slopes under broken rock (Tuttle 1975). Frost-heaving typically causes degradation of trail treads and the actions of frost-heaving being more prominent in colder, higher mountain elevations.

Mass wasting (Tuttle 1975) and/or mass movements (Ritter 1995) in mountainous areas result from gravity pulling regolith and bedrock downslope. This material is carried downstream and deposited in lower streams, rivers, and oceans. Mass wasting occurs slowly in the form of soil creep and solufication or more rapidly by slumps and landslides (Tuttle 1975).

Solufication is the slow flow ("less than one foot per year") of earth material in saturated soils (Way 1978, p.358). Solufication occurs most on steep slopes but is known to occur on slopes as low as four to five degrees (Tuttle 1975). Snow melt and rain are typical culprits of solufication, causing hillside material to flow downslope, carrying soil, boulders, and trees (Tuttle 1975). Slumps are moderately slow undercutting movements of earth caused by overstepping the base of a slope (Tuttle 1975). A large block of earth is moved during slumps and is caused by erosion, streambank cutting, and trails (Tuttle 1975).

Landslides or avalanches are more sudden than slumps. Avalanches are typically caused by the failure of saturated soils on steep bedrock slopes with thin soil cover (Ritter 1995). In 1969, Nelson County, Virginia received 30 inches of rain in eight hours resulting in a record series of avalanches destroying structures and lives (Ritter 1995). Disturbances on steep slopes have the potential to heighten the risk of avalanches.

Running water physically erodes landscapes by lifting, bouncing, rolling, or carrying particles in solution downslope along the surface or downstream in stream corridor channels (Ritter 1995). The erosive properties of water that are important to stream corridor formation and trail degradation are splash (rain drop impact), wash (overland flow) and flooding (Ritter 1995). Splash and washing affects within stream corridors and on trails are discussed further in the topography and soils sections of the literature review.

Flooding in stream corridors transfers and deposits weathered materials downstream, forming floodplains. “Floodplains are strips of relatively flat land bordering streams which are flooded, on average, once every two years ” (Williams 1978 as quoted in Hupp 1983, p.488). Floodplains have variable widths of specialized vegetation and habitats. Clues from vegetative, topographic, soil, and past flooding determine flood potentials and floodplain extents (Marsh 1991). Hupp (1983) observed different plant species and plant growth forms along the channel and floodplain of Passage Creek Gorge, in the northeastern ARVP. To some extent, vegetative types and patterns predict flooding potential even without other documented information on flooding (Hupp 1983). The vegetative patterns in the lower parts of the Passage Creek Gorge differed from vegetation patterns typical on higher parts of the floodplain.

Identifying these differences in vegetation within or near backcountry stream corridors provide clues for locating trails which avoid floodprone areas. Avoiding floodplains is a common practice (U.S. Forest Service, Trails South date unknown). Building trails outside floodplains usually avoids saturated soils. Avoiding floodplains can also protect important habitats for plants and wildlife.

Drainage Basin

A network of stream corridors typically forms a pear-shaped drainage basin. A drainage basin is a fundamental landscape unit separated from other basins by a series of ridges or other connected high points (Tuttle 1975). Drainage basins contain all sizes of streams. Each stream converges into other streams which eventually flow into the basins' mainstream.

For ease in describing different types of streams, stream channels are numerically ordered based on the nature of their branching. Each channel with actively flowing water is distinguished by a stream order (Forman 1995). "First order streams converge to form second order streams, and two second order streams converge to form a third order streams and so on" (Forman 1995, pg. 212) (See Figure 2.1).

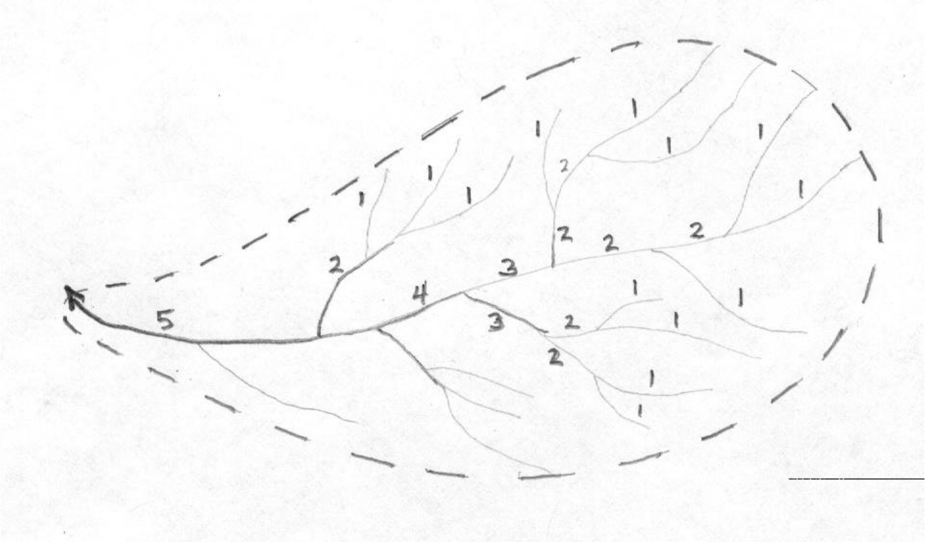

Figure 2.1 Typical Drainage Basin: Form and Stream Orders
Dotted line indicates high points or ridge lines

The branching nature of streams in drainage basins differ from region to region, forming a variety of stream network patterns (Ritter 1995). The branching nature is based on the erosion resistance of parent rock and soil material of its streambed and banks, along with streamflow regimes (Way 1978, Malanson 1993). Mountain streams typically have harder more resistant parent rock and thin soils. Valley streams, due to the process of erosion, deposit rocks, soils, and sediments that often cover erosive-prone parent rock. Stream flow regimes change as a result of precipitation differences and stream grades. Therefore, more precipitation leads to higher volumes of water and steeper grades create faster flows resulting in more erosion.

Physical differences in mountainous and valley drainage basins indicate that trails may impact the environment in different ways. Therefore, principles for locating ecologically sensitive trails may differ depending on whether they are located along steep, mountainous stream corridors or gentle sloping, valley streams.

Channel Form

Streams and rivers have distinct channel patterns depending on geology, climate and location within the watershed. Streams and rivers at lower elevations typically have a meandering or sinuous, movement pattern (Leopold 1997 and Morisawa 1968). Larger streams and rivers (high order) are depositional and have a wide meandering nature with low water velocities (Forman 1995). Streams of 2nd to 4th order (low order) in steep mountains are typically more narrow than high order streams and have higher water velocities. Low order streams often exhibit a pool-and-riffle structure (Forman 1995). Leopold (1997) indicates that streambank erosion takes place on the outer or concave side of a stream (often associated with a pool) and deposition occurs on the inner side of a stream (often associated with a riffle).

Stream channels will often braid, forming islands of varying widths (Forman 1995, and Hupp 1983). This is a result of flooding and stream channel geomorphology. According to Forman (1995, p.211), " thin islands characterize high water velocity ".

Stream dynamics such as flooding, pools and riffles, braiding and islands can be considered when locating trails. Stream dynamics and stream forms are natural indicators for ecological trail locations. Floodplains and pools and riffles indicate areas of erosion and deposition. Braiding and islands indicate areas of prior flooding.

Topography

Topographic features such as slope and grade distinguish low order, backcountry stream corridors from high order frontcountry stream corridors in mountainous regions. Slope is the change in elevation over a certain distance. Changes in slope depends on the resistance of the soil and underlying rock to erosion. Steep slopes and upper ridges of mountains are composed primarily of resistant material. The ARVP’s upper slopes are composed of sandstone and shale which are thin, excessively drained, sterile, and acidic (Barrett 1980). ARVP ridges tend to be wide and convex in shape. This is different in younger mountain regions. For instance, ridges of the Rocky Mountains are more steep and narrower with excessively drained soils. Water runoff is thus greater on ridges in the Rocky Mountains and other comparable mountain areas. Overland water flow is rapid in mountainous areas due to slope and ridge form and excessively drained soils. Overland flow on steep, excessively drained slopes results in dryer slopes.

Lower slope positions in mountains have thicker soils and are more convex in shape. This form allows weathered material and surface and subsurface water to accumulate (Ritter 1995). Lower ARVP slopes are commonly composed of highly erosive limestone and siltstone that are fertile and basic (Barrett 1980). Lower slopes accumulate water, thus overland flow is slower than on steeper mountain slopes. With continually accumulating water and sediments toe slopes are susceptible to movement. Slope shape, composition, location, and grade are important characteristics to be considered in trail designs.

Selecting durable sites with modest water retention, erosion resistant s oil, and underlying rock is often the most important tool for locating backcontry trails (Hammitt and Cole 1987). Steep mountain slopes can be ideal for trails since there is less water retention and rocky erosion resistant slopes. However, steep mountain slopes can also be restrictive to proper trail alignments.

Trail alignment is the topographic location of a trail and is usually constrained by an area's landform. The relationship of a trail's alignment to the landform and a trail's grade is important to designers. Leung and Marion (1996) indicate that trail designers often overlook a trail's alignment in relation to the landform (See Figure 2.2).

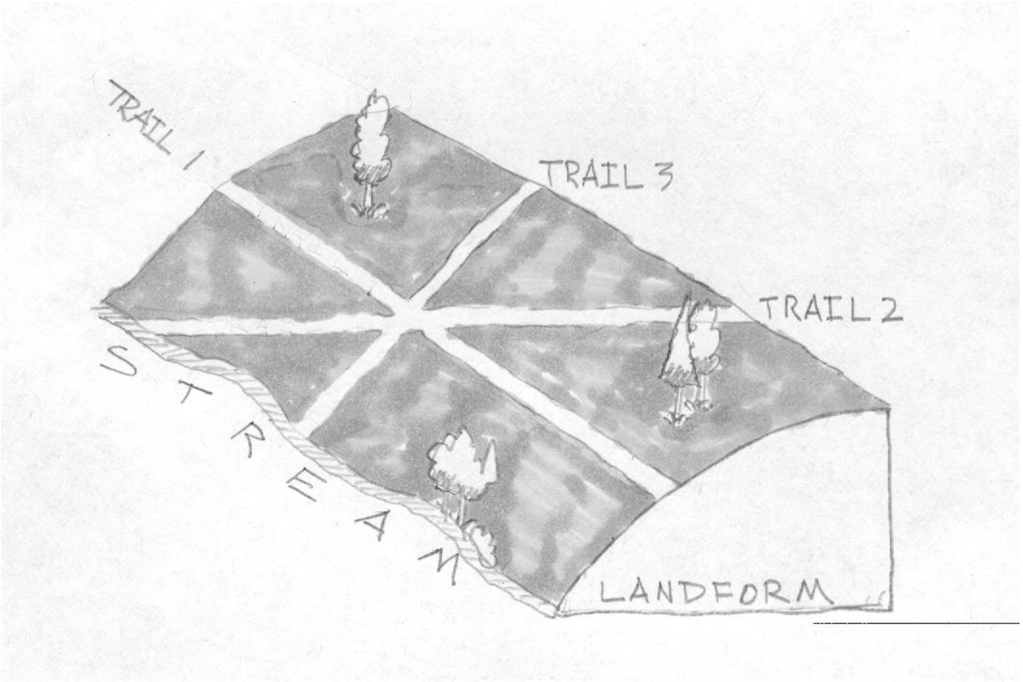

Figure 2.2 Trail Alignment. Trail 1: high slope alignment, Trail 2: intermediate slope alignment, Trail 3: low slope alignment

Trails aligned directly up or parallel to the landform are subject to extensive erosion if trail treads become incised. This type of trail layout is said to have a low slope alignment, with alignment angles between 0 and 22 degrees (Marion, 1998 Personal Communication). Accumulated water on a low slope aligned trail is nearly impossible to drain from the tread because the terrain adjacent to the trail is the same height or higher than the tread. As a trail approaches a 90 degree angle from the landform slope, aligned along the contour, it has a high slope alignment angle. Trails with intermediate to high slope alignment angles can be out-sloped or easily drained with water bars or drainage dips because the terrain slopes downward on one side of the trail.

Steep trail grades may be the most important factor leading to trail degradation (Bratton et al. 1979). Accelerated overland wash on steep slopes erodes and degrades trails more than slow overland wash on trails with modest grades. In general, trail erosion is always greater on steeper slopes (Hammit and Cole 1987). For hiking trails, it is recommended that trails have grades less than 15 percent, though 30 percent grades for short sections are permissible (Brichard 1981). A sidehill trail design that falls within the recommended grades and is angled or perpendicular to the slope is the most appropriate alignment for reducing soil erosion potentials (Bryan 1977).

Locating trails on sidehills with less than a ten percent grade requires no excavation (Brichard 1981). However, as side or landform slopes exceed 10 percent, excavation becomes necessary and increases the potential for soil slumps. Landform slopes above 70 percent require substantial soil excavation with a further threat to trail erosion and/or failure (Brichard 1981). Also important to trail alignment design is the proper use of switchbacks and cross-slopes (out-slopes) and grade.

Steep streambanks and valley walls common in mountainous areas within or near stream corridors require the proper use of trail switchbacks. Switchbacks provide the needed rise in elevation that sidehilling cannot accomplish alone (Proudman and Rajala 1981). Switchbacks should not be close together since users will take shortcuts and trample vegetation, leading to increased habitat destruction and soil erosion (Proudman and Rajala 1981).

Out-sloping allows water to run across and off trail surfaces. This is the key to reducing trail surface erosion (Hultsman and Hultsman unknown date). For an out-sloped trail the uphill edge of the tread is slightly higher than the downhill edge. The recommended trail cross-slope grade is between 2 and 3 percent (Hultsman and Hultsman unknown date) (See Figure 2.3)

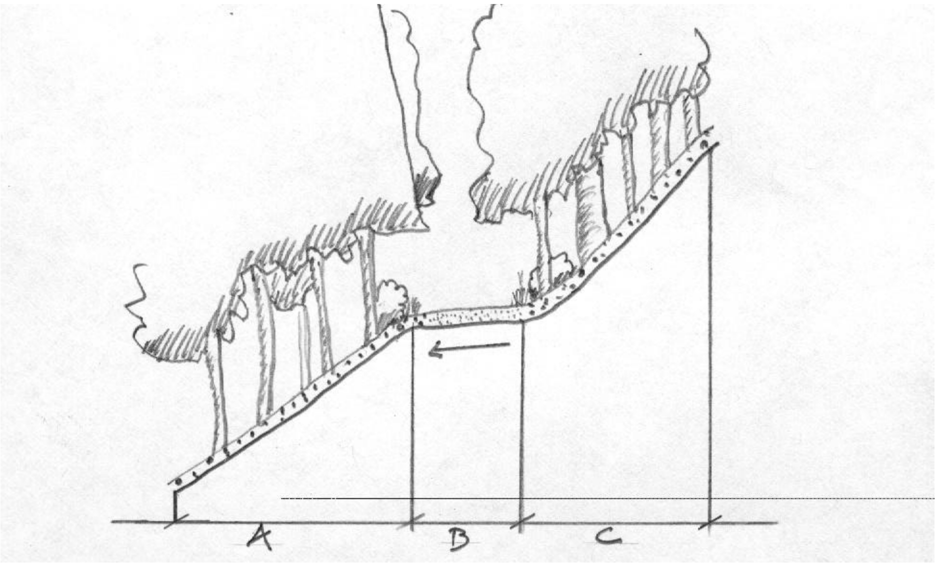

Figure 2.3 Out-Slopping Trail Tread and Relationship to the Landform

A- depicts landform habitat downhill to trail tread
B- depicts trail tread. Arrow indicates direction of out-slope, 2-3% is recommended
C- depicts landform habitat uphill from trail tread

Following recommended slope guidelines, using sidehill designs, and employing trail switchbacks can prevent tread erosion or trail incision. As trail slopes increase, water runoff velocities increase, carrying soils from trail surfaces down slope. Trail treads often become lower than trail edges without corrective maintenance work. Removing water on deep treads is difficult or impossible. Filling the trails with new earth is one way to repair these eroded trails, however, fill and other types of improvement measures can be avoided with proper trail alignment and periodic maintenance.

Typically ridgetop trail locations should be avoided in the ARVP since trail depths increase due to wide convex ridgetops that make draining incised trail treads difficult (Leung and Marion 1996). This is opposite for younger mountains since ridgetops are more easily drained due to narrow ridges. Drainage features can be used to remove water from entrenched trails. A simple drainage dip allows entrenched water to run into a dip or ditch and off the trail tread (Brichard 1981). The ditch is lower in elevation than the trail and catches water running down the trail diverting water off into down-slope areas (see Appendix D for ditch and turnpike features).

In general, trails are most appropriately located between floodplains and ridge tops within midslope positions. Floodplains are predominantly wet and have unpredictable floods. Lower slopes tend to accumulate water and cause trail degradation. However, within midslope positions steep slopes must be avoided. Later discussions of soils, vegetation, water quality, and wildlife will further narrow the optimum locations for environmentally sensitive trails.

Aspect and Elevation

Aspect and elevation are determined by topography. Variable slope angles produce variable aspects which in turn provide diverse microclimates. Elevations in mountains are simply functions of the distance between lower valleys or stream channels to steep upper slopes and ridges. Elevation differences along with other topographic features, provide advantages and disadvantages for trail design. For example, higher elevations are often colder and are more exposed to wind and storm events. Lower elevations are more sheltered but collect and hold water, making them more difficult places to construct and maintain trails.

Highly variable slopes in mountains create differing aspects and elevations which affect the microclimate and topography of areas near stream corridors (Forman 1986). Vegetation and soils are directly related to changes in aspect. Essentially, varying amounts of solar radiation and water regimes on mountain slopes cause differences in soil weathering and hydrologic conditions. Vegetation diversity and composition also differ with aspect and elevation. Similarly, soil compositions and types vary with aspect and elevation. When understood, the characteristic site conditions that aspects and elevations create can help designers choose appropriate trail locations.

North and northeast aspects of mountains are typically steep, have greater water holding capacities, and low amounts of solar exposure (Marsh 1991). Typically south and southeast slopes are also steep, but receive more direct sun angles, causing drier slopes (Marsh 1991). Franzmeir (1969 as quoted in Daniels 1987) found differences in northern and southern aspects on steep slopes of virgin soils in eastern Kentucky and Tennessee. Northern aspects were wetter year round than southern slopes of the area. Also, these steep northern slopes had greater amounts of organic matter than the south facing slopes. Daniels (1983) found similar results in virgin soils in Western North Carolina. Soil organic layers were thicker on north facing slopes than south facing and this increased with elevation for both slopes. Eastern mountain slopes are favored by morning radiation and western slopes are favored in the afternoon.

Variations in aspects cause variability in vegetation types and surface moisture (Marsh 1991). Solar energy is responsible for differences in the photosynthetic and evapotranspiration rates of plants, and differences in air and soil temperature. Northern aspects have drought intolerant mesic vegetation and southern slopes typically have drought resistant xeric vegetation.

High elevation stream corridors have greater amounts of precipitation from snow and rain than lower elevation streams. Also, temperatures are colder and the net effect is a shorter growing season and limited number of plant and animal species. “ In the Great Smoky Mountains of Tennessee and North Carolina, tree species diversity declined with increasing elevation (Whittaker 1956 as quoted in Martin 1988).

The issue of aspect and its relationship to differences in vegetation, soils, hydrology and topography is interconnected. Locating trails along slope aspects that are dry or along sites with a certain type of forest canopy can help create a stable hiking path and may minimize trail degradation. Field observations for recommended soil types, land cover, land use and other environmental factors are also required to wisely locate a trail near riparian, backcountry landscapes.

Land Cover

Marsh (1991) demonstrates that land cover and vegetation are primary indicators of site conditions. Plant type, cover, and abundance differ depending on region, recent human and geomorphic activity, topographic and soil conditions, and precipitation (Marsh 1991). The ARVP, for example, is predominantly mountainous with variable slopes, aspects, elevation, and climate, resulting in a wide range of forest cover types (Barrett 1980).

Malanson (1993) describes seven environments in which stream corridor systems are found. These are: (1) arid and semi-arid gallery forests, (2) tropical forests, (3) subtropical floodplain forests, (4) humid broadleaf forests, (5) forest-grassland transition and grasslands, (6) mountains, and (7) taiga and tundra.

The ARVP is a mountain type environment. Malanson indicates that mountainous riparian zones have complex spatial patterns of vegetation due to, “elevation changes, unknown effects of mountain barriers, and nonequilibrium conditions caused by climatic changes” (Malanson 1993, p.69). These biophysical complexities can make it difficult to distinguish vegetation types of riparian zones from the surrounding matrix.

Bratton (1977, as quoted in Hammitt 1986) indicates that certain forest types are prone to soil erosion along trails in the Great Smoky Mountains. The most eroded soils occurred on trails located in balds, burnscars, spruce-fir forests, and gray beech forests. Intermediate soil erosion rates occurred under mixed northern hardwoods and hemlock coves. The least amount of erosion on trails was found under deciduous cove forests, oak forests and pines (other than white pines). Trails typically impact first the groundcover, then soils, then larger plants like shrubs and trees. This process is discussed further in the vegetation and soils section. The amount of groundcover will vary with overstory and climate. For instance, few plants grow beneath dense evergreens or where precipitation is low.

