Location and Design of Recreational Trails: *Application of GIS Technology*

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Title
LOCATION AND DESIGN OF RECREATIONAL HIKING TRAILS: APPLICATION OF GIS TECHNOLOGY

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(Abstract)

As population increases, the need for public recreation facilities and resources increases. The U.S. Forest Service, National Park Service, and other recreation providers are constrained by limited time and funding to plan for, and implement, recreational facilities for the areas that they serve. Poorly located and designed recreational trails increase maintenance costs, resource degradation, and the inefficient utilization of public resources. The potential application of Geographic Information Systems (GIS) technology to this specific type of problem is examined through the comparison of hypothetical trail routes generated by several different methods, existing trail field surveys, office design, GIS user-assisted design, and cost-path analysis design. Each method is compared statistically and qualitatively by GIS methods and office based methods. Each hypothetical trail is ranked according to effectiveness of design, providing insight into trail design methods. The office designed hypothetical trails were consistently ranked highest by an expert forest road designer.

Dedication

My father's active parenting techniques encouraged me to mature into a unique and diverse individual. This thesis is a product of years of his advising, mentoring, listening, and love. Thanks Dad.

Acknowledgments

There are numerous people whom I wish to thank for their various forms of support for this thesis. I wish to thank the Geography department at Virginia Tech for the opportunity for graduate study. I would also like to thank my committee members for their excellent guidance.

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I wish to express my appreciation to Dr. Aust for his work in evaluating each potential new trail design and to Dr. Carstensen for his excellent GIS technical assistance. These two committee members willingness to work on a research project that incorporated skills from unfamiliar areas of interest resulted in the completion of research that has until now been previously unexplored.

I would like to thank my friends Dr. Bernd Kuennecke and Dr. Lori LeMay of Radford University. Dr. Kuennecke gave me the opportunity to develop my teaching skills at Radford University and allowed me to use the department's geography lab for my GIS work. Dr. LeMay has been a great friend, traveling companion, mentor and role model for me as I did graduate work at Virginia Tech. She has shown me how to be a strong, successful woman in both life and academia.

I feel privileged to be able to thank my mother and especially my grandmother. Both of these educated women in my family have always told me that I could do anything I put my mind to. I would like to give special thanks to my grandmother who financially supported me throughout my academic career. I hope to be able to pass that gift along some day.

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Chapter 1
Introduction

As population increases, the need for public recreation facilities and resources increases. The U.S. Forest Service, National Park Service, and other recreation providers are constrained by limited time and funding to plan for, and implement, recreational facilities for the areas that they serve. Poorly sited and designed recreational trails increase maintenance costs, resource degradation, and the inefficient utilization of public resources. The potential application of Geographic Information Systems (GIS) technology to this specific type of problem has, as yet, been unexplored. GIS may serve to reduce the amount of time spent in reconnaissance during the siting process, as well as increase the productivity of reconnaissance work. Furthermore, the capability of GIS to manipulate large amounts of spatial data could increase the effectiveness of reconnaissance surveys and lead to the location of more stable trail treads.

To fully integrate the benefits of GIS technology in this area, the appropriate starting point is to identify and document current procedures employed in the siting and design of trails.

The procedures and other related concerns considered by trail planners are described in the following literature review. The areas where application of GIS technologies may most effectively aide the siting and design process are described and evaluated through field research. Specifically, six trail segments in Great Smoky Mountains National Park were evaluated using two different trail survey approaches. Siting and design attributes are then evaluated using field survey, office, and GIS-derived data and applied in the development of hypothetical trail reroutes.

Objectives

The Objectives of this research are to:

1. Conduct a comprehensive review of the literature concerning trail siting and design factors and their influence on trail degradation.

2. Conduct research to evaluate existing trail segments occupying three geographic positions (valley bottom, midslope, and ridge line). Siting and design attributes will be examined through field surveys, office evaluation, and GIS analysis. The relative capabilities of these three approaches will be compared

3. Prepare and evaluate hypothetical examples of trail reroutes or new trail alignments using traditional map - based and computer/GIS based methods.

This research advances our understanding of the range and relative importance of trail siting and design factors. An improved understanding of these relationships and capabilities provides recreation managers with critical insights into the selection, implementation, and effective application of GIS technology to the challenge of trail location and design. GIS technology provides managers with an efficient tool for evaluating trail siting and design attributes of existing inventories of trails, and, for those trails found to be deficient, the means to identify alternative trail alignments based upon improved locational criteria.

Chapter 2
Literature Review

Trail siting and design seeks to place trails in the best possible location for user enjoyment, while minimizing construction and maintenance costs and impact to the surrounding environment. Trails must be constructed so that they serve their intended purpose: providing an efficient, safe, and enjoyable transportation network for primarily human powered recreational pursuits. This literature review seeks to: 1) identify environmental factors that contribute to trail degradation and thus are important considerations to siting resistant trails, and 2) describe existing procedures employed in the siting and design of trails. Traditional field and office techniques will be examined in addition to the potential capabilities offered by Geographic Information Systems, a relatively new tool whose application to trail siting has apparently not been investigated.

Much of the information relating to trail siting and design is found in agency documents or other informal literature. Although this "gray" literature has not undergone the extensive review common for scientific journals, the information reflects the expertise and long experience of agency and private sector trail planning, construction, and maintenance professionals. The current trail siting and design literature has problems with varying nomenclature. For the purposes of this literature review, a glossary of terms is provided in appendix A to identify and standardize the most widely used definitions for key terminology.

Recreational hiking trail conditions are influenced by two groups of factors, environmental and related. Recreational trails are used by mountain bikers, horse riders, motorized vehicles, and hikers. Different types of use have varying degrees of impact on a trail's tread. This literature review focuses on environmental factors. Environmental characteristics play a major role in determining the condition of a trail. Identification of these characteristics and their respective influences can help trail designers to avoid sensitive areas (Leung & Marion 1995). Knowledge of environmental relationships are important in locating, designing, constructing, and maintaining trails that will sustain use and stay in good condition.

Environmental Factors Contributing to Trail Degradation

The construction and use of a trail exposes soils, such soils are more susceptible to degradation from environmental and use related factors. A combination of these factors can leave a trail boggy, muddy, or eroded into a trench. In addition to degradation problems, trails may undercut unstable banks and lead to increased mass movements of earth such as landslides, debris slumps, and flows (Amaranthus et al. 1985). The first component of this literature review focuses on how environmental factors influence trail degradation. Different types and amounts of trail use play a role in the degradation process, but research has found that trail degradation is also substantially influenced by location (McQuaid - Cook 1978, Bryan 1977, Nagy & Scotter 1974, Summer 1980 1986, Cole 1991, Marion 1994).

Proper drainage of a tread is the most critical factor to its durability. During rainy seasons, normal rainfall flows over the land in a sheet. Water, that is not absorbed by soils, flows over the land in intermittent or permanent channels and streams. Trails can also act as artificial channels for rainwater, increasing erosion and damaging trail treads (Cole 1987, Vogel 1982). Water is the main erosional agent affecting a trail's substrate, and the longer it remains on a tread, the more degradation occurs.

Drainage structures attempt to remove water from trails as quickly as possible. Water bars, grade dips, and outsloping of the trail surface are all features to keep water from remaining on the trail in excessive volumes and velocities (Vogel 1982). Drainage structures can reduce tread erosion, but they are a poor, and in some instances, an impossible substitute for proper trail location (Moll, date unknown). A properly located trail may minimize the number of drainage structures needed, therefore reducing capital construction costs of drainage features and recovering maintenance costs (Forest Service, date unknown). The key to ensuring the durability of a trail tread is drainage. The best way to avoid drainage problems is to place the trail in the best possible location in the planning stage of trail design. The following sections describe factors that affect tread drainage and other forms of tread degradation, including soil type, grade and slope, and trail alignment and vegetation.

Soil Type

Trail drainage can be best understood as a function of soil types and slope. Bryan (1977) found that with equal use on any two trails, soil properties were the main determinant of trail degradation. Birchard (1981) states that the first stage to trail degradation is soil compaction. He may have overlooked the removal of vegetation, which initially causes soils to be vulnerable. The influence of vegetation will be discussed further in a later section. Soils are composed of organic, mineral, and rock material. Water and air fill the space between particles. The reduction of water and air pockets in the soil due to compaction reduces the space within the soil to hold rainwater, increasing the amount of rainwater runoff. The increase in soil density lowers the surface of the tread relative to surrounding soil surfaces so that it collects and channels water. Pore space ability to hold water in the tread substrate may be altered either positively or negatively. Larger pores are broken into smaller capillary spaces, enabling the soil to hold water against the force of gravity instead of draining to lower levels. The capture of water in the upper soil horizons subsequently decreases the rate of water infiltration increasing surface runoff (Hammitt and Cole 1987, Manning 1979, Lutz 1945). Figure 1 depicts Mannings (1979) seven-step cycle of recreational impacts on soils.

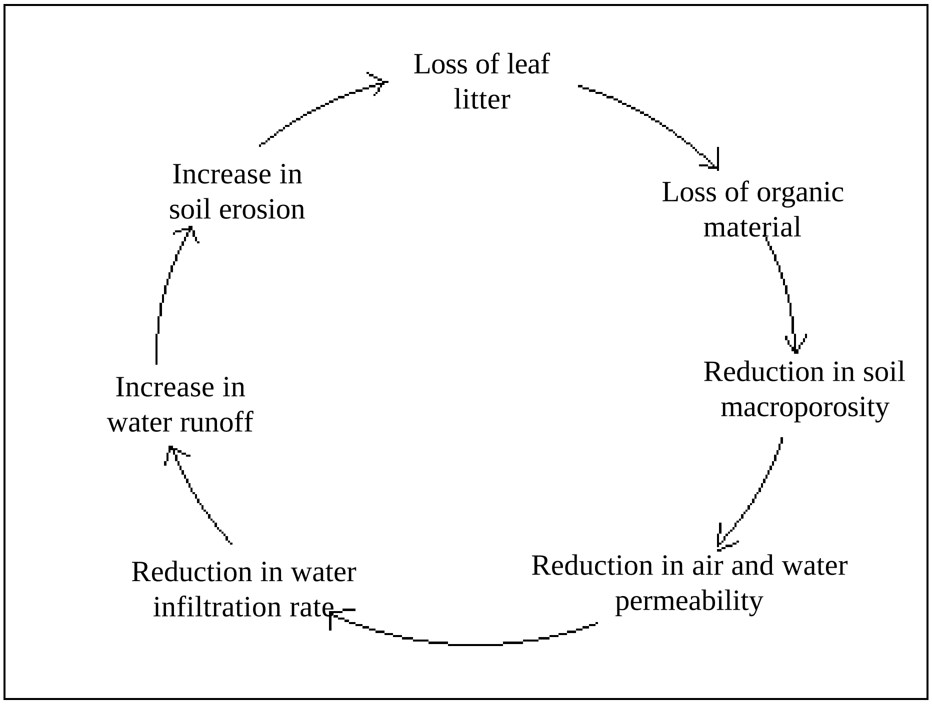

Figure 1. Recreational impact on soils. Manning 1979.