Mixed Oak (historically called Oak-Chestnut) forests with a characteristic ericaceuos understory, typifies many areas within or near stream corridors in the ARVP (Barrett 1980). Typically, narrow mountain streams are covered by a continuous and dense canopy of woody plants (Forman 1995). As a result, mountain streams have cooler water temperatures with implications for aquatic animal species composition. Forested areas within or near stream corridors inhibit the survival of shade intolerant plants, such as grasses, which are highly resistant to trampling damage. Broad-leaf plants typically inhabit understories of dense forests. Broad-leaf plants are morphologically unlike grasses and are highly susceptible to damage by trampling.

In contrast, wider frontcountry or valley streams have larger canopy openings over their channels. (Forman 1995). Grasses and other sun-loving plants frequently thrive along valley stream corridors. Greater solar exposure and lower gradient streams also create fish populations and aquatic life cycles different than those found in cooler mountain streams.

Land Use

Slope is the major landform factor affecting land uses such as transportation, agriculture, urban development and recreation in mountainous areas. Cropland is usually limited to fertile valley bottoms. Pasture land is frequently found on both moderate to steep slopes in the ARVP. Gently sloping valley sites are necessary for industry and commercial buildings. Residential areas also predominate in flatter terrain but often are found in steeper elevations. Rugged mountains are attractive to recreational trail use which, like the other land uses, have the potential to impact drainage ways and stream corridor resources.

The overall effect of human use within or near stream corridors is 1) a decrease in the size of a stream corridor, and 2) a decrease in the stream corridor variability (Forman 1995). These effects are more intense (as the result of larger human developments including frontcountry trails) than for less intensive uses such as narrow backcountry trails. In areas with heavy human activity, vegetated stream corridor widths tend to be quite variable and corridor boundaries somewhat rectilinear (Forman 1995). The rectilinear form results from adjacent land uses cutting into vegetated boundaries. It has been suggested that widths of protected stream corridor vegetation should change in response to the type and intensities of adjacent land uses (Hellmund 1993). Ideally, vegetation widths should increase opposite matrix areas with the most intensive human activities (Forman 1995). Vegetation and soils of stream corridors retard matrix inputs by way of vegetation and soil friction, plant root absorption, concentrating inputs in clays, and the breakdown of inputs from soil organic matter (Dramstad et al. 1996).

Trails are a land use type that can influence the recreation experience and impact local ecosystems in backcountry areas. Trail designs should minimize the amount of vegetation to be removed and minimize inputting sediments into streamways. Although, sedimentation is a natural process in stream ecology it is generally balanced in a less disturbed system. Increased erosion and sedimentation from trails can seriously degrade mountainous streams by burying aquatic organisms. Trail designs which provide vegetation barriers between trails and stream channels help to prevent an overabundance of sedimentation inputs. Sedimentation and water quality issues are covered further in the soils section of the literature review

Habitat Structure

Backcountry stream corridors in mountainous areas are typically heavily forested and maintain an interior upland habitat on both sides of the corridor. Riparian habitats provide: 1) control of dissolved substance inputs from the matrix, 2) a conduit for upland interior species, and 3) habitats for floodplain species (Dramstead et al. 1996).

Backcountry upland habitats are wide and diverse. There may not be much indication of change in vegetation from the upland edges to the matrix (see Figure 2.4).

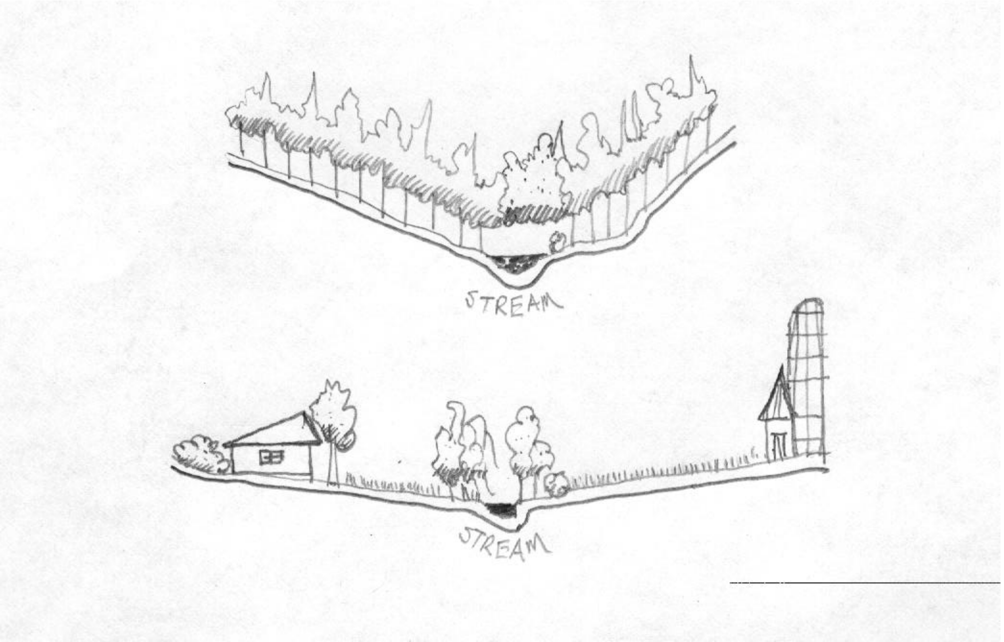

Figure 2.4 Matrix Vegetation of Backcountry and Frontcountry Stream Corridors.
Top figure illustrates typical homogenous matrix of backcountry stream corridor
Bottom figure illustrates typical mixed matrix of urban and agricultural uses in frontcountry

Vegetated frontcountry stream corridors have distinct vegetation differences between upland edges (typically forested, shrub-scrub or meadow-like) and the matrix (often agricultural, suburban, or urban). This matrix may be any type of land use or land cover type. The widths and types of vegetation change along stream corridors in frontcountry sites depend on the intrusiveness of adjacent land uses. When land uses expand into the stream corridor vegetation is impacted.

Four different types of linear habitat may be found within a stream corridor. Forman (1995) describes these habitats as the channel, streambanks, floodplain, and the uplands beyond the floodplain (see Figure 2.5).

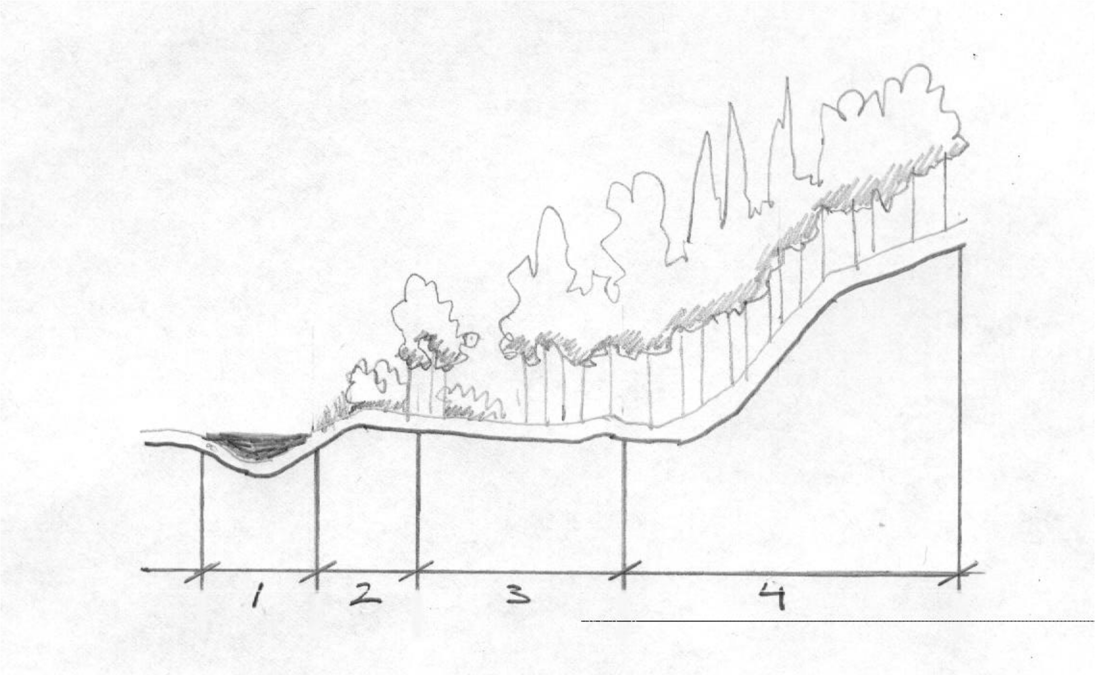

Figure 2.5 Four Different Lineal Habitats of Stream Corridors (adapted from Forman 1995)

1- Channel
2- Streambanks
3- Floodplain
4- Uplands

Widths of habitats vary with respect to the stream corridor's geomorphic location and the land uses and land cover in the surrounding matrix. Forman (1995) diagrams several corridor types showing common relationships between the channel, the floodplain and the corridor. Floodplains of mountain stream corridors are narrow. Mountainous stream corridors form steep v-shape cross sections. Floodplains are wider in valley stream corridors and these corridors form a wide u-shaped cross section.

Stream corridor habitats differ with respect to the ecological context, habitat health, impacts from roads and trails, and other uses. Habitat ecology and habitat impacts from trails are discussed further in the vegetation, soils, and wildlife sections.

Environmental Impacts Near Stream Corridors as Clues for Ecological Trail Design. A Review of Four Components for Areas Within or Near Stream Corridors: Vegetation, Soils, Water Quality and Wildlife

Vegetation and Vegetation-Soils Relationship

Retaining natural vegetation is critical for the protection of the structure and function of riparian landscapes. Vegetation provides food and habitat for wildlife and is closely connected to the physical and biological properties of soils. Vegetation is also important for those who use trails as part of a recreational experience. Thus vegetation, and its protection from trampling impacts, is a primary variable to consider in the design of trails near stream corridors.

Vegetation and soils are interdependent. For most plants soil is the structure needed to grow in. Soils provide germinating surfaces, stability, water, and chemical nutrients. In turn, vegetation provides soil with organic material necessary for microscopic and larger soil-dwelling organisms. Also, plants can stabilize soils and are responsible for balancing soil moisture.

At a microscopic level, plant roots and soils are in direct contact. Chemical interactions necessary for plant growth require this close proximity. Any change in natural conditions has detrimental physiological consequences. This relationship is evident at a macroscopic level with trampling from trail use. Manning (1979) offers a broad analysis of consequential trampling effects on vegetation and soils (See Figure 2.6).

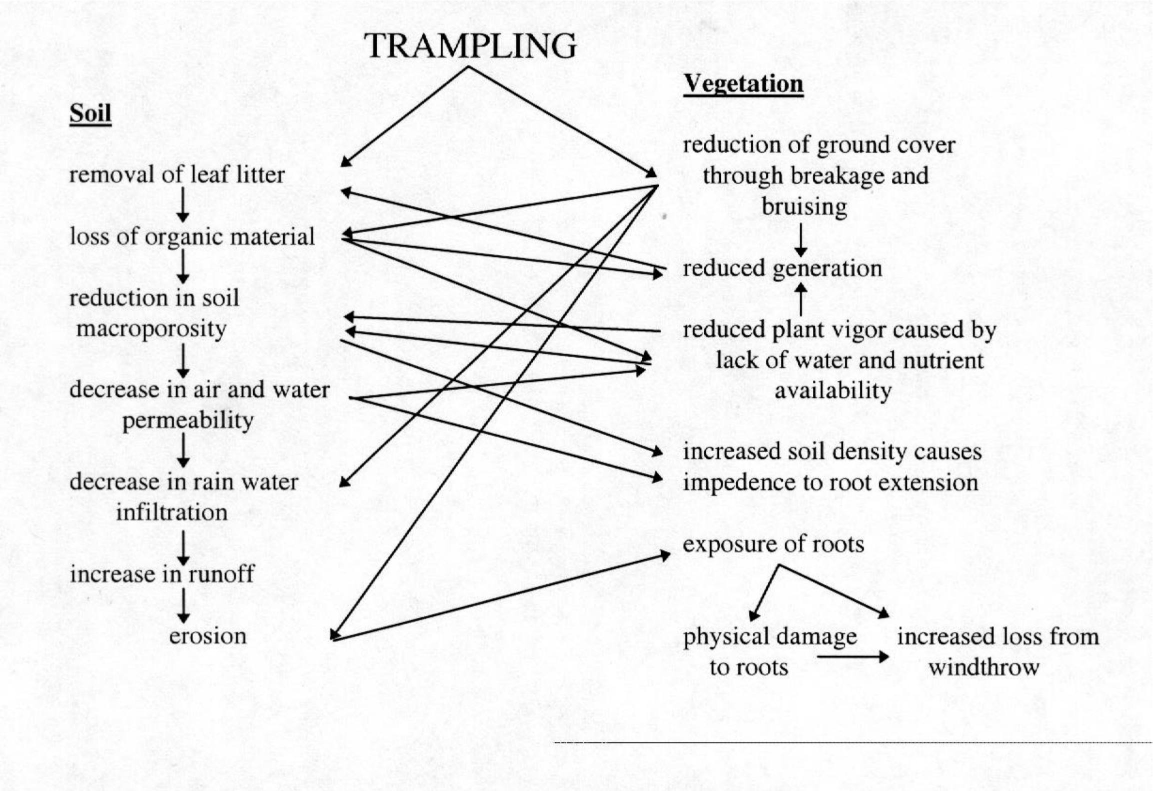

Figure 2.6 Trampling Impacts on Vegetation and Soils (source: Manning 1979)

In Figure 2.6 we can see how trampling impact on vegetation has an effect on soils and how impacts to soils influence plant health and survival. The diagram highlights how trampling can create many related impacts. These effects include the breakage of vegetation and roots, loss of organic mater, reduced plant vigor, reduction of soil porosity and infiltration, increased runoff and erosion, exposure of roots, and ultimately plant death. Mannings' diagram is used to help frame the ideas for the following sections on vegetation and soils.

Vegetation

Reduction in vegetation cover and changes in species composition are an unavoidable consequence of recreational traffic. Limiting vegetation loss along trails is necessary to retain the natural character of landscapes and to limit soil erosion and other negative ecological effects. Vegetation is the most prominent, vertical element of trail corridors and vegetation disturbance may be more noticeable to trail users than disturbance to soils, water quality, or wildlife.

Trail Impacts

Trail traffic generally removes all vegetation cover on trail treads and can also reduce or alter vegetation cover within trail corridors. Trampling impacts to vegetation may be direct from bruising, crushing, or breaking vegetative tissue, or indirect from soil compaction, alteration of surface water drainage, or introduction of exotic species (Hammitt and Cole 1987). Soil compaction reduces soil porosity, inhibiting vegetation from germinating, expanding their root systems, or vegetatively propagating (Hammitt and Cole 1987). Trampling activity and soil compaction reduces native vegetative cover, creating conditions that allow trampling resistant native species and opportunistic exotics to colonize (Hammitt and Cole 1987, Benninger-Truax 1992).

Trails are unavoidable corridors for vegetation movement. Vegetation is dispersed by water, wind, animals, and people (Malanson 1993). For example, humans and animals using trails may collect seeds or propagative tissue in mud stuck to footwear, hooves, or feet, depositing the material in other trail locations. Alteration of vegetative species composition within trail corridors can have conflicting consequences. The influx and spread of exotic species may alter an ecosystem's natural balance or, for trails, provide more trampling resistant plants able to stabilize soils within trail corridors (Benninger-Truax 1992).

Trails near stream corridors can offer special challenges. Forman (1995) notes that streambank plants are typically flood tolerant with strong resprouting abilities, indicating that they may be pre-adapted to trampling disturbance as well. However, floodplains also often include rare plant species and areas or ecosystems high in species richness (Forman 1995).

Factors That Influence Extent of Impact

There is considerable variability in the response of different plant species to trampling disturbance. Plants vary in their relative resistance to trampling disturbance and in their ability to recover from disturbance. Plants are considered resistant to trampling if: 1) their structure is low growing, 2) they have a tufted growth form, 3) they are armed with thorns or prickles, 4) they have leaves in a basil cluster (rosette), or 5) they have fleshy, flexible stems and small, flexible thick leaves that fold under pressure (Hammitt and Cole 1987). Resilience refers to a plant's ability to recover and grow after trampling damage. Resilient plants typically reproduce vegetatively from "suckers, stolons, rhizomes, corms, or underground buds, and initiate growth from basil tissues in addition to apical growth" (Hammitt and Cole 1987). Other factors regulating plant growth, such as soil productivity, moisture, and length of growing season, also influence plant resilience.

Experimental trampling studies reveal that graminoids (grasses, sedges, and rushes) have resistant and resilient characteristics allowing them to survive within disturbed trail corridors (Cole 1993 and 1978, Vanderscuaff 1982, Bright 1986, Hall and Kuss 1989). Cole (1995, 1993) found that certain matted and rosette forbs and woody species also tolerated trampling. These studies also reveal that resistant species, particularly graminoids, are often shade-intolerant, growing best in open vegetation types. Dense forests, such as occur along many mountain stream corridors, may have few resistant plant species. These forests often have an understory consisting of tall, broad-leafed plants that allow maximum solar exposure but are relatively fragile when trampled. Vegetation along the banks of larger streams or rivers often do support graminoids, both because flooding limits taller woody vegetation and because of greater sunlight penetration over water.

Vegetation density also plays a role in limiting vegetation disturbance. Forests with particularly dense understories constrict trail users to trail treads and reduce tread and trail corridor widths (Cole 1981 and 1978, Leung and Marion 1996). Vegetation that is armed with thorns can also constrict trail traffic and reduce overall vegetation impact. Kuss and Graefe (1985) state that other physical and biological habitat variables inherent in ecosystems influence trampling resistance. For instances habitat differences may make the same plant susceptible in a wet site and not susceptible in a dry area. Also community interactions affect susceptibility. Plant species growing in pure stands are more sensitive to trampling than when they grow in mixed stands (Kuss and Graefe 1985). Other variables which lead to trampling susceptibility include succession stages and adaptive strategies.

Soils and Soil -Water Quality Relationships

Soils and Trail Impacts

Soil impacts from trail use, like vegetation impacts, are unavoidable. Manning (refer back to figure 2.6) describes the degradative process of trampling to soils. Once leaf litter and organic material is lost, compaction of soils occur. Compaction decreases macro and micro pore spaces in soils causing soil and tread erosion and degradation of biological processes important to soil inhabitants and plants. The process of erosion is compounded with increased trail slope. Reducing soil erosion and biological impacts entails locating trails on resistant soils and alignments that minimize their erosion potential. Locating trails on recommended soils and grades is challenging on predominately steep mountain stream corridors. However, steep stream corridors may contain resistant soils and surface conditions. Soils and terrain will vary with region but the following general trail design ideas generally would have universal application.

Soils are layered. The top layer is leaf litter which rests on organic soils. Below organic soils are mineral soils which rest on rock and bedrock material. Mannings' diagram (Figure 2.6) illustrates the physical effects to soil layers from recreational trampling. These effects include pulverizing organic leaf litter and accelerated leaf litter loss from wind, water erosion, decay or incorporation of organics into lower soil layers. The loss of organic matter leads to exposure and compaction of mineral soil.

Soil compaction reduces water absorption, increasing overland wash of surface leaf litter and organic soils and impairing biological activities. Water runoff erodes top soil layers which entrenches trails. Decreased trail tread depths expose roots and can create muddy degraded trails. Trails widen when users avoid muddy spots or eroded ruts which further damages trailside vegetation (Leung and Marion 1996). This is compounded on steep trail slopes which increase surface runoff.

Three biological processes are affected by trampling First, increased runoff decreases water infiltration leading to decreased soil moisture for plants. Secondly, increased soil compaction decreases plant root growth. The third effect is the loss of organic material and soil making soil surfaces less hospitable for seed germination, plant growth, and animal habitat.

Trail tread compaction, however, is beneficial to designing a sustainable trail from a recreation point of view. Compacted trails provide an erosion-resistant surface that is free of vegetation and facilitates walking. The path is more visible as a result of vegetation loss. Also, overland flow may be quickly removed off of properly graded and out-slopped trails. Therefore, locating on resistant soils and aligning and grading trails to control water runoff reduces trail degradation.

Factors That Influence Extent of Impact

Resistant soils are soils that are well drained and do not easily erode once compacted. Keller (1988) provides a table of soil type and their ratings for trail construction based on soil strength, sensitivity, compressibility, erodability and permeability. Brichard (1981) recommends a sandy-loam mixed with gravel as an ideal soil type for construction. Leung and Marion (1996) indicate that trails with high rock or gravel content are less susceptible to trail erosion. They recommend that small rocks and stones remain on trails since these materials slow the velocity of water runoff. Brichard (1981) notes that trails located on sites where subsoil is three or more feet deep to bedrock increased tread durability. Thus in some cases it may be wise to remove thin soils altogether to locate treads on more durable bedrock.

Soils most prone to erosion are homogenous in texture and finely grained (Hammitt and Cole 1987). Trails on these soils have been shown to have greater tread incision (Leung and Marion 1996). Brichard (1981) recommends that silty, clayey and spongy peat soils be avoided when locating trails. Also, organic soils, especially when wet were found to form puddles and become excessively muddy (Bryan 1977, Stewart and Cameron 1992). Floodplains should be avoided as they typically have poor to very poorly drained (exceptions exist where some floodplains have very sandy soils) soils (Marsh, 1991). Similarly, Leung and Marion (1996) indicate that trails located near streams, springs, and groundwater discharge or seeps, be avoided due to potentially muddy conditions.