Keller (1988) identified several engineering properties of soils: strength, sensitivity, compressibility, erodability, permeability, corrosion potential, ease of excavation, and shrink - swell potential. The first five of these properties are most important when examining trail tread durability. These are listed in Table 1 along with a description of good and poor soil types according to property. The recommended soil properties in the category of erodability have greater than 20% clay and are naturally cemented. This contradicts each of the other categories of strength, sensitivity, compressibility and permeability. The properties of clay change for the worse when moisture is added to the equation, possibly explaining why much of the trail construction literature advises the avoidance of clay soils due to their poor performance in the other categories.

Birchard (1981) found that tread durability is increased when subsoils are three or more feet deep to bedrock and soils less than one foot deep should be avoided. However, in some situations thin soil layers can be removed to place trail treads on more durable bedrock. The depth of soil becomes more important as slope and wetness increases. Birchard (1981) recommended a sandy - clay loam mixed with gravel as an ideal soil type for trail construction, and advised to avoid silty, clayey and spongy peat soils. Soils most prone to erosion tend to be homogeneous in texture and finely grained (Hammitt and Cole 1987).

Bryan (1977) observed that even minimal trampling of organic soils can lead to the formation of mud puddles. These organic soils are very susceptible to trampling damage, especially when wet (Stewart and Cameron 1992). The same study also noted that the presence of large rocks and boulders on a trail tread corresponded to the absence of truncated soil horizons. The importance of good soil properties most manifests itself in a soil's ability to drain water. Mud puddles lead to widening of the trail by hikers and horses going around them, or even cutting new informal trails. As slope increases and a soil's durability and ability to absorb water decreases, the need for drainage structures increases. Table 2 provides recommended frequencies for drainage structures according to soil type and trail grade.

Kellers engineering properties of soil complement the recommended sandy - clay loam soil type best for trail construction. One interesting conflict between Tables 1 and 2 is that clayey soils have poor engineering properties, yet Table 2 lists clay soils as requiring fewer drainage structures than either loams or sandy clays. This may be due to the natural cementation properties of clay, which decreases its erodability.

Table 1. Engineering properties of soils.

Soil Property	**Description of Property**	**Soils Good for Construction**	**Soils Poor for Construction**
Strength	Function of cohesion and friction	sandy, gravely	clays, organic rich
Sensitivity	Extent to which disturbance affects strength	sandy, gravely	clays, finely grained
Compressibility	Elasticity	coarsely grained	finely grained and organic
Erodability	Ease of natural transportation	>20% clay and naturally cemented	silty, sandy, loosely consolidated
Permeability	Ease of water movement	clean gravels and sands	clays and finely grained soils

Source: Keller (1988).

Table 2. Frequency of drainage structures.

Soil	Grade						
	2%	**4%**	**6%**	**8%**	**10%**	**12%**	**15%**
Loam	350'	150'	100'	75'	50'	*	*
Clay - Sand	500'	350'	200'	150'	100'	50'	*
Clay or Clay - Gravel	-	500'	300'	200'	150'	100'	75'
Gravel (Round Rock)	-	-	750'	500'	350'	250'	150'
Shale or Angular Rock	-	-	800'	600'	400'	300'	250'
Sand	Varies with local amount of fine clay and silt. Drainage diversions are generally not required in "pure" sand due to the fast rate of water absorption. For sand with appreciable amounts of fine binder material, use "clay - sand" distances as shown above.						

* Grades not recommended in this material.
\- Generally no diversion required for soil stability.
Sources: U.S. Forest Service, USDA, Trails South (date unknown). Forest Service Handbook (1991). Recreation Travelways Handbook (date unknown).

Vegetation

The construction of a trail will damage and remove vegetation cover, exposing bare soil. This initial impact during trail construction is unavoidable. As distance from the tread of the trail increases, vegetative cover increases until maximum cover is reached. Typically the effects of a trail corridor on vegetation can extend up to 4 or 5 meters from the center of the tread, but can extend much further (Cole 1987 1978). Trail construction can change the characteristics of a site by allowing more sunlight and precipitation to reach the ground surface. This can lead to an actual increase in trailside vegetation. Trail maintenance and use can also alter the structure and composition of trailside vegetation (Liddle 1993, Dale and Weaver 1974). Trail users sometimes trample trailside vegetation in their efforts to avoid problem spots such as mudholes or severe tread erosion. This can lead to tread widening and destruction of bordering vegetation, reducing the aesthetic qualities of the trail. The best defense against trail widening is to ensure proper trail location. It is advisable to avoid locating trails in sensitive vegetative habitat.

Cole (1979) found that vegetation in densely forested areas changed more than vegetation in open forests and meadows. Trampling resistant species will survive while more fragile species succumb to trampling stresses. Tall plants seem more susceptible to the effects of trampling than short plants and the more resistant species are those with small prostrate leaves and graminoids (Liddle 1993, Cole 1978).

Different types of plant structure affect a species ability to withstand or resist initial impact by trampling and later regenerate. Resistance, a plant's ability to withstand the initial impact of trampling, is mostly a function of plant structure. The more erect and brittle plants are least resistant. Liddle (1993) found that herbaceous and upright woody plants were most susceptible to damage from trampling. Resilience, the ability of a plant to regenerate after trampling damage, is greatly reduced by perennating buds. Tolerance, the durability of a species after repeated cycles of trampling, is more highly correlated with resilience than resistance (Cole, 1995). All studies that have documented changes in vegetation due to the stresses of trampling, have found that sedges and grasses are the most likely to survive trampling.

Bayfield (1973) found that tread widths in grassy areas were consistently more narrow that wooded areas. Low shrubs, seedlings, and lichens are the most susceptible to damage. More mature trees and thorny shrubs are generally affected very little (Cole, 1987). With horse traffic, trail users traversing woody areas are restricted to the tread, while in grassy meadows users can spread out and create multiple treads (McQuaid-Cook 1977). With the exception of the most resistant plant species, damage occurs most rapidly during initial use, causing the relationship between impact and amount of trampling to be curvilinear. Impact ocurs less rapidly after this initial use and impact. Weaver et al. (1978) found that rates of damage to all types of vegetation increase as slope increases.

Bratton et al. (1979) found while studying trails in the Great Smoky Mountain National Park that spruce - fir, xeric oak and pine, gray beech, mesic hemlock hardwoods, hemlock, and early successional forest types were erosion sensitive environments. Trails located in northern hardwoods were generally in better shape, although Bratton noted that most of these were located on old railroad beds, explaining in part their better condition. Trail conditions in grassy balds and burn scars were significantly more degraded than those located in pastures and old fields. Areas of old growth or "virgin" forests showed some of the worst damage. Herbaceous understories were damaged more than shrub and ericaceous communities.

Management Factors

Grade and Slope

As the grade of a trail increases, soil erosion potential increases. Bratton et al. (1979) noted that the most important physical factor related to trail degradation is slope. Erosion tends to be significantly greater on steeper slopes (Hammitt and Cole 1987). Weaver and Dale (1978) found that potential damage to vegetation was greater on slopes as well. Table 3 compiles figures of recommended trail grades according to type of trail.

Trails are often located on the hillsides. Steeper sideslopes call for increased excavation to create a relatively flat tread. Rock cribs are sometimes necessary on steep sideslopes to prevent slope failures, e.g. soil slumps, from covering the trail. Figure 2 shows percent of sideslope and related problems to increased steepness. An acceptable rise of 10-70% slope or sideslope is suggested (U.S. Department of Interior 1992).

Table 3. Grade classes for different trail types.