Soil types prone to erosion erode faster on steep slopes. Drainage structures are a tool for diverting water off trails that are located on steep slopes and/or poor soils. As was mentioned in the topography section, out-sloping directs water off of trails. Out-sloping is another tool to preventing degradation to trails which are steep and have poor soils. Out-sloping water off trails may shunt sediments and other debris into streams or rivers, however, proper out-sloping shunts runoff into forested areas which can arrest sediments. Also, trail treads and soil infiltration may interrupt overland flow of sediments. Water quality is degraded by trails only when trail runoff containing sediments are drained into streams and rivers.

Soil-Water Quality Relationships

Water quality is degraded by trails when trail runoff containing suspended sediments reaches streams, rivers or lakes. Such sedimentation can alter aquatic food chains and fish populations (Forman 1995). Sedimentation causes turbidity that reduces populations of phytoplankton and zooplankton. Turbidity also negatively affects aquatic insects (Forman 1996).

Recreation ecology literature focuses on human pollutants in streams and rivers. Some literature examines trail and recreational activities along lakes and larger rivers. However, there is minimal literature in Recreation Ecology that examines sedimentation impacts from trails along mountainous streams (Marion 1998 Personal Communication). Reducing sedimentation is accomplished through good trail design and maintenance. Trails designed and maintained to reduce runoff and set back from streams, springs and seeps can help preserve water quality.

Stream Impacts From Trails

In general any input, organic or inorganic, potentially alters a quatic food chains and disrupts natural fish habitats. Forman (1995) indicates that sediment, such as sand and silt, negatively impacts the pool and riffle structure of eroding streams. Sediments may fill in pools and spaces between course gravel in the riffles. “The net effect of sedimentation is a smoothing and homogenizing of the stream bottom devastating to most fish populations” (Forman 1995 p.234).

One biological study, examined sedimentation from trails. Fritz (1993) compared high gradient trout streams in Great Smoky Mountains National Park. The purpose was to determine any differences in stream sediment loads, whether sediment loads affect salmon and trout, and whether benthic macro-invertebrate (BMI) populations were affected. A common indicator of increased stream sedimentation is a decrease in BMI population density and diversity (Fritz 1993).

The study (Fritz 1993) results indicated that the study trails do not significantly affect stream sedimentation. Sedimentation differences were attributed to heavy rains, geology, and slope conditions. Also, results indicate no measurable effects on BMI, salmonid, or trout populations. Results showed that invertebrates and fish stocks downstream may be effected, warranting further investigation in low gradient streams. Karr (Karr 1991 pers. comm., as quoted in Forman 1995) indicates that even a small eroded spot on a slope can alter stream conditions and fish populations along a stream. Protecting against sedimentation through trail design is therefore ecologically justified. Reducing erosion, locate trails wisely, and providing vegetation barriers can each help retain water quality.

Factors That Influence Extent of Impact

Brichard (1981) recommends that trail stream crossings be oriented perpendicular to streams. This keeps streams from rerouting down trail corridors during flooding. This also reduces the proximity of trail treads to streams. Trail crossings can be further enhanced by decreasing trail grades entering stream crossings. Where trails must parallel close to streams, vegetative barriers can be incorporated to reduce sedimentation from water runoff.

Vegetative buffers have been shown to remove most sediments in water runoff when meeting these criteria: 1) continuous grass/turf cover, 2) buffer widths generally greater than 50 to 100 feet, 3) gentle gradients less than 10 percent, and 4) shallow runoff depths (or thin sheets of water), generally not exceeding the height of grass (Marsh, 1991). Vegetation buffers have differing abilities in arresting sedimentation and other inputs. In backcountry stream corridors sedimentation is of some concern while in frountcountry settings matrix inputs such as fertilizers, road salts or pesticides threaten water quality. Forman (1995) describes different sediment and matrix input removal capabilities of stream corridor vegetation. Root structure, soil infiltration rates and sloping conditions encourage or discourage the sediment removing capabilities of vegetation. Upland vegetation inhibits matrix inputs where hillslopes have little affect on matrix inputs (Forman 1996). This is because hillslopes tend to be steeper than other habitats and sediments and nutrients are incorporated less across hillslopes than on flat habitats where roots and soil spaces can trap material. Hillslope vegetation, however, does have control on sediments originating on the hillslope itself (Forman 1996). Floodplain vegetation is generally not a dependable barrier from sediments entering the floodplain from higher hillslope areas (Forman 1996).

Wildlife

Recreational impacts to wildlife are caused by non-consumptive activities like hiking and birdwatching or consumptive activities such as hunting and fishing. Knight and Gutzwiller (1995) and Hammitt and Cole (1987) show that impacts affect large to small mammals, birds, fish, and amphibians. Impacts generally cause stressful situations for wildlife, changing wildlife physiology, behavior, reproduction, population levels, and species composition and diversity (Hammitt and Cole 1987). Spatial and temporal trail management strategies reduce the effects of recreational use on both wildlife and their habitats. These strategies may help to sensitively integrate humans into wildlife habitats.

Trail Impacts

Knight and Gutzwiller (1995) describe four types of recreational impacts to wildlife: harvest, habitat modification, pollution, and disturbance. These impacts are either direct or indirect (Hammitt and Cole 1987). Direct impacts are primary disturbances from human interactions. These impacts include hunting and fishing, wildlife disturbance, harassment, and feeding animals. Indirect impacts are secondary results of disturbance to wildlife habitat. Indirect impacts include unintentional wildlife feeding and habitat disturbance associated with the presence of humans and resource impacts on trails and recreation sites. These include human waste, agricultural runoff, sedimentation, and vegetation and soil impacts. Hammitt and Cole (1987) indicate that larger animals are affected more by direct impacts whereas smaller animals tend to be affected more by indirect impacts.

Direct and indirect impacts cause response behaviors in animals, including avoidance, attraction, and habituation. Some animals may avoid humans. Avoidance may displace certain animals, replacing less tolerant species with species tolerant to recreational pressure (Knight and Gutzwiller 1995, Hammitt and Cole 1987). Displacement may be spatial or temporal, causing animals to abandon or avoid their natural habitats (Knight and Gutzwiller 1995). Ultimately, avoidance displaces animals altering species richness.

Alternatively, animals may be attracted to humans and recreational activities. Some animals attract to trails and campsite noises in search of food. Food offerings change animal's feeding habits. Deer will often use trail corridors as travel routes.

Animals may habituate areas of disturbance. This is referred to as habituation or a lack of response (Knight and Gutzwiller, 1995). The affect of habituation is similar to other wildlife impacts in that it alters natural animal habits. However, habituation has benefits to trail designers and wildlife. Animals simply ignore people allowing the disturbance to their habitat.

Animals can survive recreational impacts. Animals often adapt to change. Most adaptation comes from consistent recreational use (Knight and Gutzwiller 1995). Animals may benefit from extra food, trail routes, or shelter. However, trail users who stray from trail corridors are more detrimental to wildlife than those staying on trails. Animals sensitive to human presence may not adapt to off-trail activities as well. Minimizing or avoiding direct and indirect impacts with recreational management and site design actions helps retain natural wildlife character.

Factors Influencing Extent of Impact

Knight and Gutzwiller (1995) and Marion (1998, Personal Communication) suggest the use of spatial and temporal strategies to allow coexistence between recreational use and wildlife habitat. Spatial, the most commonly used strategy, reduces or redistributes the limit of recreational use in an area. Temporal refers to seasonal differences in wildlife habit and recreational use. Marion (1998, Personal Communication) suggests a combination of spatial and temporal zoning management strategies and actions are generally most effective.

Temporal zoning refers to the closing of recreational areas during seasons or times when wildlife are particularly sensitive to disturbance. Disturbance is greatest during the wintertime, during breeding, nesting, birthing and hunting seasons (1998, Marion, Personal Communication). Spatial zoning can be used to restrict recreational use and identifies areas of sensitive or critical wildlife habitat. These might include the habitats of rare, threatened, or endangered species, dening and nesting areas of other wildlife, or water resource areas which are critical habitats to avoid.

Knight and Gutzwiller (1995) suggest that campsites be designed with enough spatial and visual restrictions to allow sensitive wildlife to exist nearby. They indicate that these sites be situated so that patches of vegetation separate recreation and wildlife habitat. These types of spatial and visual restrictions may also be implemented on stream corridor trails.

Forman (1995) describes typical wildlife movement patterns and species composition found in stream corridors. Streambank wildlife have home range movement patterns. Fluctuating water regimes can alter or impede animal movement along stream banks so these habitats do not typically serve as permanent travel routes. Floodplain habitats are similar with restricted terrestrial movement. Streambank and floodplain habitats are valuable wildlife resource areas supporting a high diversity of animals (Forman 1995). Additionally, more rare species are found in floodplains than in other habitats along a stream corridor.

Hillslope and upland habitats, serve as major movement areas for animals species within a stream corridor (Forman 1995). These movements include dispersal, migration, and escape. Animal density is high on hillslopes due to the diversity of adjacent habitat types. Uplands support multihabitat animals. Animals here are dependent upon streams and riparian vegetation for food to feed. Forman (1995) indicates that upland interiors are typically used by herbivores and predators because of good visibility along hillslopes.

In conclusion, the movement and feeding habitats of animals provide c lues to spatially and temporally designing trails in riparian habitats. Trail corridors and stream crossings located in floodplains and streambanks (areas with high diversity of animals and serve as feeding sites) may be at most risk for wildlife impacts. Hillslope and upland trails may serve as travel routes for some animals but may fragment the movement of some species trying to reach floodplains and streambanks. Ultimately, it is up to a designer or manager to decide which animals are priority for spatial and temporal trail design strategies.

Chapter 3 Synthesis and Implications of the Literature Review

Addition to Mannings' Trampling Diagram

The literature review explains ecological characteristics of areas within or near stream corridors. Integrated with this discussion is a review of trail impacts and design considerations for locating and managing trails in or near stream corridors. Mannings' diagram (see Figure 2.6) can be expanded as a result of the findings from the literature review (see Figure 3.1).

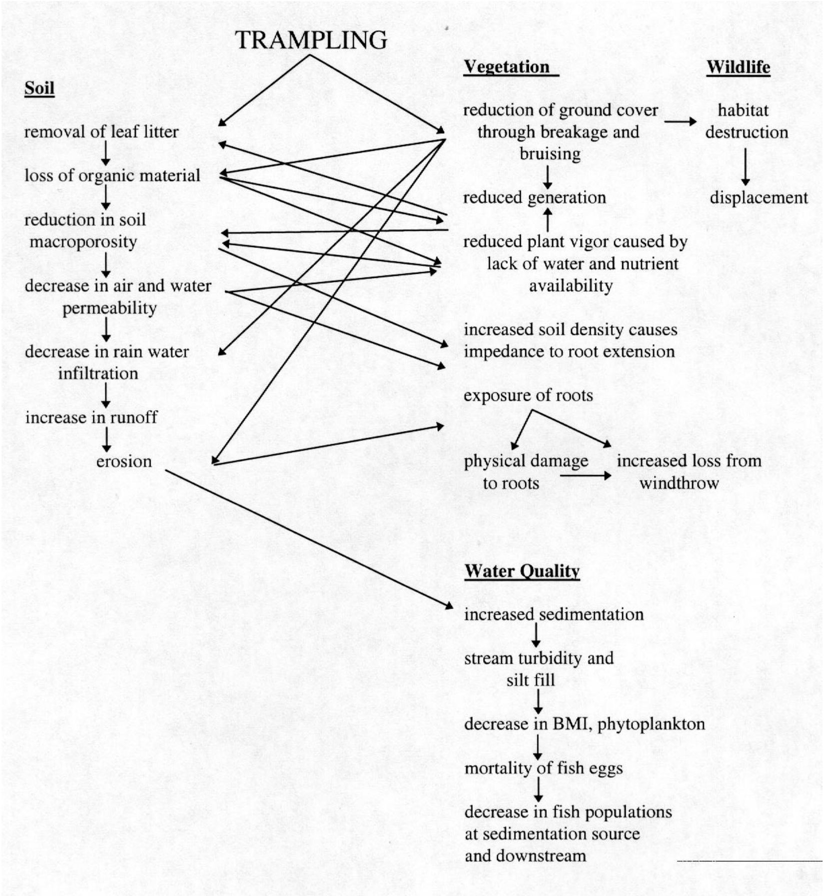

Figure 3.1 Mannings' Diagram Expanded

Figure 3.1 indicates that trampling can destroy habitat and potentially disrupt animal populations. Trampling can also affect water quality when soils are exposed or eroded. In addition, sedimentation entering streams may threaten the health of aquatic life.

Improved understanding of ecological characteristics and their implications for trail design and maintenance decisions allows for productive coexistence between recreational trails and riparian corridors. Avoiding and/or minimizing trail impacts can reduce the cumulative effects described in Figure 3.1. The key to productive coexistence (i.e., reduced trail and environmental degradation) is wise trail design and maintenance.

This synthesis interprets literature and recommends an ecological approach to trail designs within or near stream corridors. It presents principles and guidelines which may be used by trail designers. Each principle for trail design is addressed first. Guidelines for implementing the principle are under the headings trail design/siting and maintenance practices.

Summary of Ecological Trail Design Research

Trail design refers to the location and layout of trails and specification of construction practices. Trail design includes trail siting, aligning and grading. Where trails are placed, with respect to resistant soils and vegetation, is a critical issue. Trail gradients should not exceed recommended slopes. Trails should be located in areas which avoid or minimize trail and environmental degradation. Alignment refers to trail placement in the landscape and along the landform. Trail maintenance refers to trail construction and of tread drainage features like trail out-slopes, water bars, ditches, and culverts. Trails designed to retain hard, non-erosive treads, and trails that correctly cross and drain into streams are most sensitive to ecological processes and functions.

Key points in the literature review are that floodplains and footslopes (positions and slopes immediately above the valley or floodplain) and ridgetop positions are most prone to trail degradation and trail-resource related impacts. Floodplains typically have organic, poorly drained soils, flat or concave landforms, periodically flood, and often contain sensitive plant communities. Ridgetops, particularly in the Appalachian Ridge and Valley, are relatively flat or rounded. This makes ridgetops particularly hard to drain once trails, in these positions, become incised and wet. Ridges also receive greater amounts of precipitation and may also have sensitive plant communities. Therefore, the first design decision is to attempt to locate recreational trails between floodplain or footslopes and ridgetops. This area constitutes hillslopes commonly called midslopes. Midslopes can have erosion-prone areas, particularly on steep midslopes. However because flooding is not an issue, water generally drains properly. Harsh climates may also be avoided on midslope positions.

Given that trails must at times be located within floodplains/footslopes and ridges, additional efforts for routing trails along these areas should be followed to avoid or minimize degradation (See, for example, the Trail Construction and Maintenance Notebook produced by the USDA Forest Service 1996). The goal is to protect against erosion, flooding, and wet or muddy tread conditions.

Soil erosion may not be a problem in floodplains since many slopes are less than 10 percent. However, soil compaction and poor alignments can result in incised trails.

Also, gentle landform slopes are conducive to wet muddy trails. The Trail Construction and Maintenance Notebook produced by the USDA Forest Service (1996) describes the use of corduroy, turnpikes, puncheons, and geosythetics as ways to avoid wet trails where trails must pass through poorly drained landscapes (see Appendix C for graphic examples of these). Essentially these practices elevate treads or run water off of trail treads. Such treads are drier, more durable, and easier to manage than natural trail treads. The use of these features may be the only way to avoid wet soils on trails in floodplains. Some of these types of features, such as geosynthetics, may not be appropriate in primitive backcountry or wilderness areas.

Trails located along ridge lines must be designed to reduce trail incision and wet soils. Water bars, ditches and trail out-slopes are commonly used features to drain water from treads. However, if trails become incised these tread drainage features may be ineffective. Digging through 6-12 inches of soil across long distances is difficult, expensive, and generally impractical for backcountry trails. Trails that move along ridgelines should be placed so that positive drainage can be retained over the long-term.

Reducing trail erosion and wet treads keep people on trails. The more sensitive that adjacent areas are to impact the more important this fact becomes. Trail impact studies show that floodplains and ridgetops are prone to trail and environmental degradation under conditions of moderate to heavy traffic. Literature also suggests that midslopes are areas least vulnerable to trail related impacts. Furthermore, it may be easier to keep people on trails in midslope settings since off-trail areas are sloping. It is also easier to design trails that reduce trail erosion and wet trails on midslopes.

The core set of trail degradation problems include three important types: excessive trail erosion, excessively wet trails, and stream sedimentation. Controlling erosion and wet conditions on trails protects adjacent habitats along trails. Protecting streams from increased sediment input maintains the quality of water in backcountry streams. Understanding these trail impacts provides designers with a way to control trail and environmental degradation. This understanding can also be applied to stream crossing issues. Stream crossings need proper trail design to avoid increased sediment loads into streams.

The matrix in Table 3.1 and 3.2 relates environmental, use, trail design and trail maintenance factors contributing to trail erosion, wetness, and stream sedimentation.

Table 3.1 Environmental, Use, Siting, and Maintenance Factors Causing Trail Degradation

Type of Trail Degradation	Environmental Factors Causing Degradation	Use Factors Causing Degradation	Trail Layout Factors Causing Degradation	Trail Maintenance Factors Causing Degradation
Excessive Tread Erosion	**steep landform slopes** **erosive soils** **water erosion**	**amount of use** **type of use**	**trail alignment to the landform** **trail grade** **trail position in the landscape**	**insufficient and/or ineffective drainage features**
Excessively Wet Trails	**low landform slopes** **organic soils** **poorly drained soils** **seeps and streams**	**amount of use** **type of use** **user behavior**	**trail position within the landscape**	**insufficient and/or ineffective drainage features**

Table 3.2 Environmental, and Trail Use, Siting, and Maintenance Factors Causing Stream Sedimentation

Type of Impact	Environmental Factors Causing Impact	Use Factors Causing Impact	Trail Layout Factors Causing Impact	Trail Maintenance Factors Causing Impact
Stream Sedimentation	**natural sedimentation**	**amount of use** **type of use** **user behavior**	**steep trail grades at crossings**	**insufficient and/or ineffective drainage features**

Table 3.1 organizes and categorizes variables inherent in trail related degradation. It also introduces use factors related to trail degradation. Understanding the relationships between factors and degradation is crucial if we are to learn how to ecologically design sensitive and sustainable trails. Table 3.2 discusses environmental and trail factors affecting stream sedimentation.

Principles and Guidelines

This synthesis of principles and guidelines addresses primary issues designers and managers need to consider as they seek to achieve ecologically sensitive trail design and maintenance. The principles and guidelines discussed are related to landform/topography, vegetation, soils, stream sedimentation, and wildlife. The more difficult and poorly understood principles of design and maintenance conclude this section.

Landform/Topography

Principle: The position and gentle gradients associated with floodplains and rounded ridgetops cause trails to stay excessively wet and/or incised and should be avoided.

Guideline: Whenever possible locate trails above floodplains and below ridgetops

- Trail Design/Siting: Locate on landform slopes between 10-40% above floodplains and below ridgetops. Landform slopes less than 10% do not drain well while slopes greater than 40% are generally too steep. Direct trails along the contour when slopes are favorable (see Figure 2.2). Trails that ascend or descend midslopes should generally not parallel the landform (i.e., low slope alignment angles). Such trails become incised and removing running water from their treads is difficult or impossible. Ideally trail grades should be between 4-15%. It may be necessary to create trail switchbacks if landform and stream gradients are too steep.

- Maintenance: Out-slope trail treads at 2-3% (see Figure 2.3) for drainage off of the tread. Provide more drainage features (See Figures in Appendix D) as trail slope alignment angles decrease and as trail grades increase. Also provide adequate drainage when trails are located on erosion prone soils such as clays or silts or on soils with high concentrations of organic matter.

Vegetation

Principle : Trampling resistant grasses and sedges provide for stable trailsides.

Guideline: Where possible, locate trails through resistant and/or resilient plants

- Trail Design/Siting: The ability to locate trails on resistant and resilient vegetation depends on the region, elevation, and aspect. Where possible, locate trails within areas where ground vegetation is comprised of grasses and sedges (growth forms shown to be resistant to trampling effects). Trails may also be located on more productive soils and sunny locations to promote vegetative recovery after disturbance.
- Maintenance: Removal or trimming of trailside tree seedlings, and shrubs can allow sufficient sunlight to support the establishment of trampling resistant grasses. However, removal of taller vegetation in flat areas may also encourage off trail travel, leading to trail widening or parallel trail development.

Soils

Principle: Well drained soils with large soil particle sizes and rock provide for greater trail tread stability.

Guideline: Wherever possible, locate trails on resistant sandy-loam soil or soils with a high rock and gravel content.

- Trail Design/Siting: If possible, locate trails on resistant sandy-loam soils. This may be impossible or impractical due to the variations in soil types and topography. Sites high in organic soils should be avoided or organic materials removed. Small rocks and gravel present in some soils can increase tread resistance. A rocky surface that is well drained is the least conducive surface to soil erosion and wet trail effects.
- Maintenance: Remove organic materials such as leaf matter and pine needles from the tread to prevent development of muddy or mucky trail sections. Application of

gravel to problem treads is a common and recommended maintenance practice where such a practice is feasible and desired.

Crossing Streams and Draining Into Streams

Principle: Human disturbances, including poorly designed and maintained trails and trail crossings, can cause excessive stream sedimentation.