Type of Trail	Acceptable Slope	Additional Comments	Citation(s)

Hiking Trail	<15%	even in steep terrain	Birchard (1981)
	up to 30%	only if section of trail is short	Birchard (1981)
Equestrian Trail	<9%	keep a steady grade with small breaks where slope <5%	Vogel (1982)
	up to 15%	only on short segments	Vogel (1982)
Mountain Bike Trail	<15%	avoid clay soils	McCoy (date unknown)
	>15%	widen trail so that users can push their bikes	McCoy (date unknown)

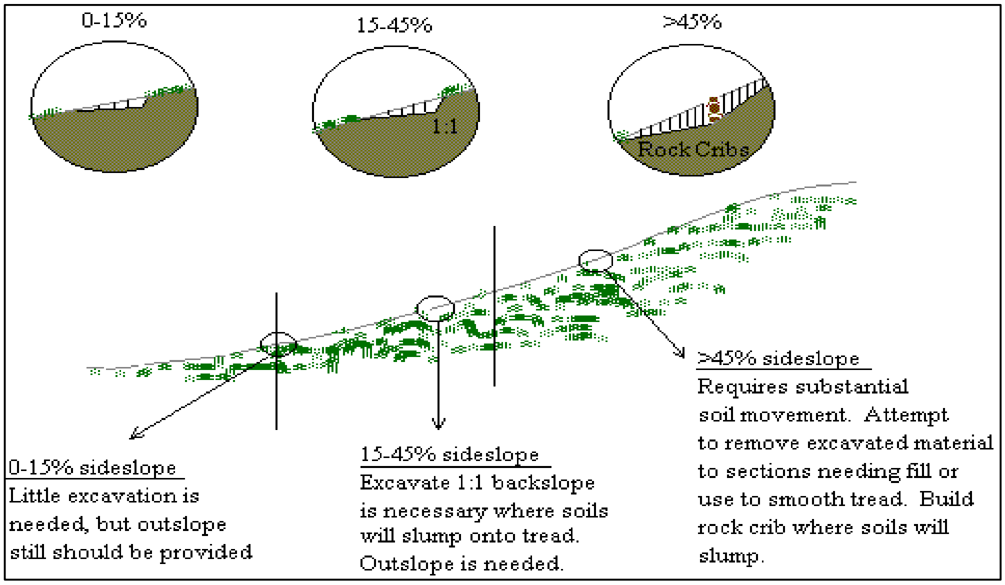

Figure 2. Sidehill Excavation.
Source: U.S. Forest Service, USDA Trails South (date unknown)

Garland (1983) found that steeper slopes with shallow soils covering an impermeable layer are more prone to failure. The excavation of a trail on a steep sideslope moves the center of gravity for the slope. This may lead to slope failure causing the trail to be covered, disturbing the natural environment. Not only does the debris cover the trail, the site's ability to resist water erosion is decreased by disturbing trailside vegetation that would normally cover and bind the soil (Amaranthus et al. 1985). Figure 3 depicts the effects of improper forest road location on a slump area.

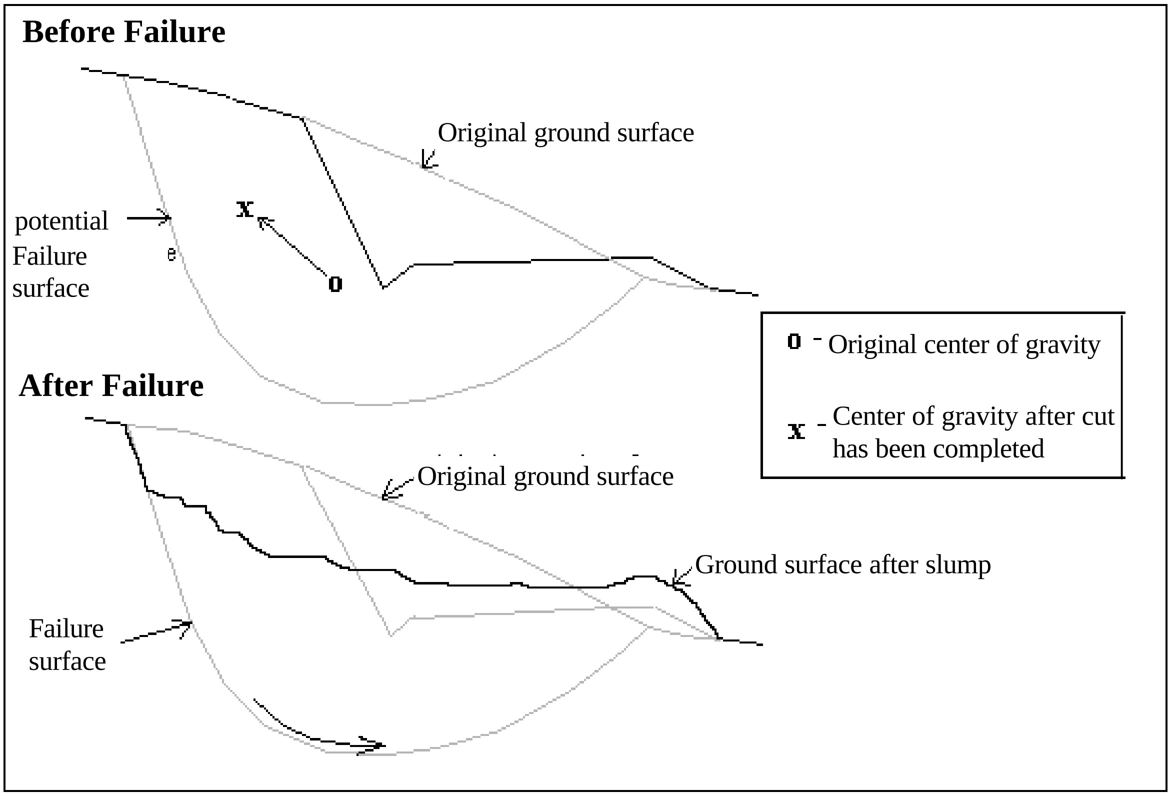

Figure 3. The effects of improper road location on a slump area

Source: Oregon State Extension Circular; Designing Woodland Roads 1983.

Trail alignment

Trail alignment refers to the topographic location of a trail in relation to local landforms. The trail alignment can be expressed by the slope alignment angle. Trails can be aligned parallel to the prevailing slope, (0^o angle), perpendicular to the slope (90^o angle), or at any angle in between ($1 - 89^o$ angle). Trails that cut across slopes at an angle are said to have sidehill design; their construction involves some degree of excavation upslope typically with soil fill added downslope. Sidehill designs are strongly recommended as being the least prone to erosion due to the ease with which water can be drained off the tread (Birchard 1981, U.S. Forest Service Handbook 1991, U.S. Forest Service Trails South date unknown). Bratton et al. (1979) found a significant correlation between a trail's angle to the prevailing slope and all forms of degradation except bank erosion. Low trail angles showed the most erosion while trails with $80 - 90^o$ angles showed the least erosion. Switchbacks, or changes in direction in a sidehill design trail can be used to gain elevation and maintain a moderate grade (Birchard 1981). At times, a quick gain in elevation may be needed to reach a particular destination.

Different alignments on a slope can lead to several site-specific problems. Often, trails are located in valley bottoms along streams to take advantage of their scenic beauty. Drainage in this type of setting can be particularly difficult, especially if the trail becomes entrenched. Persistently wet soils are prone to the development of mudholes and excessive widths as users skirt mucky areas. Cole (1983) and Marion (1994) suggest that unless a trail is rerouted completely out of a valley bottom, major construction of drainage structures and walking surfaces may become necessary.

One Forest Service publication (Forest Service 1991) recommended ridgetop trail design, yet statements elsewhere in the document suggest that trails should follow contours perpendicular to the slope. Bryan (1977) found that trails following contour lines suffered the least amount of soil erosion unless the tread has become incised, preventing runoff and channeling water along the trail. Summer (1986) found that trails located immediately below the crest of a hill in the Rocky Mountains were highly susceptible to erosion, while those located in valley bottoms were least susceptible to erosion and most susceptible to increases in width. Trails located on colluvial fans became excessively muddy and braided. Leung and Marion (1996) argue that ridgetop alignments (parallel to the slope of the land), are more susceptible to degradation due to the difficulty of draining water from the tread.

Summer (1980) found that geomorphic processes, determined to a larger degree than type of use or amount of traffic, a trail's susceptibility to degradation. Parent material, trail grade and sideslope, soil texture and organic content, rockiness, stoniness, and drainage were among the significant biophysical factors. Table 4 lists common features to avoid during trail alignment and Figures 4, 5, and 6 depict several examples of good and poor trail alignment. Figure 4 shows a ridgetop design. Ridgetop design trails are often parallel to the slope of the land and can become entrenched, creating a gully that will channel water along the trail. The classic Appalachian ridgetops are rounded and have wide ridges. These features complicate the construction of drainage structures such as water bars and drainage dips, which must have extended drainage trenches to be effective. Ridgetop designs may be less problematic on younger mountain formations with sharper, more narrow, ridges.

Figure 5 shows a valley bottom design. Again, the trail typically parallels the slope of the land, leading to drainage problems. Water bars and drainage dips are often ineffective because water remains on trails with no slope or cross slope. Figure 6 shows a typical sidehill design. The sidehill design is recommended as the most stable type of trail, avoiding both excessive grades and, for the greatest part, perpendicular to the slope. Switchbacks can be used to gain elevation.

Table 4. Features to avoid during trail alignment.

Unstable and highly erosive soils
Creek bottoms subject to predictable flooding
Rock, land, or snow slide areas
Major abrupt changes in elevation
Extensive use of switchbacks and long tangents
Known habitats of threatened or endangered species
Planned low use areas (wilderness areas)

Source: U.S. Forest Service (date unknown). Trails South.