Guideline: Avoid stream sedimentation by correctly crossing streams and, design trails and bridges so as to reduce sediment input.

- Trail Design/Siting: Trails should not directly descend into stream crossings unless tread runoff is removed and filtered by vegetation and organic litter prior to entering stream channels. Trails should approach streams at an angle or curve into streams (see figure 5.6). This minimizes tread erosion and subsequent sedimentation of streams. Trail segments at stream crossings should be as short in length as possible to reduce the amount of tread surface prone to erosion. The crossing should be at the straightest portion of the stream channel. These guidelines apply to feeder streams and main streams potentially affected by a trail. Segments of trails that immediately precede a stream crossing should have as gentle a grade as possible. Bridges can significantly reduce sedimentation inputs.
- Maintenance: Ensure a minimum of ten or more feet of organic litter and plant cover downslope from any drainage feature that drains trail tread sediments off the side of a trail. Drainage features close to streams should fan and disperse water drained from treads so that soil particles can be quickly filtered and deposited by vegetation and organic litter. Provide additional drainage features if needed for trails with poor soils or steep trail segments. Culverts can be used in areas where they are appropriate for routing stream water under trails. Because, undersized culverts may fail during larger storms oversize culverts where this is feasible. In general, bridging is the ideal solution to protecting trails and reducing sedimentation.

Wildlife

Principle: Wildlife have important spatial and temporal needs which should be considered and accounted for by trail designers and managers.

Guideline: Use spatial and temporal management practices to help minimize wildlife disturbance along trails.

- Trail Design/Siting and Management: Knowing what to avoid with respect to wildlife depends on the region and animal species important to protect. Typically, rare, threatened, or endangered wildlife are considered first. Use spatial and temporal management techniques as appropriate to the place and species. Avoid routing trails near nesting and dening areas or other areas of critical habitat. Avoid interference with sensitive wildlife movements (corridor). Also avoid recreational use during seasons or times when wildlife are particularly sensitive to disturbance. Wildlife can adapt to consistent patterns of human activity. Educate and manage trail users to stay on designated trails.

- Consulting with the appropriate experts related to landform/topography, vegetation, soils, streams, and wildlife are essential for designing and maintaining ecologically sensitive trails and is strongly recommended.

Difficult to Implement and Poorly Understood Principles

The following principles may be poorly understood or are difficult to implement without the expertise of ecologists, botanists, or wildlife scientists and geologists.

- Siting and managing trails to protect rare, threatened, and endangered vegetation and wildlife
- Designing trails to protect other critical wildlife habitat (spatial design)
- Planning recreational use according to critical wildlife seasons (temporal design)
- Designing within floodplains according to times and extents of floods
- Avoiding sensitive plant communities such as wetlands or documented areas of erosive or recreation sensitive communities
- Avoiding areas of mass wasting
- Understanding the user carrying capacities of trails and backcountry areas

Answering these issues requires expert judgements. Experts in geology, botany, ecology and wildlife sciences will likely be needed. The level of understanding required to effectively address these issues are not generally held by trail designers and addressing these issues require more information, time, and money. Trails, designers, and managers should seek to understand and accommodate these special concerns when time and resources allow. Filed reviews with biologists and other experts early in the planning and assessment process can generally improve trail design and management practices.

Chapter 4 Trail Study Sites and Case Study Methodology

This thesis examines three riparian corridor trails. Each trail has variable landform positions and trail slopes. A description of each trail follows.

Trail Descriptions

Trail 1: Appalachian Trail at Peters Mountain Wilderness along the Pine Swamp Branch.

Trail 1 is located in a backcountry wilderness area. The trail is designated as hiking only. Use amount is light. During field work I saw very few users.

Land cover is typical of the Appalachian Ridge and Valley Province. Rhododendrons are the predominant vegetation along the stream and forest canopies are dense, shading the trail corridor and stream. Forests consist mostly of oak, hickory and pines. Forest floor groundcover is sparse. Grasses are the predominant groundcover along trail edges.

Trail 1 does not run adjacent to the stream until about 3,500 feet from the trailhead. From that point, the trail follows the stream in a valley landform position. Trail grades are noticeably steep. The landform adjacent to the trail is also steep. Evidence of soil erosion is evident in many locations, primarily due to steep trail grades and landform. Most eroded segments have no out-slope or drainage features.

Figure 4.1 shows the approximate landform position and route of Trail 1. The trail section studied extends a little over 5,000 feet on Peters Mountain to the point where it crosses Pine Swamp Branch. There is an abandoned trail beginning at the stream crossing which traverses the mountain north along the stream. This abandoned trail was replaced with the trail shown in Figure 4.1 (solid line). This new trail is in excellent condition. No eroded or wet spots were visible on this stretch of newly constructed trail.

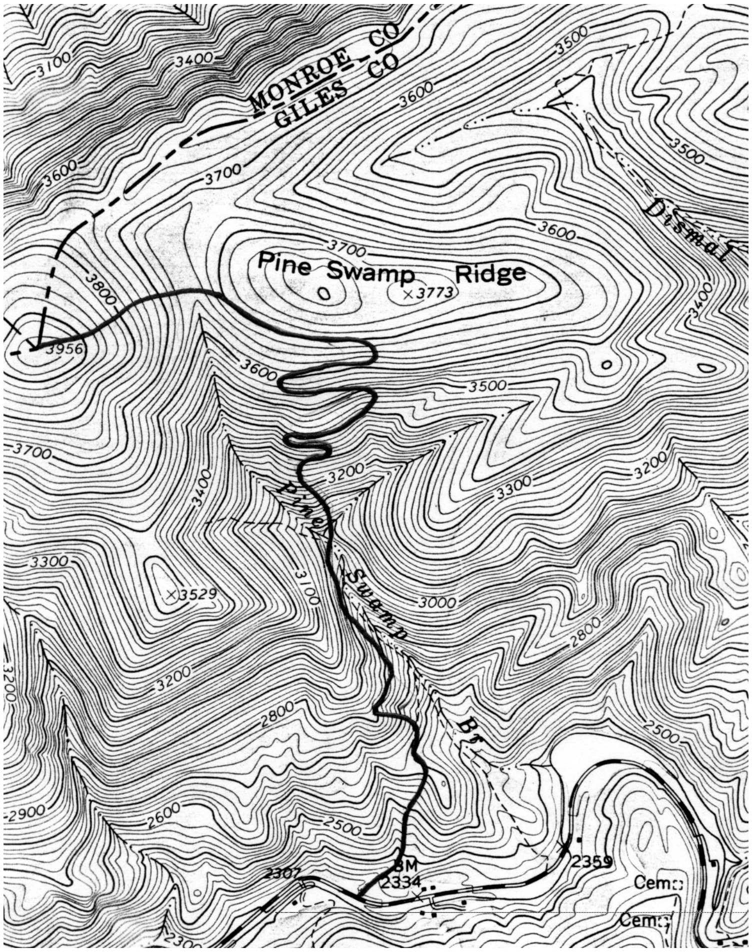

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Figure 4.1 Trail 1: Appalachian Trail at Peters Mountain Wilderness along the Pine Swamp Branch. Image not to scale.

Trail 2: Cascades Trail along Little Stony Creek

Trail 2 is located in a heavily used backcountry setting. The trail parallels Little Stony Creek, a popular trout fishing stream, and is designated “hiking only.” The Cascades is one of the most popular attractions in the region. A 66 foot waterfall serves as the terminus of this trail and a viewing platform has been constructed for observing the falls. Because the trail is built, in part, upon a old jeep trail, and because of the large amount of day use a facility is located at the trailhead. The hiking experience along the Cascades Trail is therefore very different from primitive backcountry trails.

Land cover, however is very similar to Trail 1. Rhododendrons predominate habitats along the stream and forests consist of mixed Appalachian hardwoods and pines. Forest canopies are dense at times but open up in other areas along the trail. Areas along the beginning of the trail have dense ground cover, mostly grasses. As the trail proceeds into higher elevations groundcover becomes sparse.

The trail begins in the valley landform position on an approximate ten foot wide abandoned jeep trail. Mid-way up, the trail narrows into a fairly wide hiking trail in a steep midslope location. There is evidence of erosion and maintenance along the first quarter of the trail. Portions were washed out during winter 1996 floods. Trail managers have laid down gravel and installed drainage ditches during trail reconstruction.

Trail grades are moderate along the first third of the trail. Some trail grade segments are flat and have wet soils. There is evidence of active seeps sending water on the tread in several places. Soil erosion is evident on steeper grades. The last half of Trail 2 is steep. Then the trail levels off and runs closely along the stream as it approaches the falls. Near the falls there is evidence of flood damage and use-related damage, including noticeably flat, scoured, wet soil treads and highly exposed roots.

Figure 4.2 shows the approximate landform position and route for Trail 2. The trail extends approximately two miles between the parking and the picnic area up to the falls. The trail never crosses the creek but does cross over several perennial streams. Each stream crossing is constructed over a buried culvert. There is evidence of trail sedimentation in the creek at the top of the trail near the falls.

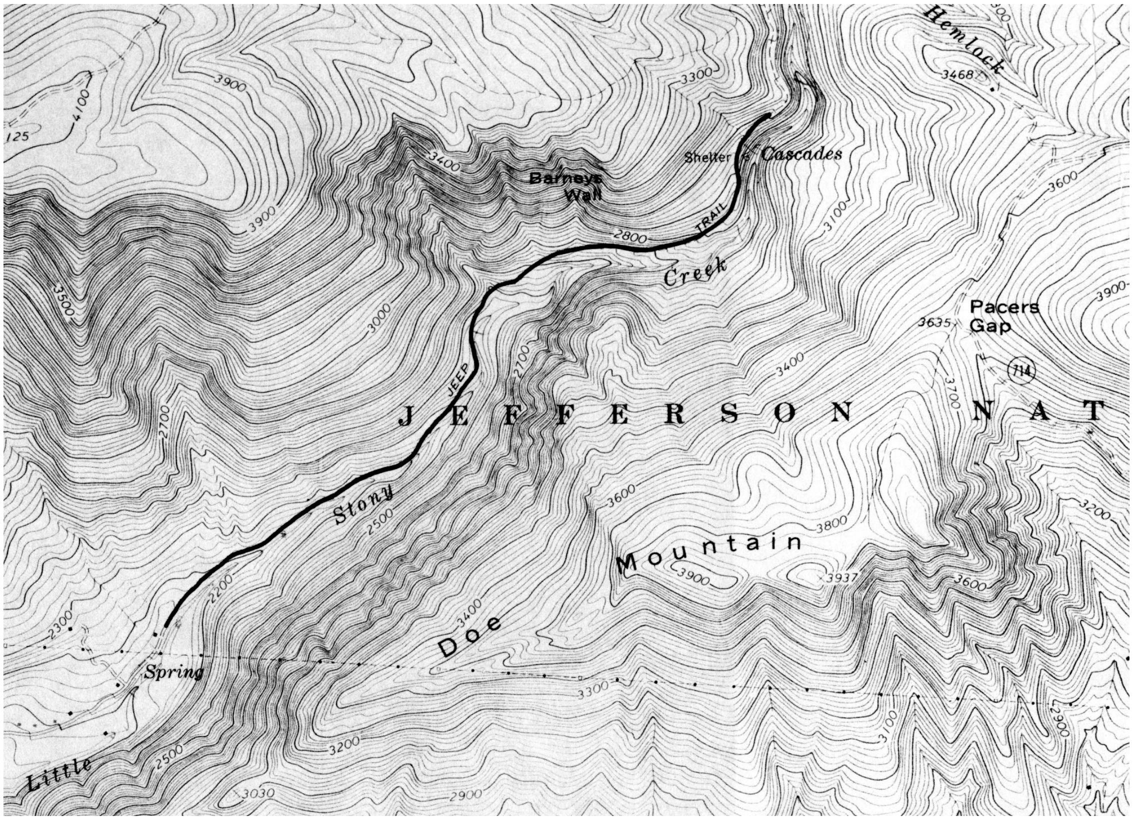

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Figure 4.2 Trail 2: Cascades Trail along Little Stony Creek. Image not to scale.

Trail 3: Pandapas Pond Trail along Poverty Creek

Trail 3 is the most heavily used trail of the trail study sites. This popular backcountry trail, once an old forest road, receives heavy use by hikers and mountain bikers. It also receives light horse use. As with the Cascades Trail, the Pandapas Pond Trail experience is very different from primitive backcountry trails like the trail along Pine Swamp Branch. The reasons for this include the large size of trailhead facilities and intensity of use.

Land cover on Trail 3 is similar to Trail 1 and 2 but forest canopies are generally less dense. Rhododendrons are evident in a much wider extent around the stream than in trails 1 and 2. There is a greater number of pine stands than along the other two trails. There were no instances of groundcover on tread surfaces and very little along trail edges.

Trail grades and landform slopes are relatively flat. Much of the trail is damaged with wet and very muddy trails. Bike treads are visible along muddy trail sections. Trails have many maintenance features like corduroy and ditches. There is little evidence of the use of trail out-slopping along trail treads.

Figure 4.3 shows the approximate landform position and route of Trail 3. The trail extends about 3,500 feet to the point where it crosses Poverty Creek. Trail conditions are poor along much of this length. The trail crosses active and perennial feeder streams. Some crossings are over culverts and some cross directly through the feeder streams. The trail crosses Poverty Creek without a bridge or culvert. Trail managers have laid large stones to provide for better footing across the creek.

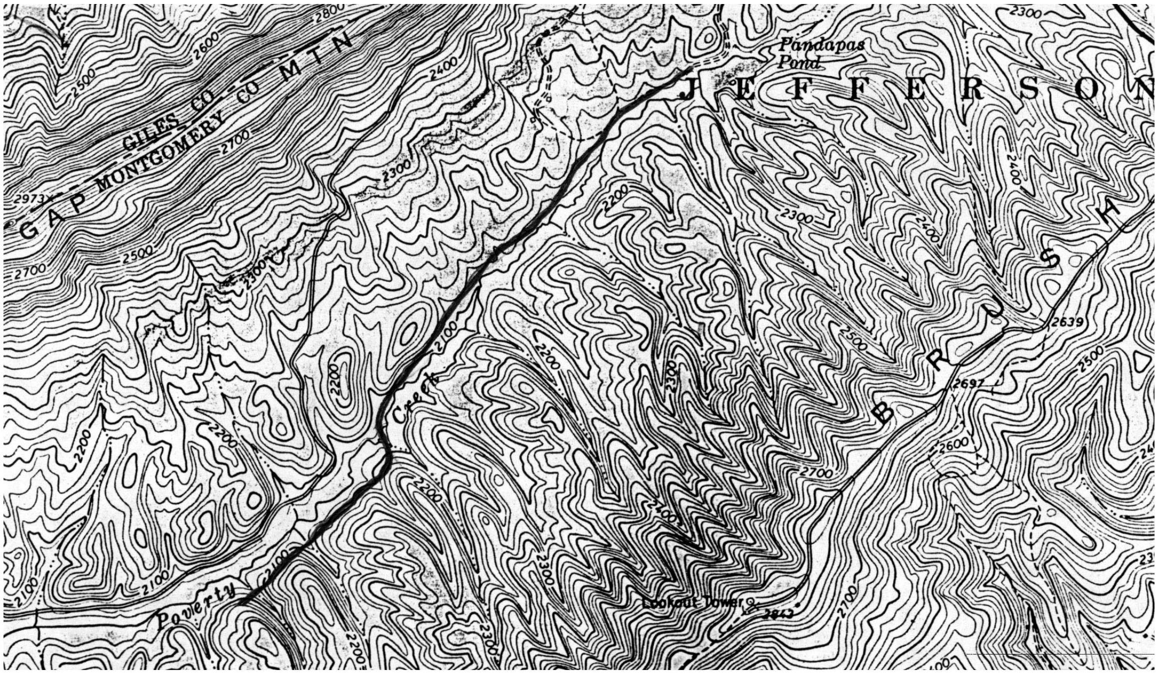

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Figure 4.3 Trail 3: Pandapas Pond Trail along Poverty Creek. Image not to scale.

Case Study Methodology

Selection of Study Sites

Each trail was selected as being representative of: 1) trails within the Appalachian Ridge and Valley in Virginia, 2) within or near stream corridors, 3) having substantial use, and 4) located in backcountry (primitive or semi-primitive/rural) sites. Trails were selected in areas having a diversity of landform types. Each trail traverses flat valley locations and steep higher elevation positions. Study sites were also chosen based on the trails proximity to stream corridors and the number of stream crossings. A large enough sample size was required to measure the variety of trail related problems and assess associated environmental characteristics. The hope was to identify common problems and to identify and characterize the causative factors. The diversity of site conditions represented by the three trails ensured that I would not be misled by studying atypical trails near stream corridors. Selecting just three trails allowed a sample size that saved time and was manageable.

Process

The process was to complete a trail condition assessment and a problem evaluation for trail erosion, trail muddiness, and stream sedimentation along each trail. Stream sedimentation is difficult to measure. Therefore, only areas which have the greatest potential for sedimentation input were noted. Potential sites of sedimentation are at crossings or where trail surfaces clearly drain into adjacent streams. Through the trail condition assessment the following resource impacts are recorded:

1. Soil Erosion
2. Root Exposure
3. Excessive Width
4. Wet Soil
5. Water on Trails
6. Multiple Treads
7. Stream Sedimentation

Each problem area was identified and measured. Soil erosion, wet soil/water on trails, and stream sedimentation were evaluated based on the characteristics of the trail and its surroundings. Notes about the following were recorded:

1. Slope of the Landform (grade of the landform adjacent to the trail)
2. Tread Distance Below Grade (depth of the trail tread from its original layout depth)
3. Soil Classification
4. Soil Moisture
5. Type of Use Permitted on the Trail and Use Amount
6. Trail Grade
7. Trail Cross-slope
8. Trail Alignment (angle the trail lies along the landform)
9. Trail Position or Elevation (in reference to the landform)
10. Trail Drainage Features

The next step was to rank principal factors contributing to soil erosion, wet trails, and stream sedimentation. The process of ranking factors is described in detail in Appendix A. The ranking procedure evaluates six factors that affect soil erosion and wet soils or water on trails:

<u>Factors Conducive to Soil Erosion</u>
1. amount and type of use
2. trail grade
3. soil type
4. trail alignment
5. tread drainage features
6. effectiveness of tread drainage features

<u>Factors Conducive to Wet Soils and Water on Trails</u>
1. amount and type of use

2. soils conducive to holding water
3. landform slope
4. tread drainage features
5. effectiveness of tread drainage features

Following trail assessments, each stream and its trail related problems were evaluated. The results of the study were input into Microsoft Excel for Windows version 7.0. This was then converted into SPSS for Windows 7.5.1. Two types of data were obtained, categorical and continuous metric data. Categorical data refers to data such as soil type and landform position. Continuous metric data refers to data such as trail grade and lineal feet.

Results are presented in three categories for discussion. First is a description of the trail as it is located within the landform. Next is a table for relating the lineal distances and point data of the seven resource impacts. Stream sedimentation is measured as point data. Finally a summary table of the ranking procedures is presented. The evaluation for these results is written in the results/discussion section.

The results describe trail resource impacts affecting each trail. With sufficient data we should be able to see relationships between trail impacts and trail locations, impacts and environment, and impacts and use. The discussion section will also discuss the effectiveness of the trail assessment procedures. It will determine, based on professional judgment, the significance and relationship of problem trails to environmental issues. Suggested improvements to the trail assessment manual are also discussed.

Chapter 5 Results/Discussion

Introduction

This section presents field data to characterize impacts (soil erosion, wet soils, water on treads, excessive width, root exposure, and multiple trails) along trail segments assessed. Field results are presented to show trail characteristics that may be important influences on the types and intensities of impacts. The discussion for each trail includes a summary of how the principles and guidelines help us understand why impacts occur and suggest how these impacts can be prevented. Stream sedimentation, including a design that shows a recommended stream crossing, is presented in a separate section. A summary for all trails and the implications of the case study results concludes this chapter.

Trail1: Pine Swamp Branch segment of the Appalachian Trail

Table 5.1 indicates that the Pine Swamp Branch Trail has steep slopes, intermediate slope alignments, and highly favorable landform slopes for impacted segments along Trail 1.

Table 5.1 Trail 1, Pine Swamp Branch segment of the Appalachian Trail. Means, minimum, and maximum measurements for trail resource impact segments:
Trail Distance: 5,035 feet

Trail Measurement	Mean	Minimum	Maximum
Trail Grade (%)	21	13	30
Trail Alignment (degrees)	54	0	90
Landform Slope %	36	15	48

Trail grades vary from a minimum of 13% to a maximum of 30%. Trail grades averaged 21%. Trail alignments averaged 54 degrees (about intermediate on a scale of 0 to 90). However, there were two impacted segments with 0 degree slope alignments and one trail segment with a 90 degree slope alignment, running along the contour. Landform slopes average 36%. Minimum landform slopes of 15% are sufficient for draining trails and a maximum of 48% indicates a section of very steep landform (see Table B.1 for field data).

Table 5.2 reveals that soil erosion was the most common impact with 9 occurrences, covering 19% of the trail's total lineal distance.