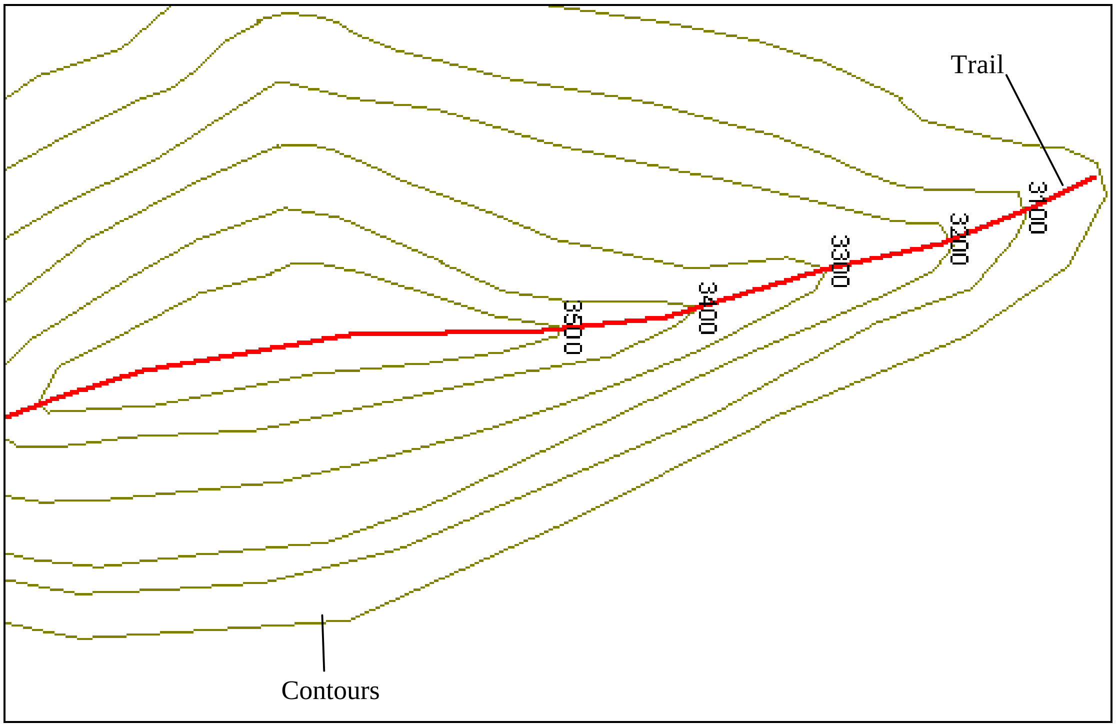

Figure 4. Ridgetop Trail Design

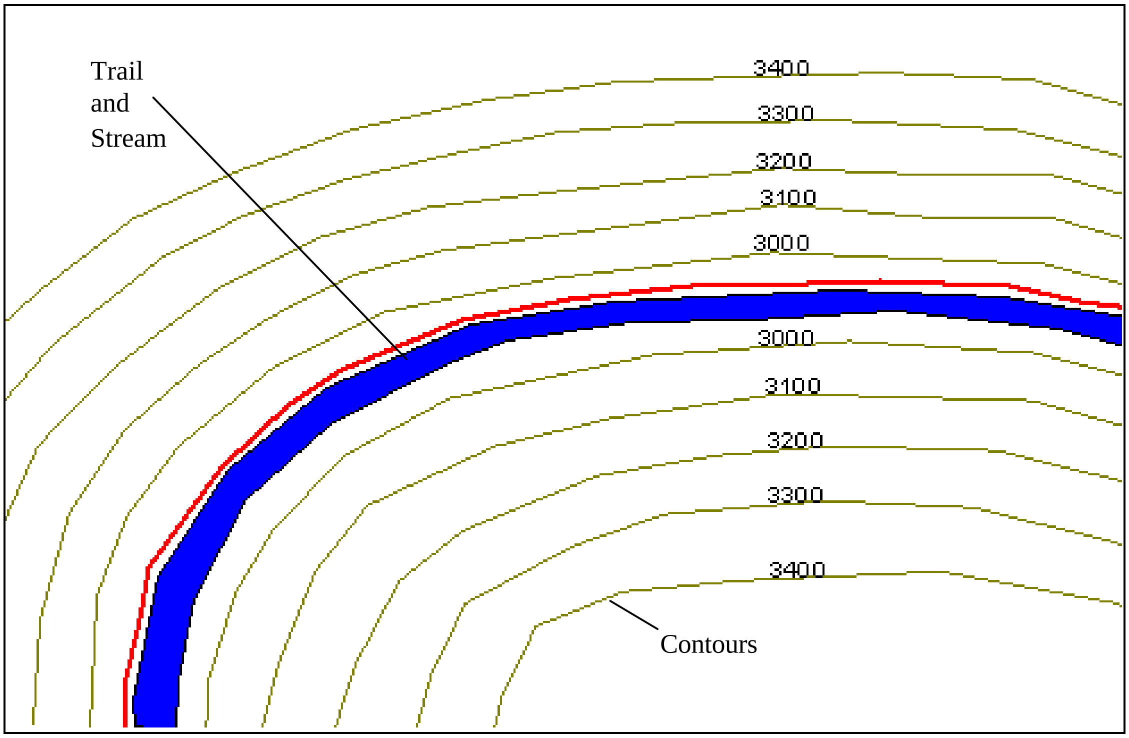

Figure 5. Valley Bottom Trail Design

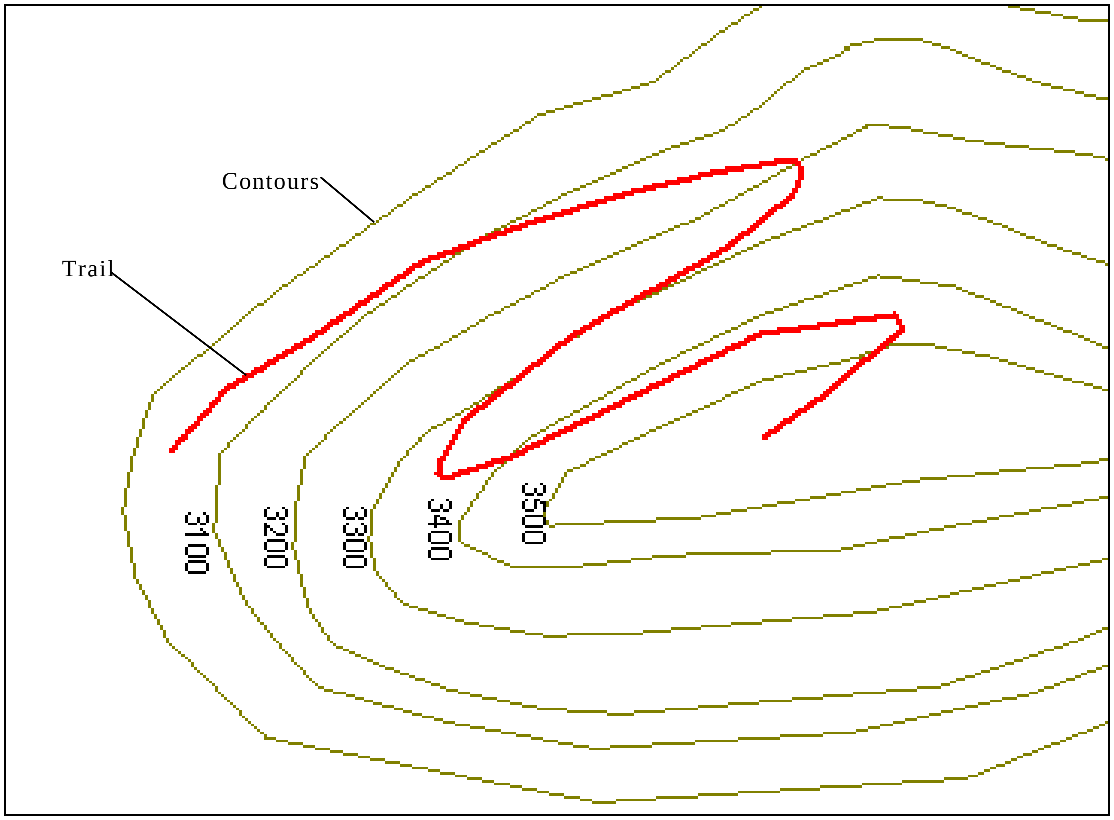

Figure 6. Sidehill Trail Design

Existing Procedures of Siting and Design

The body of literature describing in detail, procedures used to site and design a recreational hiking trail, is relatively small. Proudman and Rajala (1981) suggest in their book Trail Building and Maintenance that trail planners look for well designed old logging roads that can be used for a trail. Abandoned logging roads are often later used as recreational trails. To add to the general knowledge of recreational trail siting and design, some forest road engineering publications are explored in addition to trail design publications. Forest road engineering principles are closely related to trail siting and design. Publications dealing with the procedures of forest road siting and design provide a more comprehensive examination of this body of knowledge.

Proudman and Rajala (1981), identify the first stage of trail planning as field reconnaissance. Two trail planners hike into the area a trail is desired and flag potential routes with different colored ribbons. The planners use note cards to record and describe different features encountered in the field. Ideally, these features should be labeled on a topographic map. It is suggested that trail planners keep the potential trail in a sidehill alignment and under a 20% gradient. To reach high points of interest switchbacks can be used to gain elevation. Wide rounded switchbacks are recommended to avoid hikers creating short cuts from one section of trail to another. Recreational Hiking Trails are often initially designed in an office using topographic maps.

Garland (1987) details the steps taken in constructing a forest road. Table 5 above lists and describes each step. Woodbridge and Franklin (1984) detail an office procedure that can be used to design a forest road after points of destination are identified. First, a beginning and ending point are selected. The second consideration in routing a trail is the initial trail's grade. To calculate the grade, the difference in elevation between the two points is determined in feet. This number is then divided by the horizontal distance between the two points in feet. If the two points are 1 in. apart on the map, but the map scale is 1 in. = 500 ft., the distance is 500 ft. The distance is then divided by the approximate change in elevation.

Once the initial grade is determined, a draftsman's instrument know as a divider can be used to "step" along the map between the beginning and ending points. The distance at which to set the divider is found by dividing the contour interval of the map by the initial % grade. For example a 20 ft. contour interval / 7% initial grade = 285.7 ft. To set the divider in proportion to the map, x in./draftsman's divider = 1 in./map scale. A draftsman's scale is used to set the distance of the divider to the result of the previous formula. The divider is used to step from one contour to the next. If only one contour interval falls between the legs of the divider, the grade of the trail will never exceed the initial grade desired. Figure 7 depicts designing a trail using these methods.

Table 5. Steps in Forest Road Building.

Step	Description
Reconnaissance	Scout property, find control points.
Design	Determine grades, widths, curves, cut and fill information.
Layout	Mark route with ribbons and stakes.
Logging the right-of-way	Remove timber.
Clearing and grubbing	Remove stumps and organic debris.
Excavation to grade	Cut the earth down to grade, fill low areas up to grade.
Installing drainage features	Cross steams with culverts or bridges
Surfacing	Shape road surface and spread gravel if needed.

Source: Garland (1987).