Table 5.2 Total lineal distances of resource impacts for The Appalachian Trail along the Pine Swamp Branch Creek(total distance 5,035 feet). Total Resource Impacts: 1,341 feet

Resource Condition Indicator	***Occurrence***	***Total Lineal Distance***			
	Number	**Feet**	**Percent**	**Ft/Mile**	**Mean**
Soil Erosion	9	977	19	1025	109
Wet Soil	0	0	0	0	0
Water on Trail	0	0	0	0	0
Excessive Width	5	253	5	265	51
Root Exposure	0	0	0	0	0
Multiple Trails	4	111	2	116	28
Stream Sedimentation[1]	1	-	-	-	-

1. Stream Sedimentation is a point feature with no lineal distance.

Excessive width occurred five times, multiple trails occurred four times, and there was one instance of stream sedimentation. There were no occurrences of wet soil nor water on trails. Total impacted area is 1,341 feet or 26% of the length of Trail 1.

Excessive width and multiple trails did not occur alone in field assessment results but where always associated with a soil erosion segment (refer to Table B. 1, Appendix B). Soil erosion had the highest total lineal distance in both total feet and feet per mile of impact. The average length of soil erosion was 109 feet compared to 51 feet for excessive width and 28 feet for multiple trails. The preponderance of soil erosion impact compared to other impacts was expected given that trail segments were predominately steep.

Table 5.3 shows the contributions of specific trail related factors for use, siting, and construction/maintenance.

Table 5.3 Contributions of Individual Factors of Use, Siting, and Construction/Maintenance to Soil Erosion (SE) on Trail 1

	Factors							Ranking Sums		
Segment	AU	TY	TG	S	TA	TDF	ETDF	Use	Siting	Construc/Man
SE 83-176	1	0	3	1	0	3	3	1	4	6
SE 188-220	1	0	2	1	0	3	3	1	3	6
SE 2249-2569	1	0	1	1	0	3	3	1	2	6
SE 2615-2668	1	0	2	1	0	3	3	1	3	6
SE 2785-2827	1	0	1	1	0	3	3	1	2	6
SE 2985-3049	1	0	3	1	1	3	3	1	5	6
SE 3149-3191	1	0	3	1	0	2	0	1	4	2
SE 3319-3535	1	0	3	1	0	3	3	1	4	6
SE 3982-4097	1	0	3	1	1	3	3	1	5	6

AU- amount of use
TY- type of use
TG - trail grade
S- soil texture(conducive to soil erosion)
TA- trail alignment
TDF- tread drainage feature density
ETDF- effectiveness of tread drainage features

Individual ranks for each factor are shown to help assess which trail attributes contribute to soil erosion.

Use amount is consistently ranked low for conducive to soil erosion. Type of use is consistently ranked not conducive to soil erosion. Siting factors are attributed mostly to trail grade and soil texture. Trail grades range from low to highly conducive to soil erosion. Soil texture is consistently ranked one or low in terms of being conducive to soil erosion.

Trial alignments are generally not conducive to soil erosion along Pine Swamp Branch. Two segments to trail alignment are highly conducive for soil erosion, one is somewhat conducive, and the remaining alignments are not conducive. Construction/maintenance factors are consistently ranked highly conducive to soil erosion for all but segment 3149-3191.

Summary for Trail 1

Soil erosion makes up the majority of impacts found along Trail 1. Trail 1 does not have wet soils or water on the trails. Excessive widths and multiple trails occurred only on soil erosion segments. As a result, excessive width and multiple trails degraded 364 feet of vegetation adjacent to trail treads.

The results indicate that steep trail slopes on segments are conducive to soil erosion but are not conducive to wet soils. Slopes ranged from an average of 21% and as high as 30%. Principles and guidelines indicate that slopes above 20% are highly susceptible to erosion. Trail 1 confirmed this. High slope alignments and steep landform slopes along impacted segments are favorable for draining trails and are thus not susceptible to wet soils. Consistent with the principles and guidelines landform slopes above 10% were not found conducive to wet soils along the Pine Swamp Branch Trail.

Results from Table 5.3 indicate that construction/maintenance features are poor along Trail 1. Water is allowed to run down steep trail treads for too long and cannot drain off the tread. Principles and guidelines show that when trail slopes increase so should the amount of drainage features. It is possible that additional drainage features would have protected these eroded segments. Table 5.3 shows that soils are ranked low in terms of conducive to soil erosion. Soil type is probably not a major reason for erosion along Trail 1.

Landform slopes and stream gradients are steep along Trail 1. This indicates that a combination of recommended slopes and of drainage features are needed to decrease the potential for soil erosion. Principles and guidelines show that as landform slopes increase, switchbacking can be used to gain elevation with recommended trail grades. Switchbacking may reduce trail grades enough to achieve consistent recommended slopes along the trail and subsequently reduce the effects of water erosion.

Use amounts and types were not conducive to soil erosion. Increased use types and amounts on this trail would more than likely cause more trail damage. Since excessive width and multiple trails occurred together, degradation to adjacent trail areas would also likely increase with increased trail use.

Trail 2: Cascades Trail along Little Stony Creek

Table 5.4 indicates that the cascades trail has low to steep trail grades, high slope alignments, and low to steep landform slopes for impacted trail segments.

Table 5.4 Trail 2, Cascades Trail along Little Stony Creek. Means, minimum, and maximum measurements for trail resource impact segments:
Trail Distance: 9,690 feet

Trail Measurement	Mean	Minimum	Maximum
Trail Grade (%)	13	1	27
Trail Alignment (degrees)	73	60	90
Landform Slope (%)	29	5	50

Trail grades vary from a minimum of 1% to a maximum of 27%. Trail grades average 13%. Trail alignments are high (above intermediate to along the contour) with little variance among impacted segments. The minimum slope alignment is high at 60 degrees. Two trail segments were located along the contour at 90 degrees. Trail alignments average 73 degrees. Landform slopes on the other hand vary greatly, from a minimum of 5% to a maximum of 50%. The average landform slope is 29% which is good for positive trail drainage.

Table 5.5 indicates a variety of resource impacts. These impacts are somewhat predictable given that both steep slopes and low landform slopes exist along Trail 2.

Table 5.5 Summary of number of occurrences and total lineal distance of trail attributes for The Cascades Trail along Little Stony Creek (total distance 9,690 feet). Total Resource Impact: 2,103 feet

Resource Condition Indicator	***Occurrence***	***Total Lineal Distance***			
	Number	**Feet**	**Percent**	**Ft/Mile**	**Mean**
Soil Erosion	10	791	8	431	79
Wet Soil	3	497	5	271	166
Water on Trail	3	243	3	132	81
Excessive Width	4	541	6	295	135
Root Exposure	1	31	0	17	31
Multiple Trails	0	0	0	0	0
Stream Sedimentation[1]	2	-	-	-	-

[1] Stream Sedimentation is a point feature with no lineal distance.

Soil erosion occurred 10 times, wet soil occurred three times, and water on trail also occurred three times. Total resource impacts occurred on 2,103 feet or 21.5% of the trail.

Excessive width and root exposure were associated only when soil erosion, wet soil and water on trails occurred (refer to Table B.2 Appendix B). Root exposure occurred once and there were no instances of multiple trials. Excessive width occurred four times. Excessive width impact was nearly as high in total lineal distance of impact when compared to soil erosion, wet soil and water on trail impacts. Excessive width and root exposure impacted 6% of the trail.

Soil erosion had the greatest lineal distance of impact at 791 feet and the greatest feet per mile of impact at 431 feet. The combined wet soil and water on trail was 740 feet along the trail and 403 feet per mile. Excessive width measured 541 feet of total impact along the trail and 295 feet per mile. Lineal distances of impacts are consistent resource conditions when combining wet soils and water on trails. However, wet soils and water on trails alone were both less than excessive width in terms of lineal distance of impact and feet per mile of impact. No significant lineal distance relationship exists among these four impacts.

Average distances of impacts varied. Wet soil and excessive width had the highest average total distance at 135 feet and 166 feet respectively. Soil erosion had an average segment of only 79 feet. This indicates that wet soil and excessive width segments occurred less but had greater distances of impact than soil erosion segments. It may be expected that on Trail 2 soil erosion, wet soil, and water on trail impacts will create few but extensively long segments of excessive width. Table 5.6 shows that amount of use is highly conducive to soil erosion and that type of use is non-conducive to soil erosion.

Table 5.6 Contributions of Individual Factors of Use, Siting, and Construction/Maintenance to Soil Erosion (SE) on Trail 2

	Factors							Ranking Sums		
Segment	AU	TY	TG	S	TA	TDF	ETDF	Use	Siting	Construc/Mant
SE 357-413	3	0	3	2	0	3	3	3	5	6
SE 621-670	3	0	2	2	0	3	3	3	4	6
SE 764-841	3	0	0	2	0	2	3	3	2	5
SE 1188-1258	3	0	0	1	0	3	3	3	1	6
SE 2821-2855	3	0	2	2	0	3	3	3	4	6
SE 3214-3325	3	0	2	2	0	2	2	3	4	4
SE 3663-3718	3	0	2	2	0	3	3	3	4	6
SE 3857-4096	3	0	1	1	0	0	2	3	2	2
SE 8083-8134	3	0	3	1	1	0	0	3	4	0
SE 8290-8339	3	0	2	1	0	3	3	3	3	6

AU- amount of use
TY- type of use
TG - trail grade
S- soil texture(conducive to soil erosion)
TA- trail alignment
TDF- tread drainage feature density
ETDF- effectiveness of tread drainage features

Siting factors show that soil textures are consistently ranked from low to moderate for their conduciveness to soil erosion. Trail grades vary from not conducive to highly conducive. Trail alignments are consistently not conducive to soil erosion. One segment has a low rank for trail alignment that is conducive to soil erosion. Construction/maintenance factors are consistently poor for drainage of trails. Tread drainage features and the effectiveness of tread drainage features range mostly moderate to highly conducive to soil erosion.

Table 5.7 shows the contributions of specific trail related factors for use, siting, and construction/maintenance. Individual ranks for factors are shown to help assess which trail attributes contribute to wet soil and water on trails.

Table 5.7 Contributions of Individual Factors for Use, Siting, and Construction/Maintenance for Wet Soil (WS) and Water on Trails (WT) on Trail 2

	Factors						Ranking Sums		
Segment	AU	TY	LS	SCHW	TDF	ETDF	Use	Siting	Construc/Mant
WT 841-864	3	0	2	2	2	3	3	4	5
WT 2328-2368	3	0	0	2	3	3	3	2	6
WT 3877-4057	3	0	0	1	0	3	3	1	3
WS 3957-4257	3	0	3	1	3	3	3	4	6
WS 4198-4364	3	0	3	1	3	3	3	4	6
WS 9538-9569	3	0	3	1	3	3	3	4	6

AU- amount of use
TY- type of use
LS- landform slope
SCHW- soils conducive to holding water
TDF- tread drainage features
ETDF- effectiveness of tread drainage features

Table 5.7 shows consistency among rankings for wet soil but variable rankings among water on trail factors. Also, the amount of use is ranked highly conducive along all segments. Type of use is not conducive for all segments.

Landform slopes are ranked high for wet soil segments and soils conducive to holding water (SCHW) is ranked low on all segments. TDF and ETDF are both ranked high along all wet soil segments. Water on trails is more variable.

Factors leading to water on trails is predominately attributed to amount of use, soils conducive to holding water, and the effectiveness of tread drainage features. Type of use is not conducive along segments and landform slopes are not conducive on two segments and moderate for one segment.

Summary for Trail 2

Soil erosion impacts occurred more than other impacts. Segments for soil erosion were similar for the combined distances for wet soil and water on trail impacts. Wet soils from either precipitation or from a seep causing water on trail is discussed together since the way to control (or design to prevent) these impacts is similar. Essentially proper drainage features and recommended landform slopes are needed to remove excess water off of trail treads.

Degradation to adjacent trail and on trail segments has occurred. Root exposure makes up a small percentage of the damage, however excessive width and its length of impact compared to the other trail impacts is substantial. We can see that excessive width and root exposure are associated with soil erosion, wet soils, and water on trail segments. Excessive width and root exposure degraded 572 feet of the trails total distance.

Results show that impacted segments had variable measurements for trail grades and landform slopes. Steep trail segments indicate the potential for soil erosion and low landform slopes indicate the potential for wet soils. Results indicate that there must be other factors causing these impacts since there are impacted segments which have recommended trail grades and landform slopes. Alignments are good and are not conducive to holding water on the trail.

Trail 2 has variable landform grades along the stream corridor. Closer to the creek gentler landform and stream gradient grades occur. It is possible that Trail 2 could have followed areas with recommended trail slopes and landform slopes conducive to proper drainage. However the principles and guidelines show that as we approach streams and when landform slopes decrease the potential for wet soils increase. If the trial is located near the stream then recommended drainage features will be needed. Also there must be consideration for the proximity of drained surfaces to streams and the types of soils that exists. On the other hand, a properly switchbacked trail on steeper landform slopes that were farther away from the stream may have prevented soil erosion and wet soil impacts altogether.

For Trail 2 drainage features were not used frequently enough or were otherwise not effective along impacted segments. Soil texture had the greatest potential effect on soil erosion but is probably not an important factor for wet soils. Water on trail segments show a stronger relationship to soils conducive to holding water. Adding effective drainage features, plus gravel to areas with poor soils (where this is possible and desirable), can prevent further degradation to impacted trail segments. Adding gravel may be more appropriate along this trail than on Trail 1 as the trail along the Pine Swamp Branch is located in a backcountry wilderness whereas Trail 2 is in a semi-primitive/rural setting.

Use amount is heavy and highly conducive to trail related impacts along all impacted segments. This is a leading factor of trail degradation along the Cascades trail. Any increase in use or type would probably worsen impacted segments. However, if measures are met for controlling impacts use increases would be less of a threat.

Trail 3: Pandapas Pond Trail along Poverty Creek

Table 5.8 indicates that the Pandapas Pond/Poverty Creek Trail has gentle trail slopes, high trail slope alignments and gentle landform slopes for impacted trail segments.

Table 5.8 Trail 3, Pandapas Pond Trail along Poverty Creek. Means, minimum, and maximum measurements for trail resource impact segments. Trail Distance: 5,478 feet

Trail Measurement	Mean	Minimum	Maximum
Trail Grade (%)	5	1	18
Trail Alignment (degrees)	67	45	90
Landform Slope (%)	10	2	40

Trail grades average 5% with a minimum of 1% and maximum of 18%. Trail alignments on average were high at 67 degrees. Minimum trail alignments are moderate at 45 degrees with maximum trail alignments at 90 degrees. On average landform slopes were low (10%) with a very low landform slope at two percent. The maximum landform slope was 40%.

Table 5.9 indicates a variety of resource impacts types and extents. Wet soils and excessive widths occurred most often with 18 occurrences each.

Table 5.9 Summary of number of occurrences and total lineal distance of trail attributes for The Pandapas Pond Trail along Poverty Creek (total distance 5,478 feet). Total Resource Impact: 2,301

Resource Condition Indicator	***Occurrence***	***Total Lineal Distance***			
	Number	**Feet**	**Percent**	**Ft/Mile**	**Mean**
Soil Erosion	6	329	6	317	55
Wet Soil	18	1015	19	978	56
Water on Trail	0	0	0	0	0
Excessive Width	18	828	15	798	46
Root Exposure	1	32	1	31	32
Multiple Trails	4	90	2	87	21
Stream Sedimentation[1]	6	-	-	-	-

1. Stream Sedimentation is a point feature with no lineal distance.

Soil erosion occurred six times, root exposure occurred one time, and multiple trails occurred four times. There were no occurrences of water on trails. Total distance of impact is 2,301 feet or 43% of the total trail distance studied.

Wet soil and excessive width had the greatest total lineal distance of impact (in feet and feet per mile). This covered 34% of the trails total distance studied. Soil erosion and wet soil had nearly the same average distance of impact with 55 feet and 56 feet respectively.

Excessive width, root exposure, and multiple trails occurred only with soil erosion and wet soil segments (refer to Table B.3 Appendix B). Neither of these three impacts occurred alone on Trail 3.

Table 5.10 shows that use factors are consistently high in terms of being conducive to soil erosion.

Table 5.10 Contributions of Individual Factors of Use, Siting, and Construction/Maintenance for Soil Erosion along Trail 3

	Factors							Ranking Sums		
Segment	AU	TY	TG	S	TA	TDF	ETDF	Use	Siting	Construc/Man
SE 104-146	3	0	2	3	2	2	0	3	7	2
SE 1970-2044	3	3	0	1	0	2	0	6	1	2
SE 2834-2888	3	3	0	1	0	3	0	6	1	3
SE 4180-4283	3	3	0	3	0	0	0	6	3	0
SE 4525-4543	3	3	1	3	0	0	3	6	4	3
SE 5440-5478	3	3	0	1	0	2	0	6	1	2

AU- amount of use
TY- type of use
TG - trail grade
S- soil texture(conducive to soil erosion)
TA- trail alignment
TDF- tread drainage feature density
ETDF- effectiveness of tread drainage features

Only one segment has a non-conducive type of use for soil erosion. Rankings for siting factors are dominated by soil conditions low to highly conducive to soil erosion. Trail grades and trail alignments are mostly non-conducive to soil erosion. Rankings for construction/maintenance factors are dominated by tread drainage features. This indicates a lack of drainage features for preventing soil erosion impacts.

Table 5.11 shows that use factors are consistently ranked highly conducive to wet soil.

Table 5.11 Contributions of Individual Factors of Use, Siting, and Construction/Maintenance for Wet Soils on Trail 3.

	Factors						Ranking Sums		
Segment	AU	TY	LS	SCHW	TDF	ETDF	Use	Siting	Construc/Maint
WS 226-248	3	0	3	1	2	2	3	4	4
WS 879-908	3	3	2	1	2	2	6	3	4
WS 1075-1161	3	3	2	2	2	0	6	4	2
WS 1179-1205	3	3	3	2	2	0	6	5	2
WS 1431-1554	3	3	3	3	2	0	6	6	2
WS 1707-1770	3	3	3	2	2	0	6	5	2
WS 1837-1866	3	3	3	2	2	3	6	5	5
WS 2106-2203	3	3	2	2	2	2	6	4	4
WS 2453-2488	3	3	2	2	3	3	6	4	6
WS 2834-2888	3	3	2	2	3	0	6	4	3
WS 3126-3175	3	3	2	2	3	3	6	4	6
WS 3282-3400	3	3	2	2	3	3	6	4	6
WS 3460-3489	3	3	2	2	3	3	6	4	6
WS 3513-3585	3	3	2	2	3	3	6	4	6
WS 3692-3702	3	3	2	2	3	3	6	4	6
WS 3715-3751	3	3	2	2	3	3	6	4	6
WS 4180-4283	3	3	2	3	0	0	6	5	0
WS 4909-4943	3	3	2	2	2	0	6	4	2

AU- amount of use
TY- type of use
LS- landform slope
SCHW- soils conducive to holding water
TDF- tread drainage features
ETDF- effectiveness of tread drainage features

Siting factors are less consistent but are ranked moderate to highly conducive to wet soil. Landform slopes range from moderate to highly conducive to wet soils and soils conducive to holding water range from low to highly conducive to wet soils. Construction/maintenance factors are variable. Rankings for tread drainage features are mostly moderate to highly conducive to wet soil and effectiveness of tread drainage feature factors range from non-conducive to highly conducive to wet soils. Use, siting, and construction/maintenance factors all play a role in wet soils along Trail 3. Use type and amount, landform slopes, SCHW, and TDF seem to be contributing the most influence for wet soil segments.

Summary for Trail 3

Wet soils and excessive width are the primary impacts along Trail 3, occurring 18 times each. Soil erosion only occurred six times. Excessive width, root exposure and multiple trails were found only on soil erosion and wet soil segments.

Trail grades are well the within recommended gradients. A maximum of 18% is high but good given that trail segments are properly drained and laid out across non-erosive soils. Trail slope alignments are not conducive to holding water on trails. Low landform slopes (10% or less) on impacted segments do indicate a high potential for wet trails.

Controlling wet soil segments is a primary recommendation for Trail 3. Reducing further trail degradation from wet soils with corduroy or puncheons may decrease impacts to trails and adjacent areas of trails. According to the principles and guidelines these maintenance practices are probably the most logical defense against increased trail degradation as this trail is in a valley or floodplain location. Landform slopes are too gentle to properly out-slope trails to recommended cross-slopes.

Heavy use by bikers and hikers, light horse use, erosive soil conditions, plus the lack of drainage features appear to be the leading causes of soil erosion along trails.

Heavy use compacts soils making it easier to wash away top soil layers. The lack of drainage features allows water to increase in velocity as it moves down the tread. Drainage features would allow water to drain off in places needed to reduce water velocities. Providing gravel and effective drainage features to these trail segments would help to reduce soil erosion. Gravel is appropriate along this trail since it is a semi-primitive/rural site and access to problem segments is easy. This is probably the best solution for reducing soil erosion along the existing Pandapas Pond/Poverty Creek Trail.

In the long term, reducing the amount and type of use would reduce further trail degradation to Trail 3. Given the popularity of this trail use reduction is probably not likely. Additional drainage and maintenance features like drainage ditches, trail out-slopes(where landform slopes allow), corduroy and puncheons may reduce further damage and protect trouble segments prone to impact. However, moving the location of this trail is probably the most logical management decision. Moving the trail to a higher landform position with steeper landform slopes is possible. Use could remain heavy if trail conditions are ideal for drainage.