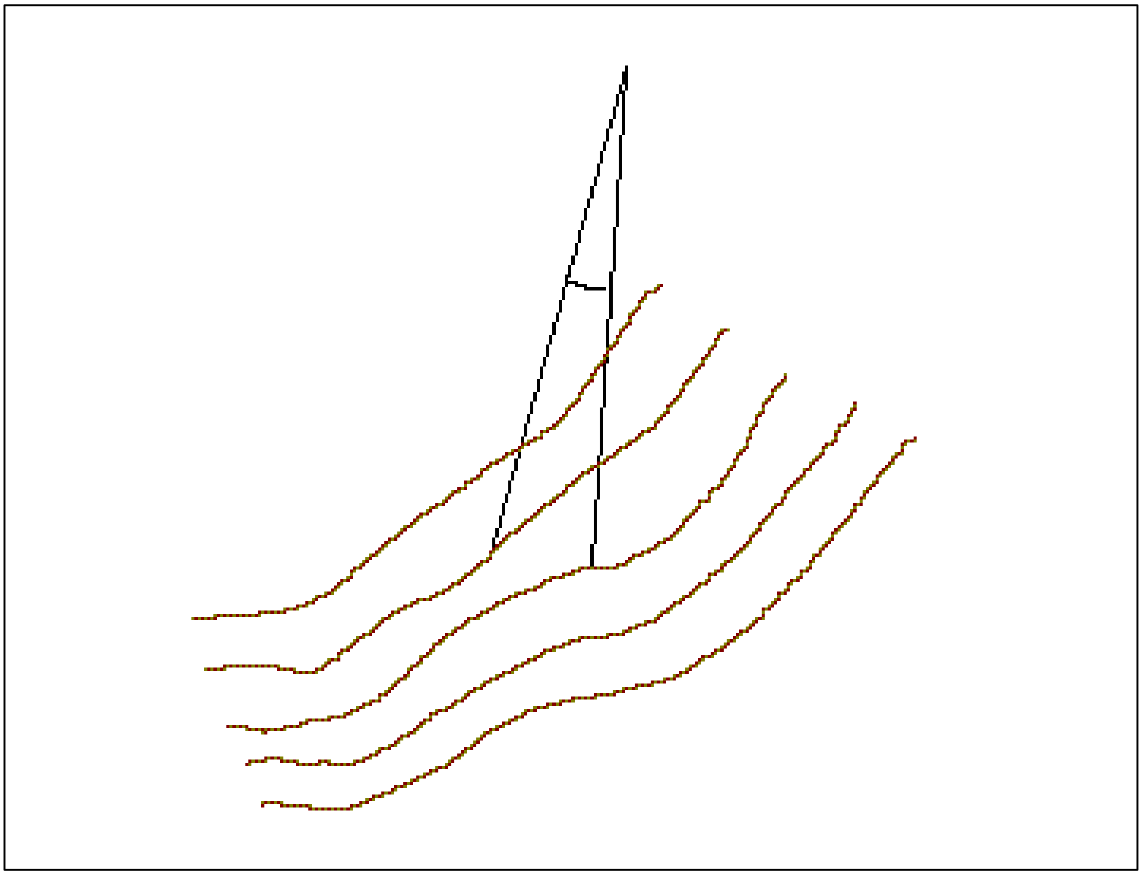

Figure 7. Using dividers to step from one contour to the next.

Chapter 3

Study Area

Field research was performed in the Great Smoky Mountains National Park (GSMNP) located on the border between North Carolina and Tennessee in the Appalachian Mountains. The park was formally established in 1934 after nine years of land acquisition by the federal government. In 1976, GSMNP was designated as a Biosphere Reserve and is managed in accordance with the "Man in the Biosphere" program. Today, 83 percent of the park is recommended for wilderness designation and managed as wilderness until release by Congress (Marion 1994, NPS 1988). The current General Management Plan for the park calls for the provision of public benefit and enjoyment while preserving the resources and leaving the natural processes unaltered (NPS 1981). These two park management objectives often are in conflict, requiring a delicate balance between recreation and protecting the environment.

GSMNP receives among the highest amounts of precipitation in the Eastern United States. Precipitation increases with elevation, averaging over 162 cm annually. Fully saturated soils from extended rainfall and snowmelt are common. Soils in valley bottoms tend to be deep and poorly drained, while soils on steep slopes and ridgelines often are relatively thin. The abundance of rainfall, a major erosional agent, increases the importance of proper trail alignment.

The Great Smoky Mountains is known for its black bear population. The flora and fauna throughout the park is quite diverse. Tree cover is almost continuous over the park, only high elevation balds lack an overhead canopy. Common forest communities include cove hardwoods, hemlock, mixed oak, northern hardwood, pine and oak, beech, and spruce-fir. The GSMNP is home to some of the most extensive old growth and virgin forest communities in the east. One of the oldest hemlocks in the park was found to be close to 500 years old.

Visitation to the park was approximately 9 million in 1992, making it one of the most heavily visited parks in the National Park System (NPS 1992). Most visitors stay close to their cars, but many also enjoy day and overnight hiking trips. A 1985 study estimated that, 700,000 visitors engage in day hiking activities each year (Peine and Renfro 1988). Visitors can choose from approximately 930 miles of official park trails, 68% of which are open to horse use. The Civilian Conservation Corps (CCC) between 1933 and 1943 developed many of the trails originally as either roads or trails. Some of the trails follow manways developed as wagon roads by settlers. Some old railroad beds, no longer used for logging purposes, have been converted to trails with relatively even grades.

Chapter 4
Methods

Field Survey Methods

Close to 16 miles of trail in the Great Smoky Mountains National Park (GSMNP) were selected for surveying and sampling of various environmental, design, and managerial attributes. A field survey employing two different approaches was developed and applied to each of the study trails. The study trails were selected by their geographic position on the landscape. Trails can exhibit varied types of degradation according the their landscape position. Table 6 lists each trail, it's predominant alignment position, and the approximate number of miles surveyed. To avoid future problems interpreting the data, all of the trails selected are multiple use trails, including both horse and hiker use. As each trail was surveyed, a hand held GPS unit was carried by the surveyors to map each trail as accurately as possible.

Two types of surveys were used to assess and to catalogue managerial, design, and environmental attributes of each trail. The first type of survey procedure was a problem assessment of both linear and point features. The problem assessment procedures adapted were replicated from the approach developed by Marion (1994) used to assess trail conditions in GSMNP in 1994. A measuring wheel was pushed along the trail to measure distance. Some of the trail attributes (water bars and drainage dips) were point features, recorded by noting the distance from the starting point (usually the trailhead) that the attribute occurred. Other attributes were linear features, recorded by noting the starting and ending points of the feature. Examples of linear features include wet soils, excessive root exposure, or excessive soil erosion. A detailed survey manual describing types of attributes catalogued, and data recording procedures for the problem assessment survey is included in Appendix C.

A systematic point measurement procedure was used to collect pertinent environmental information and to assess tread conditions every 300 feet along the trail. Initially, systematic point sampling was attempted at every 250 feet, after the completion of Beech Gap Trail, it was evident that sample spacing needed to be increased at least to 300 feet to accommodate time constraints. Among the attributes recorded at each point are tread width, trail corridor width, incision, soil type, and soil moisture. This method of sampling yielded a sequence of values for trail condition indicators. A detailed manual used in the systematic point measurement survey is included in Appendix B.

Table 6. Trail alignment and length.

Trail Name	Predominant Topographic Alignment	Segment Length (miles)
Pretty Hollow Gap	midslope	2.7
Palmer Creek	midslope	3.3
Cataloochie Divide	ridgetop	2.9
Caldwell Fork	valley bottom	2.9
Sterling Ridge	midslope	1.5
Beech Gap	midslope	0.8

Data Entry and Analysis Methods

After the field work was completed, several databases were constructed in dBASE III. The systematic point measurement data was entered into a separate database for each trail. Fields were developed for each attribute recorded and a record was created for each sample point. Another database was developed for the problem assessment data. Fields identified the trail, location, and code corresponding to the description of the problem in the field manual. Both data sets were checked for data entry errors by calculating minimum and maximum values and randomly selecting records to check for accuracy. The databases were then exported to SPSS, a statistical package, and to Arc/Info Geographic Information System (GIS) software. A variety of descriptive procedures and frequencies were run in SPSS to characterize environmental attributes and trail conditions for each assessed trail. GIS procedures are described later in a separate section.

Office Methods

Map - Based Trail Design Method

Recreational hiking trails are often initially designed in an office using topographic maps. For this study, procedures from Walbridge and Franklin (1984) were used to reroute the study trails previously surveyed in the GSMNP. The design procedures are described in the literature review and detailed in Appendix D.

Using these procedures an alternate route was developed for each of the study trails. If after calculating the initial slope, the number was less than 0.03 (3%), 0.03 was used for the initial slope calculation. The initial slope of 0.03 (3%) was chosen as the lowest acceptable gradient for a trail to ensure enough gradient for drainage features to be effective. If the initial slope calculation was over 0.10 (10%), 0.07 (7%) was used instead. Limiting the maximum slope keeps the trail's grade within a moderate difficulty range and creates a trail less vulnerable to tread erosion.

Trail Design GIS Methods

A variety of GIS procedures were developed and applied in an effort to explore GIS capabilities in designing recreational hiking trails. These procedures included customizing a user friendly menu interface for trail planners to use with Arc/Info and Cost

- Path analysis described in the following sections.

Trails and roads data were acquired as Arc/Info coverages for the entire park from the GIS office at GSMNP. To make the file sizes more manageable, the files were subset to only include the study area. The digital elevation models (DEMs) were purchased from the USGS in a 30 meter resolution. The DEMs were used to calculate a Triangulated Irregular Network (TIN) with default settings. Each triangular polygon in the TIN has several attributes attached to it: slope, aspect, and elevation. The default setting for the z tolerance used to generate a TIN in Arc/Info is the (zmax - zmin) / 100. The default z tolerance calculated by Arc/Info and used to generate the TIN for this study is 19. A smaller z tolerance would have caused the statistics to be more precise, but the file size would have been cumbersome. Due to the interpolation of values, the z tolerance of 19 may have caused the statistics reported in tables 13 through 15 to be underestimated.

The coverage of trails developed by the GSMNP was then used as a line coverage upon which the surveyed trail attributes could be plotted. The Arc/Info Dynamic Segmentation procedure was used to plot trail attributes along each line representing a specific study trail. Initially, the distance from the starting point of a trail was used as the distance along a line upon which to plot a point with all trail attributes. This proved to be ineffective due to the shortening of the representation of the trail because of unavoidable generalization of the digital line representing a trail. The generalization of the horizontal and vertical curvature of the trail decreased the GIS calculation of distance between two points along that line. Thus, the survey points were plotted further along the line than they were located in reality. To alleviate this problem, the surface length of the line was determined by running the SURFACELENGTH option on Arc/Info, using the TIN developed from the USGS DEM. The computer calculated length of the trails using the SURFACELENGTH option was generally within 15 feet of the length of the trail calculated by the measuring wheel used when survey data was collected.

Each survey point was then replotted on the line representing the trail according to the percent of distance away from the starting point of the line to the known end of the trail. After the survey points were in place, the field data was converted from Dbase III to an ASCII file format. Then, the point coverages info files were altered to accept the associated attributes. Once the Info structure was in place, the ASCII data was easily imported and attached to the appropriate points.

Arc Macro Language (AML) Program Development

A series of AMLs were developed so that trail planners with little to no GIS training could design a trail on the computer screen, and generate statistics to compare various hypothetical trail alignments with each other or with an existing trail. The trail planner is able to specify what percent slopes he/she would like to avoid during trail design and is able to see surrounding data including topography, roads, streams, and existing trails. In addition to viewing the surrounding features, the planner is also able to plot the field survey information. The planner can click on points and lines to view the associated survey attributes of that section of trail.

Once the planner has selected the information he/she wishes to appear on the screen, the planner may then draw a hypothetical trail location on the screen of the computer. The computer then saves this new trail as an individual file. Using this separate file, the planner can then choose to view an elevation profile of that trail and compare it to any other trail alignment. After viewing a profile, the planner can easily generate statistics about the average slope and cumulative slope of the trail. Each of the study trails were rerouted using the AML menus developed. A new trail was designed on the screen of the GIS and evaluated using the AML menus developed. Appendix E lists the AML programs.

Cost Path GIS Analysis

GIS was also used to generate alternate trail alignments through a least cost - path weighted distance algorithm. The least cost - path algorithm uses an acumulative cost grid and a backlink grid to determine the least accumulated cost from one point to another. First, an accumulative cost grid is generated from a grid with values representing slope. Each cell in the accumulative cost grid stores a value, which represents the cost from that cell to travel to a source cell. Each cell in the backlink grid stores a number which represents to direction one would need to travel to get back to the source cell. The source cell is stored in a separate grid and is at one end of a trail. The least - cost weighted distance function uses four separate files to determine the least accumulative cost to get from one point to another.

Through previous research, it is known that trail planners and designers try to avoid locating recreational trail in certain areas. In this analysis, areas within 60 meters of a stream, and with a slope of less than 5% or greater than 70% were given a value of 100 in a separate grid file. This grid file was then added to the accumulative cost grid file. The resulting composite accumulative cost grid was then used to determine the least - cost path between two points representing the beginning and ending of a trail. The addition of high values for obviously inappropriate trail locations deterred the computer from placing the new trail through these areas. This method was employed to automatically generate new trail alignments for each of the study trails.

Comparison of Alternate Methods for Designing Trails

The GIS system was used to statistically compare the alternate routes of a trail designed using the existing trail route, office procedures, cost - path GIS computed trail routes, and the GIS user designed trail routes. All five trail routes start and end at the same point. For each trail, the length, slope, cumulative slope, and profile was generated.

Dr. Mike Aust, an expert in forest road design, was also asked to evaluate the existing study trail designs as shown on 1:24000 USGS topographic maps. His evaluations were based on their design features only. He was asked to rank them numerically from best to worst, 1 being the best and 4 being the worst, and give any subjective or quantitative reasons for his evaluations. The cost for alternate trail route construction was not considered as a factor when comparing alternate trail routes. Higher trail costs do not necessarily indicate a trail design more or less resistant to degradation.

Chapter 5
Materials

Field Survey Materials

Equipment required to complete the field surveys include a clinometer, compass, trowel, water, measuring wheel, tape, procedural manuals, field forms, and pencil. The measuring wheel was used to keep track of the distance between points. A clinometer was used to measure the percent slope and cross slope of the trail. The compass was then used to determine the slope alignment angle by subtracting the azimuth of the trail from the azimuth of the landform. Water and trowel were used to perform the field method of determining soil texture. A measuring tape was used to measure the width of the tread and trail corridor. Both the tape measure and trowel were used to measure the incision of the trail tread. The tape measure, pulled tight, served as a straight line to indicate the approximate original surface of the tread. The trowel, which had inch marks on the back, was then used to measure the distance from the tape measure and the lowest point on the tread.

As the trails were hiked during survey, a Global Positioning System (GPS) was carried in an attempt to obtain a more accurate digital representation of the trail for later use in the GIS. It became evident very quickly that the rugged mountain terrain prevented the hand held GPS receiver unit from communicating with the minimum number of satellites required for effective GPS operation.

Office Materials

USGS 1:24000 topographic maps were used to identify and mark with a pencil the beginning and ending points of each rerouted or newly designed trail. An engineering scale was used to measure distances. A draftsman’s divider was used to step from one contour to another, and a calculator was used to determine percentages.

GIS Materials / Data

The Great Smoky National Park GIS houses digitized coverages of all their trails and roads in an Arc/Info format. A trip was made to the GIS office at GSMNP to retrieve those files for this study. For hydrology information, Digital Line Graphs (DLGs) were downloaded from the USGS (United States Geological Survey) Internet web pages. Elevation data was purchased from the USGS in the form of Digital Elevation Models (DEMs) in a 30 meter resolution format. Secondary source data was used so that the study would closely correspond to a trail planner's budget and time constraints. The cost and time associated with primary data collection at a resolution smaller than available data, would greatly outweigh the benefits of using GIS in trail planning.

Chapter 6
Results

Field Survey Results and Trail Summaries

Six trails were selected for the detailed field survey. Each of the trails from the 1:24000 USGS topographic quadrangles appeared to exhibit a characteristic alignment type (valley bottom, midslope, or ridgetop). Field research revealed that the scale of the topographic quadrangles was not detailed enough to always make accurate distinctions between these three topographic positions. The trails drawn by the USGS are shown on a topographic map in appendix F. The USGS topographic maps are the most accurate representation of the trails. The hand held GPS unit carried by the surveyors was unable to maintain communication with satellites due to the dense vegetation and rugged terrain. Two trails assumed to be predominately valley bottom were in actuality predominantly midslope. This section summarizes three of the study trails. One trail for each topographic alignment: midslope, ridgetop, and valley bottom. A summary of each trail, selected descriptive statistics generated from the systematic point measurement, and problem assessment surveys are provided.

Pretty Hollow Gap

Pretty Hollow Gap appears to be a valley bottom trail on the 1:24000 topographic quadrangle, yet field research quickly revealed that the trail was predominately aligned in a midslope position according to the survey criteria. Trails located over 60 feet vertically above a stream or the bottom of a valley were considered midslope. A distance of 60 feet is sufficient to avoid problems characteristic to valley bottom trail designs (muddy soils, poor drainage with the absence of cross slope). Periodically, the trail alignment switched from midslope to valley bottom, displaying in those areas classic valley bottom tread characteristics. The most common problem for this trail is wet soil, including 37 occurrences and 1244 lineal feet (Table 7).

The systematic point sampling surveys show that the average grade of Pretty Hollow Gap trail is 8 percent (Figure 8). The average slope of the landform the trail is located on is 39 percent (Figure 9). The majority of the trail is aligned at over a 60 percent angle from the general direction of slope of the landform (Figure 10). The trails tread is mostly bare soil and scattered rocks (Figure 11).

Table 7. Pretty Hollow Gap Trail Summary (2.7 mi)

TRAIL ATTRIBUTE	OCCURRENCES		TOTAL LINEAL DISTANCE		
	#	#/mi	ft	ft/mi	%
Soil Erosion: 1 - 1.9 ft.	1	0.4	15	6	0.1
Multiple Tread	1	0.4	37	14	0.3
Excessive Root Exposure	8	2.9	422	156	2.9
Trail Corduroy	1	0.4	33	12	0.2
Excessive Width: >6 ft.	7	2.6	209	77	1.4
Wet Soil	37	13.6	1244	461	8.6
Running Water on Trail	4	1.5	122	45	0.8
Retaining Wall	1	0.4	22	8	0.2
Culvert	1	0.4			
Drainage Dip: Ineffective	8	2.9			
Drainage Dip: Partially Effective	5	1.8			
Drainage Dip: Very Effective	1	0.4			
Water Bar: Ineffective	8	2.9			
Water Bar: Partially Effective	6	2.2			
Water Bar: Very Effective	7	2.6			

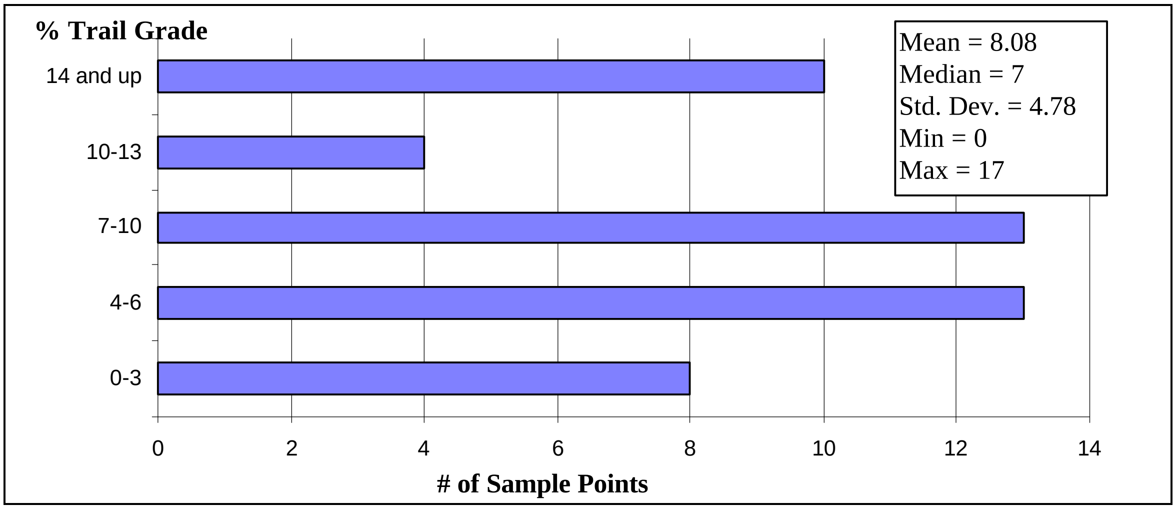

Figure 8. Frequency distribution and descriptive statistics for trail grade in percent.