Stream Sedimentation

This section presents data related to stream sedimentation as recorded from field assessments. Only the number of potential stream sedimentation occurrences and the types of sedimentation inputs along trails were evaluated. This field data was not as useful for thesis due to the infrequency of potential sedimentation inputs and the difficulty of assessing sedimentation impacts in general. A design concept which shows a proper way to cross streams is presented below. This design concept was developed as result of the literature review and field studies.

Table 5.12 shows the number of occurrences and types of stream sedimentation along all trails.

Table 5.12 Occurrences and Types of Related Stream Sedimentation along all Studied Trails

		Types of Sedimentation	
Trail	Number of Occurrences	TT	UD
Pine Swamp Branch Segment of the Appalachian Trail	1	1	0
Cascades Trail along Little Stony Creek	2	0	2
Panadapas Pond Trail along Poverty Creek	6	3	3

TT- trail treads drain directly into a stream at a stream crossing
UD- unfiltered tread drainage into streams less than 10 feet

There are few instances of potential sedimentation in all study trails. Trail one had one stream crossing and no off trail drainage within 10 feet. Trail 2 had two occurrences of sedimentation, both where unfiltered drainage from trail treads within 10 feet. Trail 2 did not cross the stream. Trails 1 and 2 probably input negligible amounts of sediments. Trail 2 could have its section of drainage input reduced. Managers could reroute these sections of trail to a higher area (away from the stream) so as to provide at least 10 feet of separation between the trail and top of streambank.

Trail 3 had three instances of trails draining into streams and three instances of unfiltered drainage. Trail three is more of a threat than the other study trails for potentially degrading aquatic life. Correcting stream crossings so that trails correctly ascend into stream would benefit this trail (see Figure 5.6). Tread drainage areas may be planted with vegetation to retard sediment inputs. Rerouting the segments of trails that drain into streams is also a possibility. Managers should reroute trail sections more than 10 feet to allow more distance between the stream and the trail.

Figure 5.6 illustrates a design concept for minimizing stream sedimentation at stream crossings in backcountry settings.

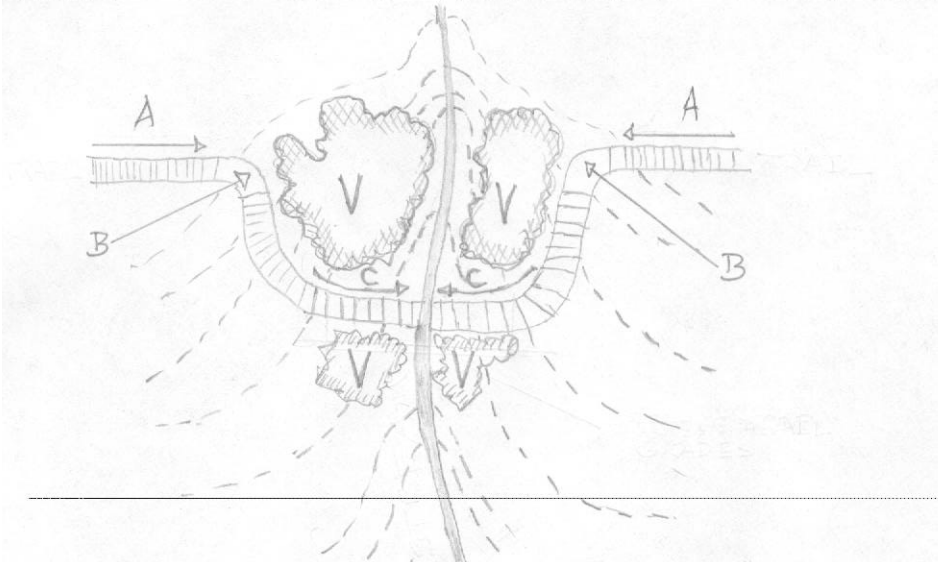

Figure 5.6 Stream Crossing Design Concept

Stream crossings may be the most strategic and difficult design decision for ecologically designing a trail within a backcountry riparian landscape. Providing a wooden (on site material) bridge across streams is the ideal solution. The difficulty is that nearly all environmental factors of a stream corridor and the principles and guidelines mentioned in the thesis apply to the design concept.

Trail gradients must be gentle when descending into streams. See figure 5.6, sections C. This reduces the velocity of water on trail treads reducing soil erosion. Also, trails must cross perpendicular to streams. Curving the trail into the stream crossing area allows for trail surfaces to be constructed so as to reduce and redirect runoff.

Section B in Figure 5.6 shows where trails should be bermed. A berm here shunts water from descending trails (sections A) back away from the stream. Trail sections between the stream and berms may be out-sloped toward the stream only if ten or more feet of vegetation exists as is shown in Section V. Abiding by this design will reduce sediment inputs. However, more difficult decisions must be implemented with respect to vegetation, soils, and wildlife.

Floodplains and streambanks at stream crossings are vulnerable to both trail and environmental degradation as described in the synthesis of the literature review and principles and guidelines section. These habitats usually have rare plant species and soils are usually poorly drained and organic. Experts are needed to locate rare or sensitive vegetation.

Floodplains have flat landform slopes. Designing gentle trail grades on flat landform slopes makes such areas conducive to wet soils. Wet soils can cause excessive widths and/or multiple trails at stream crossings. Wider trails provide more surface area for potential sediment inputs. Avoiding poor soil conditions and flat landform grades will in most cases be unavoidable when designing a backcountry stream crossing. However, managers and designers may be able to locate recommended soil conditions or areas with naturally high rock content.

Wildlife impacts in these habitats may also be significantly challenging to backcountry stream crossing designs. Floodplains and streambank habitats are important feeding areas for wildlife and may have a high diversity of rare animals. Avoiding sensitive or rare wildlife, like vegetation, requires expert opinions. However, with available resources (as discussed in the principles and guidelines) issues of vegetation, and wildlife may be addressed and used in the design of stream crossings.

Summary of Findings for all Trails and Implications for Ecological Trail Design and Future Research

This summary presents the significant findings for the three trails studied. It shows how use, siting, and maintenance factors relate to the principles and guidelines. A discussion of the implications of the findings for ecological trail design and the need for future trail design research concludes this section.

There were several common findings among the trails studied and the types of impacts recorded. First, excessive width, root exposure, and multiple trails, when they occurred, were associated with soil erosion, wet soils, and water on trail for the three trails studied. Where the trail tread is wet, soft and/or eroded users avoid these areas, creating new trails or walking on the edge of the existing trail. These actions trample vegetation and cause root exposure. The process of erosion likewise exposes roots. This initial assessment seems to indicate that controlling wet soil, soil erosion, and water on trails will decrease excessive width, root exposure, and multiple trail impacts.

Findings related directly to the principles and guidelines include the following. Trail 1 showed that steep trail grades with even light use can lead to incised and eroded trail treads. Trail 3 shows that gentle landform slopes (particularly in floodplains) tend to have wet mucky soils and that out-slopping these trail treads is difficult. Trail 2 has sections with soil erosion and wet soil impacts. This is because Trail 2 had both steep and very flat landforms or slopes.

Trail 3 highlights another issue important for designers and managers. Use strongly relates to the type and intensity of trail impacts (though, as alluded to above, use is not generally the primary factor). Trail 3 has both soil erosion and wet soil impacts related to heavy use. Trail 3 exhibited many areas with multiple trails clearly the result of spontaneous avoidance of wet and mucky treads by bikers, hikers, and horses. There was an overall increase in the types and amounts of trail impact related to use for each trail. Trail 1 exhibited the least use related impacts. Trail 2 exhibited moderate use impacts. Trail 3, as indicated above, exhibited extremely high use impacts.

Use and topography/landform factors seem to have a very strong relationship to the types and amounts of impacts along all trails studied. This knowledge however, complicates making direct relationships among other factors that contribute to trail impacts since each stream corridor, trail, and set of uses differ. If trail use and topography/landform were identical along each trail studied then other contributing factors would be more easy to identify and measure. The data therefore, does not lend itself to detailed statistical analysis. These facts relate to both the method for which trail impacts were assessed and how study sites where chosen. The method assumed, based on professional judgment and the literature, that certain characteristics were conducive to impacts. Measuring these in the field to determine the specific relationships between landform, trail design/maintenance, and use requires more field time and better analytical methods than were allowed for in this research.

The assessment manual and rankings do however present a way to characterize trail impacts and to some extent the topography and soil conditions of the site. The manual also gives an understanding of the type and extent of degradation associated with trail treads and adjacent trail areas. Degradation in any amount means that vegetation is trampled and habitats degraded. What is not clear from the thesis findings is how much degradation is “too much”. The answer(s) to this question is not an absolute due to the fact that different people, even different “experts”, will have different opinions about “what is an acceptable level of impact”.

Future research for related studies should concentrate on characterizing areas within or near stream corridors. Research should relate the different sensitivities that riparian areas have to trail types and impacts. The intent of such research would be to understand how resilient different ecosystem types or landscape settings are to trails and trail related impacts.

It is clear that issues like rare and threatened species, wildlife impacts, and stream sedimentation are very difficult to assess. Research related to these three variables would add to the currently limited knowledge regarding ecological trail design. The current literature shows that riparian/trail related information is deficient, yet trails continue to be placed along stream corridors. More focused research can allow us to improve trail design and trail maintenance near stream corridors for both frontcountry and backcountry settings.

As we can see from findings noted above, degradation to trail treads and adjacent areas has a strong relationship to soil erosion, wet soils, and water on trails. More research into reasons for these relationships can help reduce the situations that cause people to walk around these impact or problem areas and subsequently reduce degradation to vegetation and soils along backcountry trails.

Educating those who design and manage trails may be the most significant use of riparian/trail related research. It is the trail designers who will ultimately lay out trails. They must know where to put trails so impacts are avoided or minimized. In addition, it is the trail manager who will make decisions about how to correct problems evident on existing backcountry trails.

Chapter 6 Conclusion

The thesis problem statement includes three important questions. Each question represents a major section or chapter of the thesis. Answers to the questions in this concluding section elaborates on significant findings from the literature review and synthesis sections, as well as from the results and discussion sections. As appropriate, areas for further investigation into trail-riparian related design are discussed.

- What are the essential issues to consider in the layout and construction of trails within or near backcountry stream corridors and what issues of trail design are most to least understood within the literature?

Two important issues are needed for a designer to layout and construct ecologically sensitive trails within or near backcountry stream corridors. First is an understanding of broad issues namely, riparian geomorphology, vegetation, soils, water quality, and wildlife and the relationships of these biophysical factors to trail design and construction. These broad issues introduce ecological characteristics of riparian corridors and methods for constructing sustainable trails. Secondly, a designer should understand three trail impacts that are frequently major sources of environmental degradation: excessive trail erosion, wet trails, and stream sedimentation. This second area targets trail impacts which may cause post construction, environmental degradation.

Issues of riparian geomorphology, vegetation, soils, water quality, and wildlife characterize riparian landscapes. This educates designers and managers about the complex interrelation among these issues or variables. Synthesizing these variables with trail construction that reduces trail degradation help determine trail locations that reduce unnecessary environmental and trail degradation. This type of synthesis for a specific site, such as this thesis does with backcountry riparian corridors, provides a manageable set of principles and guidelines. Research focused on understanding sensitivities of different riparian landscapes to trail impacts will greatly improve the concepts for developing principles and guidelines of ecological trail design.

Results of the literature review synthesis indicate that it is essential to understand and reduce the factors that cause excessive trail erosion and wet trails. People will walk around eroded or wet trail segments trampling adjacent trail vegetation. Therefore, reducing occurrences of soil erosion and wet soils reduces adjacent trail impacts like excessive width, multiple trails and can reduce root exposure. The literature review also shows that it is essential to examine and reduce the factors causing stream sedimentation. Likewise, reducing sediment input at stream crossings and sediment inputs from trail drainage reduces impacts to aquatic life.

Much is written on ripariangeomorphology, riparian and trail related vegetation, and soil issues. This is because riparian resources are highly valued and sensitive to human interactions. Understanding and applying these ideas, as they relate to human impacts, helps protect riparian resources.

Trail impact studies concentrate on impacts to vegetation and soils. This is because trail related vegetation and soil impacts are the most common and identifiable landscape impacts of recreational use. Also, methods for studying these impacts are common, borrowed from a variety of ecological and biological studies. However, no known study relates ecological trail design within riparian corridors.

The least studied issues are trail related impacts to water quality and wildlife. These issues are described in broad terms mostly large scale (lakes and rivers) recreation impacts. Only one study was found that examines the impacts of stream sediment inputs from trails running along streams in the Great Smoky Mountains. Wildlife is difficult to study since animals are mobile and their interactions with the environment and recreation are complex. It is important that future research examine water quality and wildlife impacts from trail related recreation.

- What can we do to avoid trail degradation and associated natural resource impacts when we design and construct a low impact, backcountry trail?

Avoiding or reducing trail impacts (excessive erosion, wet trails, water on trails, excessive width, multiple trails, root exposure, and stream sedimentation) and environmental impacts requires ecologically sensitive design/siting and maintenance principles and guidelines. Principles and guidelines in this thesis exemplify ecological trail design for areas within or near backcountry stream corridors emphasizing mountain streams.

Thesis principles and guidelines show ways to reduce trail erosion and wet trails, and stream sedimentation. To reduce trail erosion, grade trails at 4-15% and with high slope alignments to the landform. To reduce wet or mucky trails, position trails on landform slopes greater than 10% allowing positive drainage. If it is difficult to achieve the recommended conditions mentioned or when use impacts increase, increase the amount of drainage features to allow positive drainage. Also, increase drainage features when soils are conducive to erosion or holding water (soils consisting of clays, silts and organic soils). Locating trails on sites with high rock or gravel content and/or on sandy-loam soils can reduce the effects of erosion and wet soils and may reduce the amount of drainage features needed.

Mountain riparian corridors are typically densely forested reducing solar exposure to the forest floor. For this reason, ground cover, shrubs, and seedlings are usually sparse. Therefore, siting trails through recommended resistant and resilient plant types is probably impossible. Trails should however be located through resistant and resilient vegetation when possible and always avoid rare, threatened or endangered species. This is an issue to consider mostly at stream crossings in mountain riparian corridors. Literature indicates that floodplains often have disturbance tolerant vegetation types due to periodic flooding. However, floodplains and stream banks usually have rare plant species. Avoiding these areas and locating on recommended plant types presents designers a challenge. Also, trails should be located in areas where positive regrowth can occur after trail construction. Reducing further impacts to adjacent plant life is accomplished using other trail principles and guidelines.

If not too steep midslope locations usually offer optimum sites for trails. Often, midslopes will have recommended slopes for trail grades and landforms conducive to positive trail drainage. Also, soil types are usually not conducive to erosion or holding water. Flood extents along streams usually will not reach midslopes and wildlife habitat and movement is less sensitive to trail impacts. Wildlife should be accounted for even though impacts of trails on wildlife are less understood. Designers and managers should identify animals most threatened by recreation and design to avoid these and other obvious places of wildlife activities. It is important to note that some animals may habituate recreation areas allowing disturbance without any effect to their natural habits.

Stream sedimentation can be greatly reduced by not crossing or bridging trails across streams. However, riparian corridors with steep landforms may require stream crossings to attain recommended trail grades. Building a bridge in the backcountry may be inappropriate, expensive, labor intensive, or site materials simply may not exist. Therefore designers must reduce stream sedimentation by routing and constructing a stream crossing so that trails drain into vegetation buffers and have gentle trail grades at stream crossings. Designing trail crossings to reduce excessive width and multiple trails is also necessary because both increase the surface area of trail treads increasing potential sediment inputs.

- What types of trail degradation occur on backcountry trails within or near stream corridors? Given that these problems exist, why do they occur and how are they affected by various environmental and managerial factors?

Study sites are geomorphically different and representative of trails within or near stream corridors in the Appalachian Ridge and Valley Province of Virginia. Trail degradation resulting from soil erosion and wet trail segments, occurred for a variety of reasons including geomorphology. The most common impacts were excessive erosion on steep trail segments and wet trail segments located on landform slopes less than 10%. Environmental degradation from excessive width, multiple trails, and root exposure occurred only when there was excessive erosion or wet trail segments. These types of degradation to habitat occurred in different amounts. Multiple widths and excessively wide trails result when users avoid impacted segments. This thesis did not determine the causes of relationships between these types of environmental degradation (excessive width, multiple trails, and root exposure) to excessive erosion or wet trails. They were only found to occur together. Therefore, future research identifying reasons for relationships between excessive erosion and wet trail impacts and unwanted use behavior impacts is valuable. This will lead to improved trail design that encourages correct trail use.

Drainage features were major factors for impacts on most impacted segments. Drainage features were either not present, in low densities, or not effective for draining trail surfaces. Essentially, trail managers use little preventative and post construction drainage practices on study trails.

Use factors contributing to trail impacts were variable among studied trails. Trail three (Pandapas Pond trail along Poverty Creek) shows an example of significant trail degradation from heavy trail use located in a flat floodplain area. This trail allows heavy use by hikers and mountain bikers, and light horse travel. The trail and wet trail segments are mostly located on landform slopes less than 10%. This is a poorly designed trail and heavily degraded.

Probably the most valuable result of this thesis is the strong relationship between principles and guidelines and the types of impacts found along studied trails. Therefore, the principles and guidelines are useful for laying out new ecologically sensitive trails within or near stream corridors, especially in mountainous backcountry settings. A designer can correlate principles and guidelines with assessment data for rerouting or locating new trails. The only way to test this is to design a trail according to the principles and guidelines. The design of the trail requires consulting with relevant disciplines in biology, geology, and recreation ecology sharing ideas and improving ecological concepts.

The application of these principles and guidelines may be the most important type of follow up study. This would involve comparing a traditionally designed trail against a trail using the thesis principles and guidelines. The comparison would offer insights into different amounts, rates, and locations of trail and environmental degradation. Results may improve the principles and guidelines, determining areas of weakness and strengths.

BIBLIOGRAPHY

Barrett, John W. 1980. Regional Silviculture of the United States. John Wiley and Sons: New York.

Bratton, Susan P., Matthew G. Hickler, and James H. Graves. 1979. Trail erosion patterns in Great Smokey Mountains National Park. Environmental Management 3(5): 431-445.

Bright, Julie A. 1986. Hiker impact on herbaceous vegetation along trails in an evergreen woodland of Central Texas. Biological Conservation 36: 53-69.

Benninger-Truax, Mary, John L. Vankat and Robert L. Schaefer. 1992. Trail corridors as habitat and conduits for movement of plant species in Rocky Mountain National Park, Colorado, USA. Landscape Ecology 6(4):269-278.

Brichard, William Jr. and Robert D. Proudman. 1981. Trail Design, Construction, and Maintenance. The Appalachian Trail Conference: Harpers Ferry, WV.

Brown, Perry J., B.L. Driver, Donald H. Burns, and Charles McConnell. 1979. The outdoor recreation opportunity spectrum in wildland recreation planning: Development and application. In: Proceedings: 1st Annual Conference on Recreation Planning and Development. American Society of Civil Engineers. 2: 527-538.

Bryan, Rorke B. 1977. The influence of soil properties on degradation of mountain hiking trails at Grovelsjon. Geografiska Annaler 59(A) 49-65.

Cole, David N. 1978. Estimating the susceptibility of wildland vegetation to trail-side alteration. Journal of Applied Ecology 15:281-286.

------------------. 1995. Experimental trampling of vegetation. II. Predictors of resistance and resilience. Journal of Applied Ecology 32:215-224.

------------------. 1993. Trampling effects on Mountain Vegetation in Washington, Colorado, New Hampshire, and North Carolina. U.S. Department of Agriculture, Forest Service, Intermountain Station. Research Paper INT-464

------------------. 1981. Vegetational changes associated with recreational use and fire suppression in the Eagle Cap Wilderness. Biological Conservation 20:247-270.

Daniels, Walter L., C. J. Everett, and L.W. Zelazny. 1987. Virgin hardwood forest soils of the Southern Appalachian Mountains: I. Soil Morphology and Geomorphology. Soil Science Society of America Journal 51(3): 722-729

Daniels, Walter L. 1983. Virgin hardwood forest soils of Western North Carolina. Virginia Polytechnical Institute and State University. Dissertation. 134-136.

Dramstead W.E., Olson J.D., and R.T.T. Forman. 1996. Landscape Ecology Principles in
Landscape Architecture and Land-Use Planning. Island Pres: Washington, D.C.

Forman R. T. T., and M. Gordon. 1986. Landscape Ecology. John Wiley and Sons: New York.

Forman, R. T. T. 1995. Landscape Mosaics: The Ecology of Landscapes and Regions. Cambridge University Pres. p. 211, 214, 234

Foth, Henry D. 1990. Fundamentals of Soil Science. John Wiley and Sons: New York

Fritz, Jerry D. 1993. Effects of trail-induced sediment loads on Great Smokey Mountains National Park high gradient trout streams. Tennessee Technological University, Department Biology. M.S. Paper. 1-4, 28-29 pp.

Hall, Christine N. and Kuss, Fred R. 1989. Vegetation alteration along trails in Shenandoah National Park, Virginia. Biological Conservation 48: 211-227.

Hammitt, W.E. and David N. Cole. 1987. Wildland Recreation: Ecology and Management. John Wiley and Sons.

Hammit, William E. 1986. Resource impacts on Wilderness. In Kulhavy, D.L. and Conner, R.N., Editors. Symposium Proceedings-Wildernes and Natural Areas in the Eastern United States: A management challenge. Nacogdoches, TX: Stephen F. Austin State University, School of Forestry, Center for Applied Studies

Hultsman, Wendy and John Hultsman. date unknown. Pathway for people: Trail design to minimize environmental damage and enhance user enjoyment. Forestry and natural outdoor recreation resources. Purdue University Cooperative Extension Service.