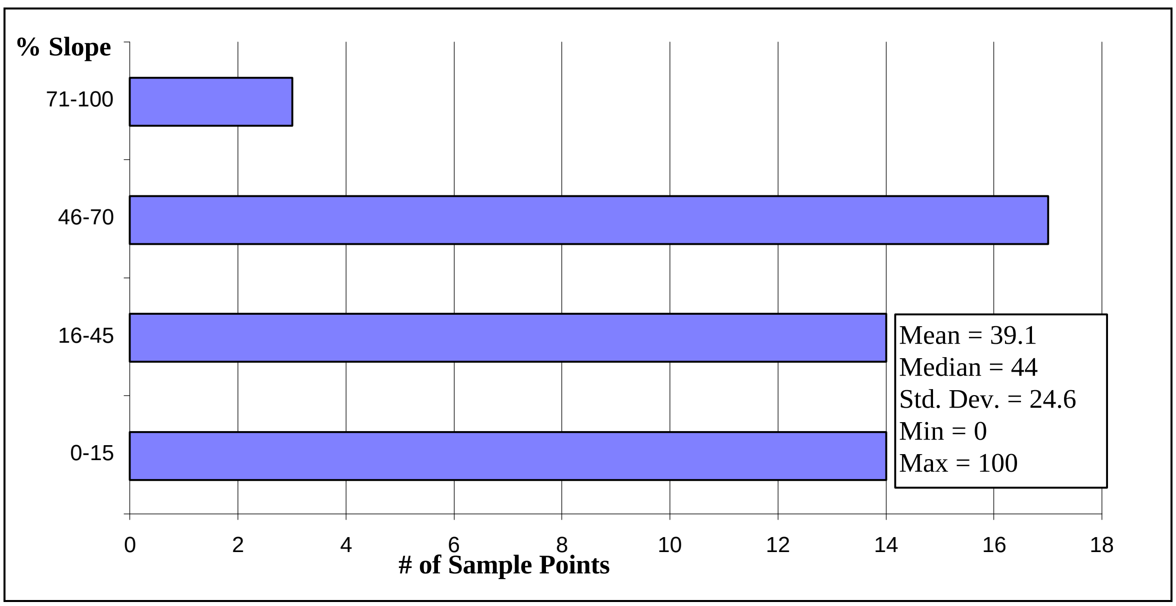

Figure 9. Frequency distribution and descriptive statistics for slope of landform in percent.

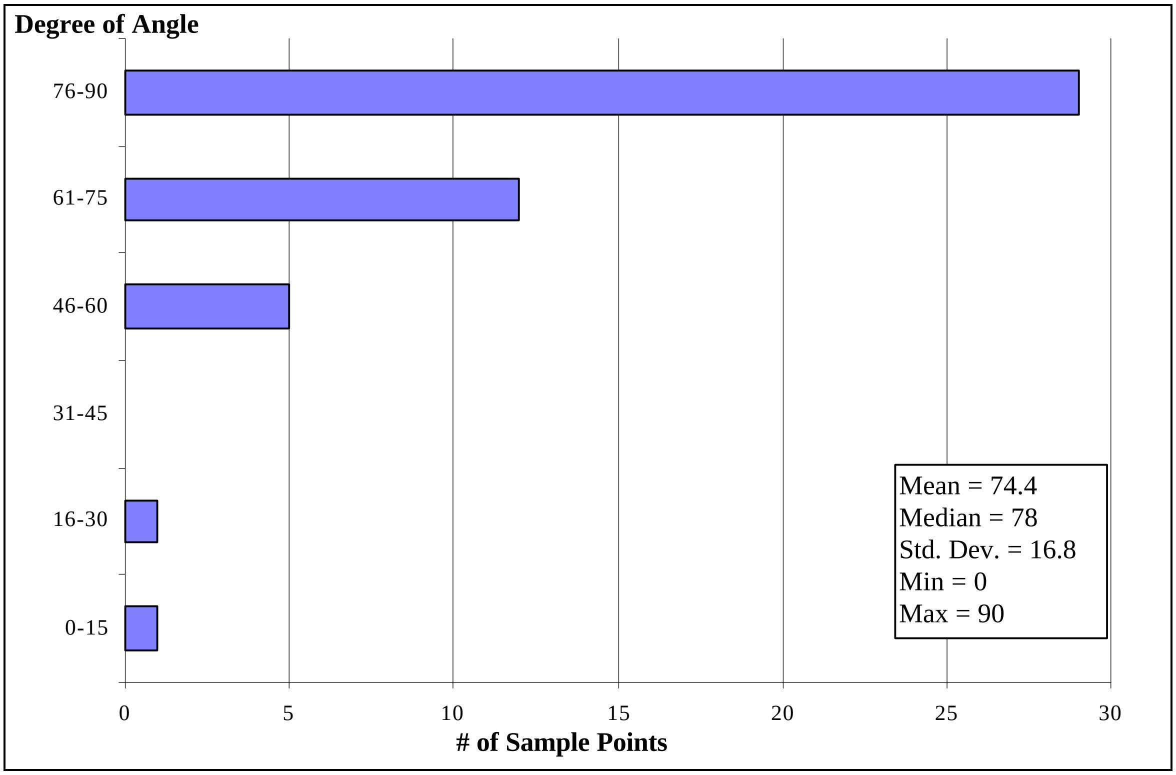

Figure 10. Frequency distribution and descriptive statistics for slope alignment in degrees.

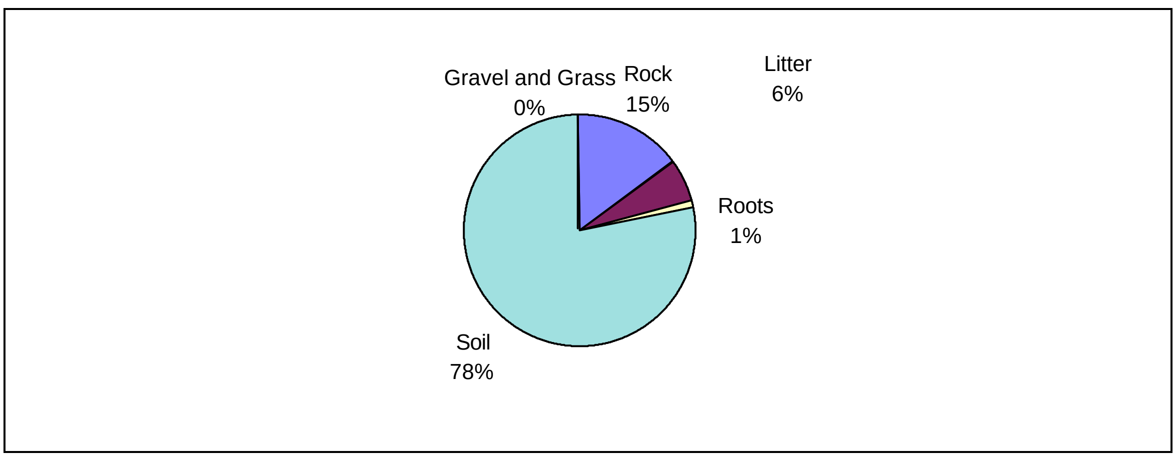

Figure 11. Average percent of trail tread composition.

Cataloochie Divide

The Cataloochie Divide Tail is classified as predominately ridgetop. Wet soil is the most common tread problem surveyed (Table 8). The extensive horse use on this trail, combined with wet soils, creates a distinctive hummocky degradation phenomena in some areas. The repeated step of the horses in the same place creates a ripple in the tread. As the troughs in the ripple deepen, the horses became unable to step on the crests. Any attempt of the horse to step on the crests results in the hoof sliding down into the trough, furthering the degradation.

The systematic point sampling survey shows that the average grade of the trail is 10.4 percent (Figure 12). The average slope of the landform is approximately 18 percent (Figure 13). The median alignment of the trail to the general direction of the landform's slope is 0 degrees (Figure 14). Most of the trails tread is bare soil with scattered patches of grass (Figure 15).

Table 8. Cataloochie Divide Trail Summary (2.9 mi.).