Hupp, Cliff R. 1982. Stream-grade variation and riparian forest ecology along Passage Creek, Virginia. Bulletin of The Botanical Club 109(4): 488-499

----------------. 1983. Vegetation pattern on channel features in the Passage Creek Gorge, Virginia. Castenea 48(2): 62-72.

Keller, Edward A. 1988. Environmental Geology 5th Edition. Merill Publishing Company: Columbus Ohio.

Knight, Richard L. and Kevin J.Gutzwiller. 1995. Wildlife Recreationists: Coexistence Through Management and Research. Island Press: Washington, D.C. Covelo, California.

Kuss, Fred R. and Alan R.Graefe. 1985. Effects of Recreation Trampling on Natural Area Vegetation. Journal of Leisure Research 17(3):165 -183.

Kuss, Fred R. and Alan R.Graefe. 1985. Effects of recreation trampling on natural area vegetation. Journal of Leisure Research 17(3): 165-183.

Leopold, Luna B. 1997. Water, Rivers and Creeks. University Science Books Sausalito, California.

Leung, Yu-fai and Jeff Marion. 1996. Trail degradation as influenced by environmental factors: A state-of-the knowledge review. J. Soil and Water Conservation 51(2): 130-136.

Malanson, George P. 1993. Riparian Landscapes: Cambridge University Press 181p.

Manning, Robert E. 1979. Impacts of recreation on riparian soils and vegetation. Water Resource Bulletin, American Water Resources Association. 15(1):30-43; Figure 2, 34 p.

Marion, Jeffrey L. 1998. Personal Communication.

Marsh, William M. 1991. Landscape Planning: Environmental Applications. John Wiley and Sons Inc. New York, New York.

Martin, Steven M. 1988. Select geomorphological components of Wildlife Habitat in the Ridge and Valley Province of Virginia. Virginia Polytechnical Institute and State University. Fisheries and Wildlife Science. Masters.

Morisawa, Marie. 1968. Streams: Their Dynamics and Morphology. McGraw-Hill Book Company: New York.

Proudman, Robert D. and Reuben Rajala. 1981. AMC Field Guide to Trail Building and Maintenance 2nd Edition. Appalachian Mountain Club.

Ritter, Dale F., Craig R. Kochel and Jerry R. Miller. 1995. Process Geomorphology. Wm. C. Brown Publishers: Dubuque, IA.

Smith, Daniel S. and Paul C. Hellmund. 1993. Ecology of Greenways: Design and Function of Linear Conservation Areas. University of Minnesota Press.

Stewart, D.P.C. and K.C. Cameron. 1992. Effect of trampling on the soils of the St. James Walkway, New Zealand. Soil Use and Management 8(1): 30-36.

Tuttle, Sherwood D. 1975. Landforms and Landscapes. WM. Brown Company Publishers: Dubuque, Iowa.

USDA Forest Service. 1996. Trail Construction and Maintenance Notebook.

U.S. Forest Service, Department of Agriculture. date unknown. Trails South; A guide dealing with forest trails in the southern region.

Vanderscuaff, Dick. 1982. Ecological effects of recreational use on subalpine meadow plant communities in Jefferson Park, M.T. Jefferson Wilderness. University of Oregon.

Way, Douglas S. 1978. Terrain Analysis: A Guide to Site Using Aerial Photographic Interpretation.

Appendix A Trail Assessment Manual

This manual describes procedures for assessing backcountry trail conditions and factors that contribute to poor trail conditions and potential stream sedimentation. An initial set of procedures is designed to identify the location and lineal extent of six common tread problems (excessive tread erosion, muddiness, width, tree root exposure, multiple treads, and running water on tread) and potential stream sedimentation sites. All occurrences of these pre-defined problems will be identified on the sampled trail segments. A second set of procedures is designed to identify and assess the relative importance of various use-related, trail layout or siting, and construction and maintenance factors which contribute to specific occurrences of two of the six trail problems: excessive trail erosion and muddiness. Also, there is a procedure for identifying and assessing potential stream sedimentation. The occurrence of primary tread degradation problems often contribute to the development of related problems such as tread widening and development of multiple treads. The effect of improper stream crossing and tread drainage into streams can lead to lower water quality. Understanding the relationships between these factors and trail degradation and impacts can help designers build future trails with reduced trail resource impact potentials and sedimentation.

These procedures will be applied to selected backcountry trail segments near stream corridors. The idea is to learn how to protect areas within or near stream corridors by controlling trail erosion, wetness, and controlling sedimentation from trails. Controlling erosion and wetness on trails helps to keep people on trails, thereby reducing vegetation loss. Controlling stream sedimentation protects aquatic life.

Process and Materials

Process:

Only selected problem segments are assessed but observations are made along the entire trail. The survey requires two field personnel to push a measuring wheel along the trail recording codes and measurements for each problem site. The manual describes the procedure from preliminary materials to gather to assessing and ranking problem segments.

Materials:
USGS topographic maps (1/24,000) for each trail
Measuring Wheel (this study will use a standard field wheel with a 4 ft. circumference)
Clinometer
Camera, clipboard, manual, field forms, pencils
Compass

Trail Condition Assessment Procedures

These parameters provide information on the condition of the trail as influenced by human use, layout or siting, and construction/management factors. All parameters are of the begin/end type so be extremely careful to watch for and record beginning and ending distances. Record only those problems which exceed a lineal distance of 10 feet (Distance of 10 feet is derived from the Great Smoky Mountain Study). Record all stream crossings and drainage occurring from trails adjacent to streams as point measurements. These are the only point measurements made. Do not discontinue a parameter if the gap between two sections exhibiting the problem is less than 10 feet.

Procedures:

- Obtain a USGS map of each trail and carry the map during the survey. If the USGS map is noticeably different from the field observation revise as accurate as possible.

- Trail Name: Record the name of the trail or trail segment on each form.

- Select a location near the beginning of the trail segment which is easily identifiable for future reference. Begin the wheel at this location (distance one recorded on Resource Condition Form as 0) and write a brief description which would allow someone else to replicate precisely where to start the wheel in order to replicate the survey. Begin measuring with the wheel until you reach a problem section as defined for the seven resource condition parameters described below. Record the beginning lineal distance for the problem area and proceed measuring until you reach the end of the problem area. Record the end distance for the problem. Two problems may co-occur with the same or different begin and end distances. Remember all stream crossings and trail drainage areas are recorded at the point of the problem (when stream crosses or when a ditch or waterbar occurs adjacent within 10 feet of the stream). Record all values on the Resource Condition field form. Then, proceed with the measurements and ranking procedures

Resource Conditions Parameters

1) **SE** - Soil Erosion: The intent of this parameter is to identify trail sections which have experienced substantial soil erosion (> 6 inches) following trail construction. Careful attention to the general natural contour of the land in adjacent off-trail areas and to telltale clues regarding the surface of the original tread location and subsequent erosion is necessary. In particular, look for large rocks or boulders and tree roots whose tops were likely at the original trail surface but, through subsequent erosion, have been exposed more fully.

2) **RE** - Root Exposure: Record for trail sections exhibiting severe tree root exposure such that the tops and sides of many roots are exposed.
3) **EW** - Excessive Width: Record when the trail exhibits a greater than 3 foot expansion in width that is clearly attributable to recreational uses, such as walking/riding around tree falls, wet or muddy areas, eroded areas, multiple treads, etc. Be alert: this parameter will often be recorded in combination with the other resource problem parameters, i.e. excessive soil erosion, wet soils, and multiple treads often cause an excessive widening of the tread. Trail boundaries, like campsite boundaries, are indicated by pronounced changes in ground vegetation cover, composition, and height, or organic litter.

4) **WS** - Wet Soil: Record for trail sections which exhibit temporary, seasonally, or permanently wet or boggy soils on more than half the width of the tread. Wet soils typically occur in low areas, depressions, or are associated with hillside seeps. Mud-holes and other situations with standing water should be assessed with this parameter. If actual overground water flow is present record parameter WT - Water on Trail instead. The objective is to record begin/end distances which reflect normal soil moisture conditions. If little or no rain has fallen in the previous few weeks, look more carefully for signs of seeps and damp soils and use your judgment in recording distances which would reflect more typical soil moisture conditions. The opposite is true if the assessment is conducted soon after rain. Use your judgment to deduce somewhat reduced begin/end distances.

5) **WT** - Water on Trail: Record whenever water from a large seep or small stream runs on the trail tread, potentially causing soil erosion and tread rutting (disregard water in lateral drains). Some degree of water flow must be present, otherwise record WS - Wet Soil. Use your judgment as described for parameter 4 to record begin/end distances that reflect normal soil moisture conditions.

6) **MT** - Multiple Tread: Record the beginning and ending points where multiple treads diverge from a single tread. Record this parameter only when multiple treads are obvious, typically separated by some feature which divides the trail into two or more treads.

7) **SS** - Stream Sedimentation: Look for and record a single distance for any location where in your judgment soil eroded from the trail is likely to be carried directly into a stream. For example, locations where water is drained from the trail over a relatively short distance(< 10 feet) directly into a stream with little filtration by ground vegetation or organic litter. Another example is when the trail descends and crosses a stream such that tread water directly enters the stream without filtration.

Problem Evaluation Procedures for Trail Erosion, Muddiness, Stream Sedimentation

The purpose of the problem evaluation procedures is to examine specific occurrences of excessive tread erosion, tread muddiness, and stream sedimentation to identify their potential contributing factors. Environmental, use-related, and trail design and maintenance factors will be evaluated. The principal contributing factors causing the assessed problems (soil erosion, wet soil, stream sedimentation) will then be listed and given a numerical rating representing their perceived contribution to each observed problem. These will be tabulated for further analyses to identify the most common causes and to identify and examine causal relationships. Data for these assessments are to be recorded on the Problem Evaluation form and ranking information on the Resource Condition Form.

Environmental Factors

Topography

- Measure the slope of the landform associated with each eroded or wet problem segment. This will be assessed with a clinometer and recorded as percent slope. Two field staff will position themselves about 3 meters from the center of the problem section oriented directly upslope and directly downslope. A clinometer will be used to determine the percent grade of the landform by sighting on a spot on the opposite person at the same height as the first person's eyes.

- Evaluate the tread distance below grade on the downhill side of the trail at each problem segment. This factor evaluates how deeply incised or embedded the trail is with respect to the adjacent landform grade. Water cannot be removed from a deeply incised tread (> 6”), rather, it is retained in flat terrain and causes tread muddiness, or is transported downhill in sloping terrain causing tread erosion. Record the approximate tread depth on the downslope side of the tread. If it is between 6” to 12 “ deep record 9” for the midpoint. This is done for any range of approximate tread distances below grade.

Soil Type and Moisture

- Classify soils near eroded and wet trail segments. This method is developed from Foth (1990). Record the soil description corresponding to the soil texture identified.
- Moisten a sample of soil the size of a golf ball but do not get it too wet. Work it until it is uniformly moist: then squeeze it out between the thumb and forefinger to try to form a uniform ribbon.

  First decision: If the moist soil is:
  Extremely sticky and stiff, it is one of the clays

Sticky and stiff to squeeze, it is one of the clay loams
Soft, easy to squeeze, and only slightly sticky, it is one of the loams

The second decision Add an adjective to refine the description. If the soil feels:
Very smooth, it is silt or silty
Somewhat gritty, use no adjective.
Very, very gritty, it is sandy.

Use the following soil texture to record the proper soil classification on the field form:

1. Sandy clay
2. Clay
3. Silty Clay
4. Sandy Clay Loam
5. Clay Loam
6. Silty Clay Loam
7. Sandy Loam
8. Loam
9. Silt Loam

Record from 1-9 on the Resource Conditions form.

- Soil moisture: If necessary, in an off-trail area, remove surface organic litter to determine the typical soil wetness. Also, take into account current landform position, aspect, and vegetation type. Use the following codes to record your description:
  D-dry **M**-moist **W**-wet
  Record either D, M, or W on the Resource Condition form.

Use Factors

Type and Amount of Use

- Record the type of use permitted on the trail and use level. Categories will vary, examples include: Hiking (walking) (W), Horseback Riding (H), and Mountain Biking (M). Record the level of use (high, medium, low) the trail segment receives as estimated by park managers or park signs for use conditions. This may also be evaluated or reaffirmed in the field by evidence of use: horse hooves, tire tracks, footprints.

Trail Design

Trail Grade

- To determine trail grade, two field staff will position themselves about 3 meters from the center of each problem segment (soil erosion, wet trail) in opposite directions along the trail. A clinometer will be used to determine the percent grade of the trail by sighting a spot on the opposite person at the same height as the first person's eyes. [[At stream crossings the person measuring will stand at the creek edge looking up the trail. Each trail segment, both sides of stream is to be measured.]](do not think I will evaluate it this way, instead just use what type of problem it is, crossing or drainage) After becoming practiced in this procedure the clinometer may not be necessary in most instances. Note: trail grade could equal landform grade if the trail runs directly upslope.

Trail Cross-Slope

- Estimate the trail tread's cross-slope . Use the mid point of the following estimates in the following categories: out-slope % (+): 0-1 record 0.5, 2-3 record 2.5, >3 record 4; in-slope (-) 0-1 record -0.5, 2-3 record -2.5, >3 record -4.

Trail Alignment

- Consider the trail's alignment with respect to the prevailing landform in the vicinity of the sample point. Take and record a compass bearing of the prevailing landform by pointing the compass directly upslope. Then take and record a compass bearing directly along the trail for the problem section. On a compass face determine the smallest number of degrees that separate these two bearings and record this also. Examples: 10o and 80o the difference is 70o; 350o and 40o the difference is 50o.

Trail Position

- Use the descriptions below to determine the trail's topographic position in the area of the problem segment. Examine a topographic map if necessary and record the corresponding letter code. Topographic maps usually have grossly estimated trail locations. Therefore, the in field location is probably more accurate.

  V - Valley Bottom: The trail is less than 30 feet above the lowest area in the closest valley bottom.
  L - Lower Slope: The trail is within 31-200 feet vertically from the lowest area in the closest valley bottom.
  M - Mid-slope: The trail is located greater than 200 feet vertically from the lowest area in the closest valley bottom.

Trail Design continued

Drainage Features (DF)

- Examine the tread in the vicinity of the problem with respect to drainage. Record the number of water bars or drainage dips within the problem area.
- Record whether ditching(DI) is used to drain water from the tread. (Y/N)
- Record whether corduroy(cord) was used as a maintenance measure to mitigate a problem. Record (Y/N) for this factor.
- Determine the relative effectiveness of tread drainage features.

> *Drainage Dip*: A drainage dip is manmade dip or shallow trench, typically with a earthen berm built across the tread, configured in a way that water is diverted off of the trail. Record in field the relative effectiveness of the drainage dip in diverting water from the trail tread. Effectiveness may be related to the quality of installation or current maintenance.
> Use following codes: **V**: very effective **P**: partially effective **I**: ineffective
>
> *Water Bar*: A water bar is manmade wooden or rock structure partially buried in the trail tread for diverting water off of the trail. Record the effectiveness of the water bar in diverting water from the trail tread. Effectiveness may be related to the quality of installation or current maintenane.
> Use following codes: **V**: very effective **P**: partially effective **I**: ineffective
>
> *Lateral Drain*: A lateral drain or ditch is a manmade trench dug along the up-slope side of the trail to collect and carry water down-slope parallel to the slope or across the trail at a water bar , drainage dip, or culvert. Record the relative effectiveness of the drain in carrying water down-slope away from the trail tread. Effectiveness may be related to the quality of installation or current maintenance or slope of drain. The slope may be gentle enough so that water can not drain.
> Use following codes: **V**: very effective **P**: partially effective **I**: ineffective

Ranking Principal Factors

Following these assessments study the tread problem and select from the lists below those factors that you believe principally contribute to the tread problem being evaluated (excessive tread erosion, tread muddiness, or stream sedimentation). There is a criteria set for each possible factor involved in the problem being assessed. The criteria ranks each individual factor as a range from highly contributing to least contributing to the problem. In some cases a factor occurs or does not occur. Certain factors and their ranking measure are derived from literature and professional judgment. Other ranking parameters derive from field evaluation and professional judgment.

Factors contributing to excessive tread erosion:

(AU) Amount of use on a trail can increase impacts. These will be ranked as Highly used to Extremely low use. Extremely low use may indicate a new trail or a typical high-end ROS backcountry trail. The range is:

3 - Highly used
2 - Moderately used
1 - Low use
0 - Extremely low use
Record from 3-0 as appropriate in the Resource Condition form.

- (TY) Type of use on a trail can indicate differences in the types and intensities of trail and environmental impact. This study only had walking(hiking), bike, and horse use. The range is derived through literature and experience. From this knowledge we can determine a range as which combination of use causes the worse potential impacts to which use alone causes minimal impact. Those with the worse receive a higher ranking and the use with the least potential impact receives the least score. The range is:

  3 - Horse, Mountain bike, and Hiker
  2 - Horse and Mountain bike
  1 - Mountain Bike
  0 - Hiker
  Record from 3-0 as appropriate in the Resource Condition form.

- (TG) Trail Grade: This is based on the importance that a set range of slope conditions is conducive or not conducive to soil erosion. The range is from Highly conducive to Not conducive as is shown.

  3 - High: >20%
  2 - Moderate: 15-20%
  1 - Low: 10-14%
  0 - Not: 0-9%
  Record from 3-0 as appropriate in the Resource Condition form.

- (S) Soil: Characteristics are broken into categories based on Highly conducive to erosion to Not conducive to erosion.

  3 - High: Clay or Silty Clay
  2 - Moderate: Silty Clay Loam or Clay Loam or Sandy Clay
  1 - Low: Sandy Clay Loam or Silt Loam or Loam
  0 - Not: Sandy Loam
  Record from 3-0 as appropriate in the Resource Condition form.

- (TA) Trail Alignment
  Rank according to whether or not the trail runs directly up the landform at 90 degrees or any other degree bearing. Between 0-22 degrees is highly conducive to keeping water on a tread since it is directly to nearly directly up the landform.

  3 - High: 0-22 degrees
  2 -Moderate: 23-45 degrees
  1 - Low: 45-67 degrees
  0 - Not: 68-90 degrees
  Record from 3-0 as appropriate in the Resource Condition form for trail alignment.

- (TDF) Tread Drainage Features: This includes ditches/drainage dips/water bars, and out-sloping. This is to determine if these are used or not on the trail so that water is removed from the trail tread. This does not measure there effectiveness. The rank is from High, 3 to Low, 0 indicating inadequate or adequate drainage features.

  3 - No tread drainage features are present.
  2 - At least one tread drainage feature is present but the density is clearly not adequate to remove water from the tread.
  1 - One or more tread drainage features are present though their density are not optimal
  0 - One or more tread drainage features are present in adequate densities to effectively drain water from the tread before it becomes erosive.
  Record from 3-0 as appropriate in the Resource Condition form.

- (ETDF) Effectiveness of Drainage Features: This determines whether or not the drainage features are properly designed and maintained.

  For Out-slope the idea is whiter or not the slope is effective at removing water from the tread:
  ≥ 2% is effective
  = 2% is fairly effective
  < 2% >.5% is somewhat effective

< .5% > 0% and in-sloped treads are<u>ineffective</u>

A dip feature must be below trail grade to be effective. Water bars must be durable and visibly able to channel water off the tread.
Rank according to:

3 - The drainage features present are ineffective in removing water from the tread. Use this rank when no drainage features are present.
2 - The features present are somewhat effective in removing water from the tread.
1 - The drainage features present are fairly effective in removing water from the tread.
0 - The drainage features present are well maintained and highly effective in removing water from the tread.
Record from 3-0 as appropriate in the Resource Condition form.

<u>Factors contributing to excessive tread muddiness</u>.

- (AU) Amount of use on a trail can increase impacts. These will be ranked as Highly used to Extremely low use. Extremely low use may indicate a new trail or a typical high-end ROS backcountry trail. The range will be record as:

  3 - Highly used
  2 - Moderately used
  1 - Low use
  0 - Extremely low use

- (TY) Type of use on a trail can indicate differences in the types and intensities of trail and environmental impact. This study only had walking(hiking), bike, and horse use. Other trails may have these uses plus other uses like motorbikes. The range is derived through literature and experience. From this knowledge we can determine a range as which combination of use causes the worse potential impacts to which use alone causes minimal impact. Those with the worse receive a higher ranking and the use with the least potential impact receives the least score. The range is:

  3 - Horse and Mountain bike
  2 - Horse
  1 - Mountain Bike
  0 - Hiker

- (LS) Landform Slope: Ranking is based on preliminary field work and professional opinion. The steeper the landform the easier it is for water to run down over the trail without settling on the trail surface. Gentle grades are conducive to standing and slow flowing water. Rank according to highly conducive slopes to not conducive slopes as is shown:

3 - Not: 0-9%
2 - Low: 10-19%
1 - Moderate: 20-29%
0 - High: >29%

- (TDF) Tread Drainage Features: This includes ditches/drainage dips/water bars, and out-sloping. This is to determine if these are used or not on the trail so that water is removed from the trail tread. This does not measure there effectiveness. The rank is from High, 3 to Low, 0 indicating inadequate or adequate drainage features. Record on the Resource Condition form as:

  3 - No tread drainage features are present.
  2 - At least one tread drainage feature is present but the density is clearly not adequate to remove water from the tread.
  1 - One or more tread drainage features are present though their density are not optimal
  0 - One or more tread drainage features are present in adequate densities to effectively drain water from the tread before it becomes erosive.
  Record from 3-0 as appropriate in the Resource Condition form.

- (ETDF) Effectiveness of Tread Drainage Features: This determines whether or not the drainage features are properly designed and maintained.

  For Out-slope the idea is whiter or not the slope is effective at removing water from the tread:
  ≥ 2% is effective
  = 2% is fairly effective
  < 2% >.5% is somewhat effective
  < .5% > 0% and in-sloped treads are ineffective

  A dip feature must be below trail grade to be effective. Water bars must be durable and visibly able to channel water off the tread.
  Rank according to:

  3 - The drainage features present are ineffective in removing water from the tread.
  2 - The features present are somewhat effective in removing water from the tread.
  1 - The drainage features present are fairly effective in removing water from the tread.

0 - The drainage features present are well maintained and highly effective in removing water from the tread.

- (SCHW) Soil Conditions Conducive to Holding Water: This rank allows us to determine the soil condition which is more to least conducive to holding water and creating wet soils. The source of water may be derived from either a seep, stream, or precipitation. Organic soils on top of trail treads make soil more prone to standing water. Rank according to the conditions observed with a numerical rank:

  3 - High: highly organic soils with Clay or Silt
  2 - Moderate: somewhat organic soils with Silty Clay Loam or Silt Loam or Clay Loam
  1 - Low: non-organic soils with Silt Loam or Sandy Clay Loam
  0 - Not: Sandy Loam

Possible factors contributing to stream sedimentation:

- (TT) Trail Treads: Trail treads drain directly into a stream at a stream crossing. Rank according to whether or not it is a crossing or drainage problem.

  Rank 1: for unfiltered crossing
  Rank 0: if it is not a crossing

- (UD) Trail is parallel to stream and water from the trail is draining for less than 10 feet and unfiltered by vegetation or organic litter or just unfiltered regardless of distance into the stream.

  Rank 1: if it is a unfiltered drainage less than 10 feet
  Rank 0: if it is not a drainage problem from an adjacent trail

Field Form: Problem Evaluation
Trail Name:
Date:

Assessed Problem and Resource Impact # from Resource Conditions Field Form

Factors	P	P	P	P	P	P
Landform Slope %						
Tread Distance Below Grade						
Soil Classification						
Soil Moisture						
Use Amount/ Type						
Trail Grade %						
Trail Cross-slope %						
Trail Alignment degrees						
Trail Position						
Drainage Features						
Proximity to Stream <u>crossing</u> or <u>alongside</u> <u><10’ or >10’</u>						

Field Form: Resource Condition Start Wheel (fixed location):
Trail Name:
Date:

				Factors Contributing to Soil Erosion							Factors Contributing to Wet Soil and Water on Trail						Factors Contributing to Stream Sedimentation	
Assessed Problem	Resource Impact	dist 1 feet	dist 2 feet	Use		Siting			Construction Maintenance		Use		Siting		Construction Maintenance			
				AU	TY	TG	S	TA	TDF	ETDF	AU	TY	SCHW	LS	TDF	ETDF	TT	UD
	Begin	0																
P 1																		

Appendix B **Field Data**

Table B.1 Resource Condition Field Data for Trail1

Resource Impact	dist1 feet	dist2 feet	Total Dist.	Feet/ mile	% trail	LF	TDBG	Tex	O.S.	Moist	Usetyp	Useamnt	TG	TCS	TA	TP	DF	DIT	Cord	DD	WB
SE	83	176	93	98	1.8	30	9	8	n	m	w	l	30	0	0	l	0	n	n		
MT	157	176	19	20	0.4						w	l									
EW	83	176	93	98	1.8						w	l									
SE	188	220	32	34	0.6	15	9	8	n	m	w	l	15	0	0	l	0	n	n		
MT	188	220	32	34	0.6						w	l									
EW	188	220	32	34	0.6						w	l									
SE	2249	2569	320	336	6.4	48	9	8	n	d	w	l	13	0	70	m	0	n	n		
SE	2615	2668	53	56	1.1	48	15	8	n	d	w	l	15	-0.5	70	m	0	n	n		
SE	2785	2827	42	44	0.8	43	9	8	n	d	w	l	13	0	90	m	0	n	n		
SE	2985	3049	64	67	1.3	40	9	8	n	m	w	l	23	0	60	m	0	n	n		
EW	2985	3049	64	67	1.3						w	l									
SE	3149	3191	42	44	0.8	45	15	8	n	m	w	l	24	0	70	l	1	y	n	v	
EW	3149	3191	42	44	0.8						w	l									
SE	3319	3535	216	227	4.3	20	9	8	n	w	w	l	25	0	70	v	0	n	n		
MT	3339	3359	20	21	0.4						w	l									
MT	3431	3471	40	42	0.8						w	l									
SE	3982	4097	115	121	2.3	35	9	8	n	m	w	l	28	0	60	l	0	n	n		
EW	4013	4035	22	23	0.4						w	l									
SS	4771			0				8	n		w	l									

note: see Trail Assessment Manual, Appendix A for descriptions for field data

Table B. 2 Resource Condition Field Data for Trail 2

Resource Impact	dist1 feet	dist2 feet	Total Dist.	Feet/ mile	% trail	LF	TDBG	Tex	O.S.	Moist	Usetyp	Useamnt	TG	TCS	TA	TP	DF	DIT	Cord	DD	WB
SE	357	413	56	31	0.6	50	15	5	n	d	w	h	25	0	70	m	0	n	n		
SE	621	670	49	27	0.5	50	9	5	n	d	w	h	15	0	90	m	0	n	n		
SE	764	841	77	42	0.8	20	15	5	n	m	w	h	5	-2.5	70	v	1	y	n	i	
WT	841	864	23	13	0.2	15	15	5	n	w	w	h	3	0	60	v	1	y	n	i	
SE	1188	1258	70	38	0.7	13	9	8	n	d	w	h	5	0	80	m	0	n	n		
WT	2328	2368	40	22	0.4	40	9	5	n	w	w	h	1	0	90	m	0	n	n		
EW	2328	2358	30	16	0.3						w	h									
SE	2821	2855	34	19	0.4	34	15	5	n	d	w	h	18	0	70	l	0	n	n		
SE	3214	3325	111	60	1.1	10	9	5	n	d	w	h	20	-2.5	70	l	1	y	n	p	
SE	3663	3718	55	30	0.6	5	9	5	n	m	w	h	15	-2.5	70	m	0	n	n		
WT	3877	4057	180	98	1.9	43	15	8	n	w	w	h	23	0	70	m	3	y	n	v	
SE	3857	4096	239	130	2.5	43	12	8	n	w	w	h	25	0	70	m	2	y	n	p	
EW	3877	4057	180	98	1.9						w	h									
WS	3957	4257	300	163	3.1	8	3	8	n	w	w	h	2	0	90	m	0	n	n		
EW	3957	4257	300	163	3.1						w	h									
WS	4198	4364	166	90	1.7	9	6	8	n	w	w	h	1	0	70	m	0	n	n		
SE	8083	8134	51	28	0.5	40	12	8	n	m	w	h	27	2.5	60	m	0	n	n		
SE	8290	8339	49	27	0.5	34	9	8	n	d	w	h	16	0	80	m	0	n	n		
SS	8677			0	0.0						w	h									
SS	9278			0	0.0						w	h									
WS	9538	9569	31	17	0.3	42	15	8	n	w	w	h	2	0	60	v	0	n	n		
RE	9538	9569	31	17	0.3						w	h									
EW	9538	9569	31	17	0.3						w	h									

note: see Trail Assessment Manual, Appendix A for descriptions for field data

Table B. 3 Resource Condition Field Data for Trail 3

Resource Impact	dist1 feet	dist2 feet	Total Dist.	Feet/ mile	% trail	LF	TDBG	Tex	os	Moist	Usetyp	Useamnt	TG	TCS	TA	TP	DF	DIT	Courd	DD	WB
SE	104	146	42	40	0.8	40	9	2	n	d	w	h	18	2.5	45	l	0	n	n		
WS	226	248	22	21	0.4	3	2	8	n	w	w	h	3	1.5	80	v	0	n	n		
WS	879	908	29	28	0.5	10	2	9	n	m	wmh	h	2	1.5	50	l	0	n	y		
EW	879	908	29	28	0.5						wmh	h									
WS	1075	1161	86	83	1.6	10	12	4	y	m	wmh	h	4	2.5	60	v	0	n	n		
WS	1179	1205	26	25	0.5	5	3	4	y	w	wmh	h	2	2.5	50	v	0	n	y		
EW	1179	1205	26	25	0.5						wmh	h									
WS	1431	1554	123	119	2.2	5	9	2	y	w	wmh	h	2	2.5	90	v	0	n	y		
EW	1431	1554	123	119	2.2						wmh	h									
WS	1707	1770	63	61	1.2	5	9	8	y	m	wmh	h	4	2.5	70	v	0	n	n		
EW	1707	1770	63	61	1.2						wmh	h									
SS	1730			0	0.0			8		m	wmh	h									
MT	1746	1760	14	13	0.3						wmh	h									
WS	1837	1866	29	28	0.5	5	3	8	y	m	wmh	h	2	0.5	55	v	0	n	n		
EW	1840	1855	15	14	0.3						wmh	h									
SE	1970	2044	74	71	1.4	10	7	8	n	m	wmh	h	6	4	75	v	0	n	n		
RE	1970	2002	32	31	0.6						wmh	h									
EW	2010	2044	34	33	0.6						wmh	h									
WS	2106	2203	97	93	1.8	10	5	8	y	m	wmh	h	2	0.5	60	v	0	n	y		
EW	2106	2203	97	93	1.8						wmh	h									
WS	2453	2488	35	34	0.6	10	3	8	y	w	wmh	h	1	-0.5	50	v	0	n	n		
EW	2453	2488	35	34	0.6						wmh	h									
WS	2834	2888	54	52	1.0	12	15	9	y	m	wmh	h	2		75	v	0	n	y		
SE	2834	2888	54	52	1.0	12	15	9	n	m	wmh	h	2		75	v	0	n	y		
EW	2840	2878	38	37	0.7						wmh	h									
WS	3126	3175	49	47	0.9	10	2	5	y	d	wmh	h	2	2.5	70	v	0	n	n		
EW	3150	3175	25	24	0.5						wmh	h									
WS	3282	3400	118	114	2.2	10	2	5	y	m	wmh	h	1	0.5	70	v	0	n	y		
EW	3282	3302	20	19	0.4						wmh	h									
EW	3349	3400	51	49	0.9						wmh	h									
WS	3460	3489	29	28	0.5	10	2	5	y	m	wmh	h	1	0.5	70	v	0	n	n		
EW	3460	3489	29	28	0.5						wmh	h									
MT	3475	3489	14	13	0.3						wmh	h									
WS	3513	3585	72	69	1.3	10	2	5	y	m	wmh	h	1	0.5	70	v	0	n	y		
EW	3513	3585	72	69	1.3						wmh	h									
MT	3513	3547	34	33	0.6						wmh	h									
WS	3692	3702	10	10	0.2	10	5	5	n	m	wmh	h	14	0	70	v	0	n	n		
EW	3692	3702	10	10	0.2						wmh	h									
SS	3710			0	0.0						wmh	h									
WS	3715	3751	36	35	0.7	10	3	5	n	m	wmh	h	10	0	70	v	0	n	n		

Table B. 3 continued. Resource Condition Field Data for Trail 3

Resource Impact	dist1 feet	dist2 feet	Total Dist.	Feet/ mile	% trail	LF	TDBG	Tex	os	Moist	Usetyp	Useamnt	TG	TCS	TA	TP	DF	DIT	Courd	DD	WB
SS	3163			0	0.0	5					wmh	h									
SE	4180	4283	103	99	1.9	10	21	3	n	w	wmh	h	4	2.5	75	v	1	y	y	i	
WS	4180	4283	103	99	1.9	10	21	3	n	w	wmh	h	4	0	75	v	0	n	y		
EW	4283	4380	97	93	1.8						wmh	h									
SS	4190			0	0.0	10					wmh	h									
SS	4245	4192		0	0.0						wmh	h									
SE	4525	4543	18	17	0.3	2	24	3	n	m	wmh	h	13	0	80	v	0	n	n		
SS	4548			0	0.0						wmh	h									
WS	4909	4943	34	33	0.6	13	3	8	n	m	wmh	h	4	2.5	50	v	0	n	y		
MT	4915	4943	28	27	0.5						wmh	h									
EW	4915	4943	28	27	0.5						wmh	h									
SE	5440	5478	38	37	0.7	8	12	8	n	m	wmh	h	8	4	70	v	0	n	n		

note: see Trail Assessment Manual, Appendix A for descriptions for field data

Appendix C Maintenance/Construction Figures

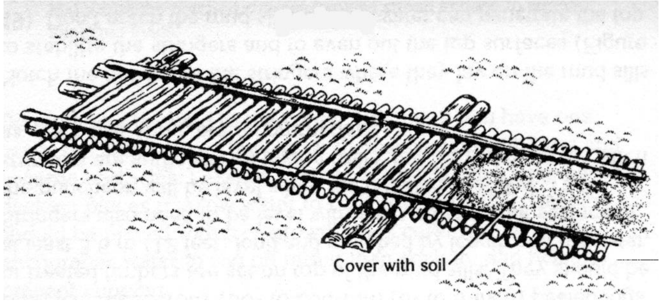

Figure C.1 Corduroy

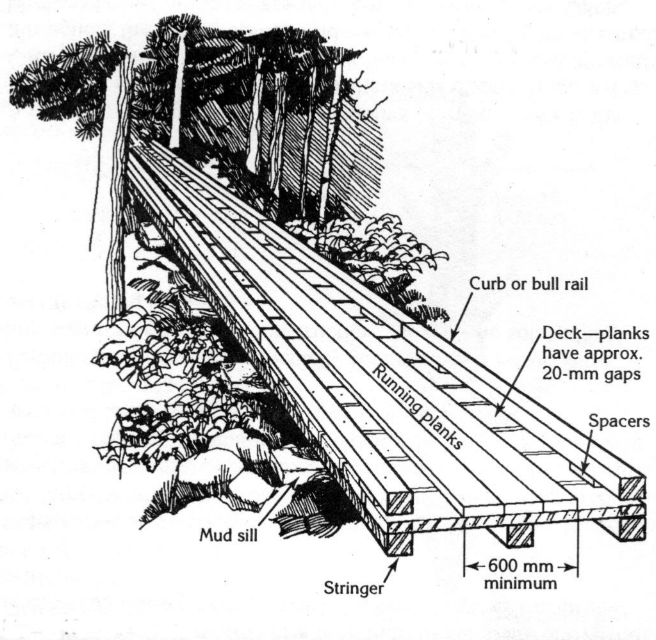

Figure C.2 Puncheon

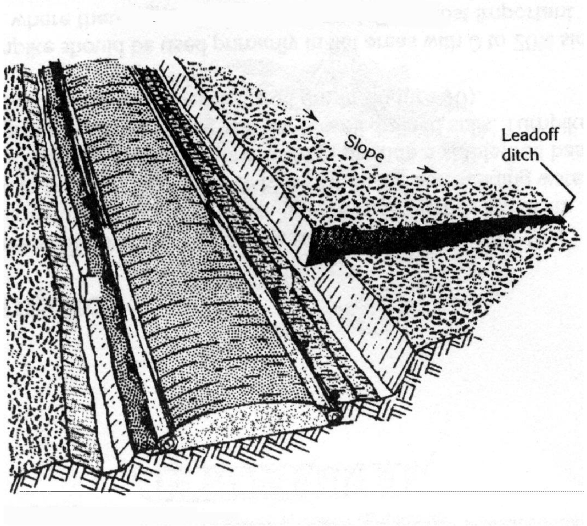

Figure C.3 Turnpike

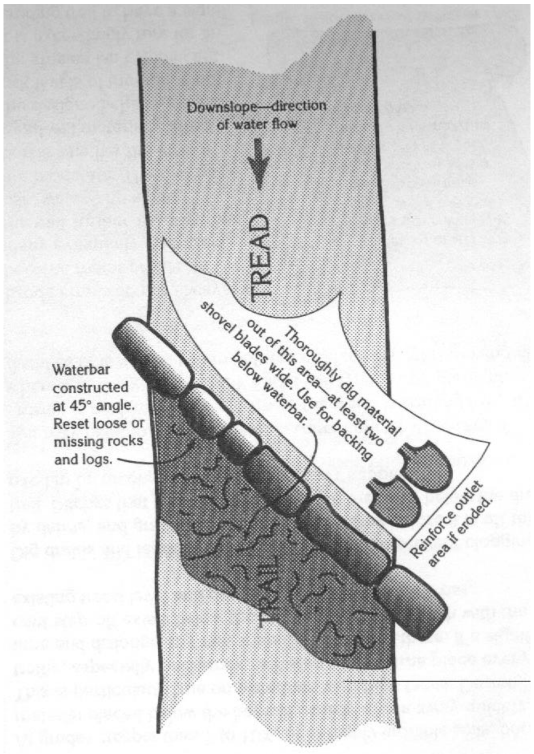

Figure C.4 Waterbar: Function and Maintenance

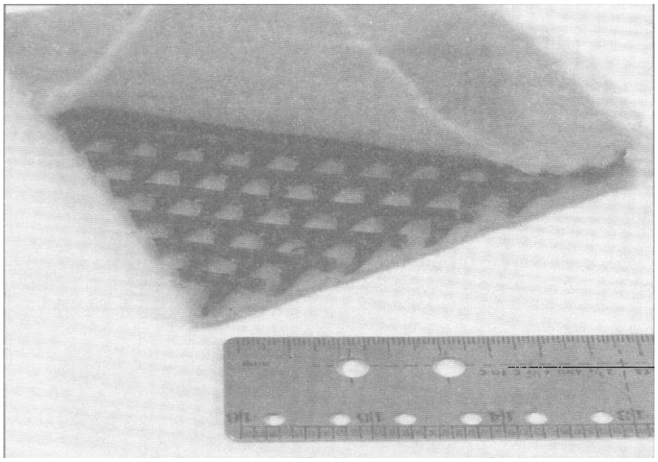

Figure C.5 Geonet

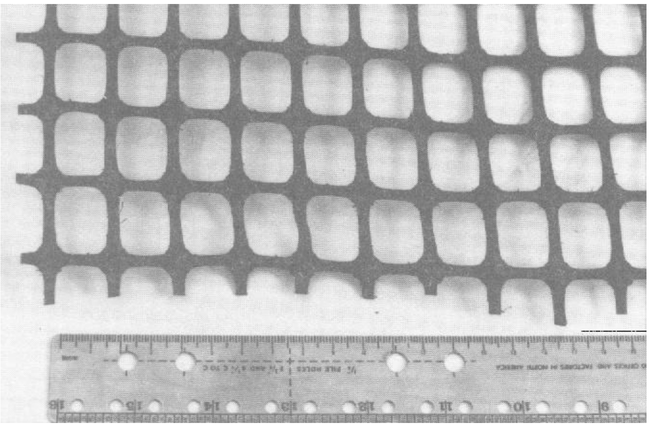

Figure C.6 Geogrids

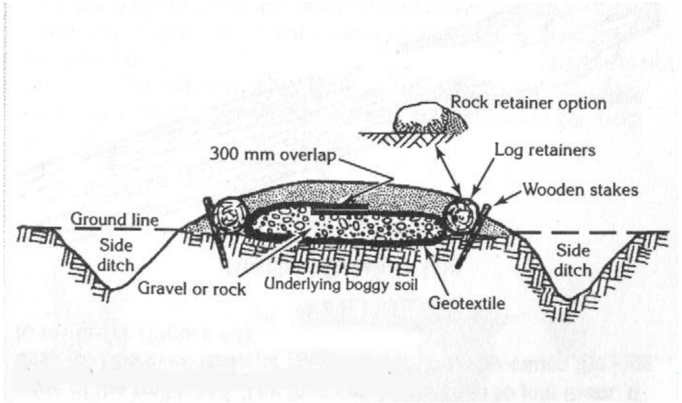

Figure C.7 Geotextile Placement

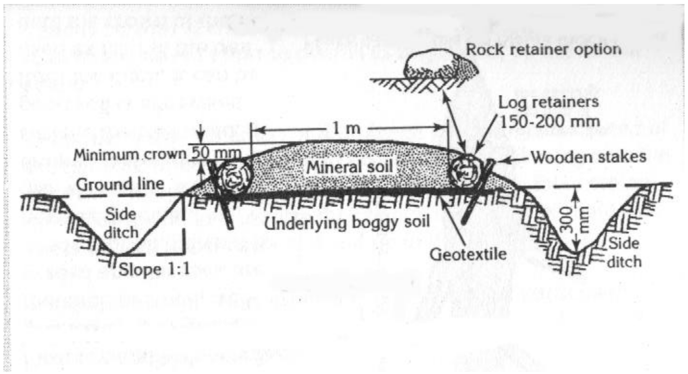

Figure C.8 Geotextile Placement

Vita

Eric Lanehart was born January 22, 1970. He presently resides in Blacksburg, Virginia. The completion of this thesis represents the work of his Masters of Landscape Architecture at Virginia Tech. Eric's previous degree is in Plant Pathology from the University of Florida.