TRAIL ATTRIBUTE	OCCURRENCES		TOTAL LINEAL DISTANCE		
	#	#/mi	ft	ft/mi	%
Soil Erosion: 1 - 1.9 ft.	2	0.7	48	17	0.3
Multiple Tread	6	2.0	169	58	1.1
Excessive Root Exposure	4	1.4	200	69	1.3
Excessive Width: >6 ft.	3	1.0	111	38	0.7
Wet Soil	41	13.9	3022	104	19.5
Drainage Dip: Ineffective	6	2.0			
Drainage Dip: Partially Effective	9	3.0			
Drainage Dip: Very Effective	5	1.7			
Water Bar: Ineffective	11	3.7			
Water Bar: Partially Effective	17	5.8			
Water Bar: Very Effective	24	8.1			

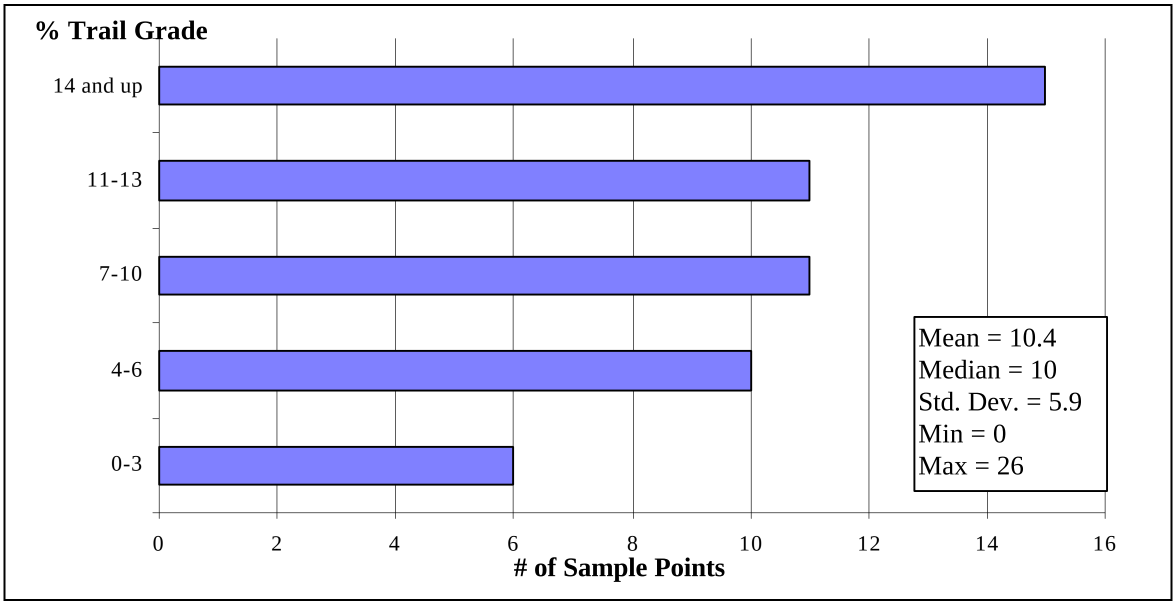

Figure 12. Frequency distribution and descriptive statistics for trail grade in percent.

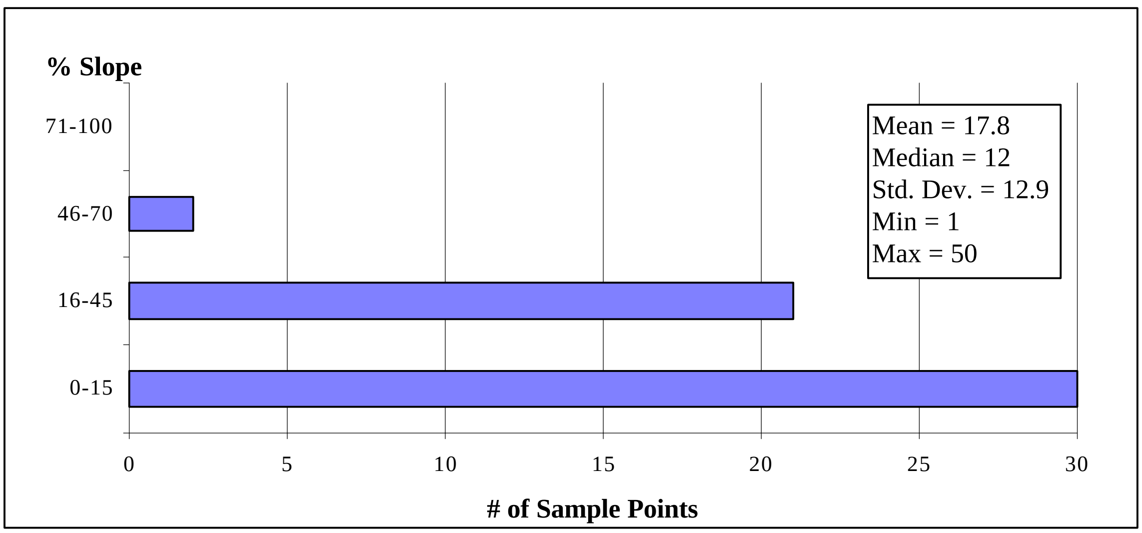

Figure 13. Frequency distribution and descriptive statistics for slope of landform in percent.

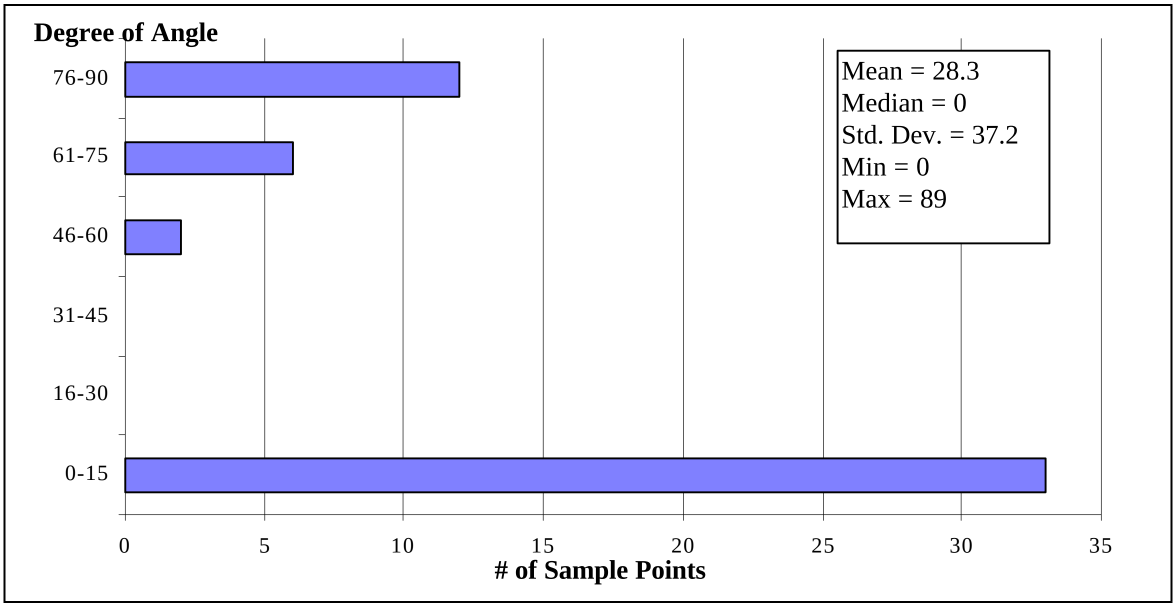

Figure 14. Frequency distribution and descriptive statistics for slope alignment in degrees.

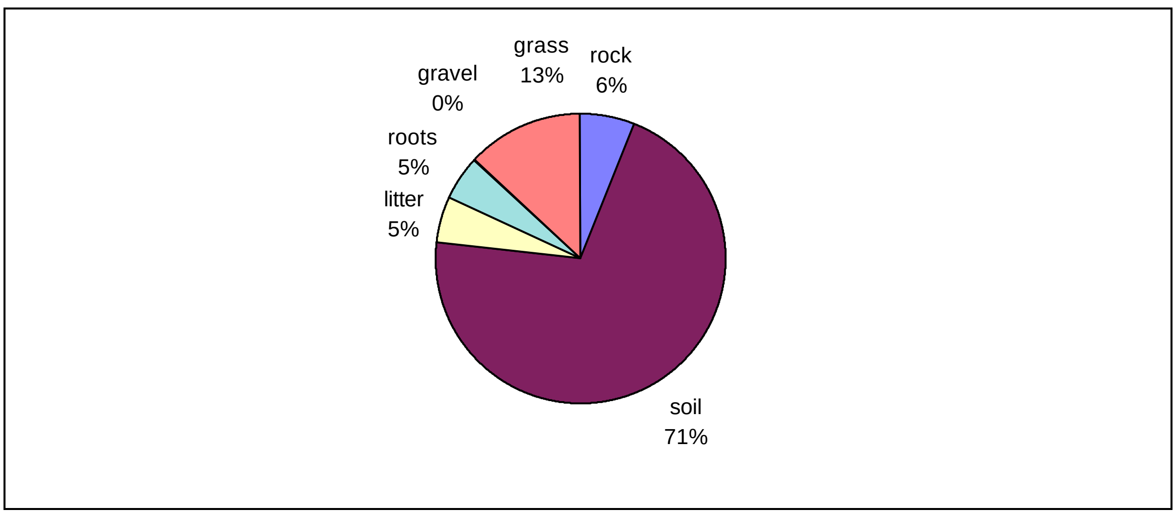

Figure 15. Average percent of trail tread composition.

Caldwell Fork

The Caldwell Fork Trail is predominately located in a valley bottom displaying many of the classic problems associated with this type of alignment. Close to ½ of a mile of tread has wet soil and 1/10 of a mile is excessively wide (Table 9). The trail crosses a stream several times. At stream crossings, horses are routed through the stream while hikers are provided a split log bridge to cross. At stream crossings, the horse use combined with very wet soils on the stream banks creates muddy, wide entrances to the stream.

The systematic point measurement survey revealed that the median grade of the trail is very low at 3 percent (Figure 16) and the slope of the landform median is also 3 percent (Figure 17). The histogram showing the frequency distribution of slope alignment angle shows a large majority of the trail tread aligned parallel to the slope of the land (Figure 18). Most of the trails tread is composed of bare soil (Figure 19). For a detailed description of each trail attribute recorded, refer to Appendixes B and C.

Table 9. Caldwell Fork Problem Assessment Trail Summary (2.9 mi.)

TRAIL ATTRIBUTE	OCCURRENCES		TOTAL LINEAL DISTANCE		
	#	#/mi	ft	ft/mi	%
Soil Erosion: 1 - 1.9 ft.	1	0.3	28	10	0.2
Soil Erosion: 2 - 2.9 ft.	2	0.7	178	61	1.1
Multiple Tread	1	0.3	89	31	0.6
Excessive Root Exposure	2	0.7	40	14	0.3
Excessive Width: >6 ft.	11	3.7	564	194	3.6
Wet Soil	38	12.9	2419	834	15.6
Running Water on Trail	2	0.7	80	28	0.5
Drainage Dip: Partially Effective	4	1.4			
Drainage Dip: Very Effective	4	1.4			
Water Bar: Very Effective	5	1.7			

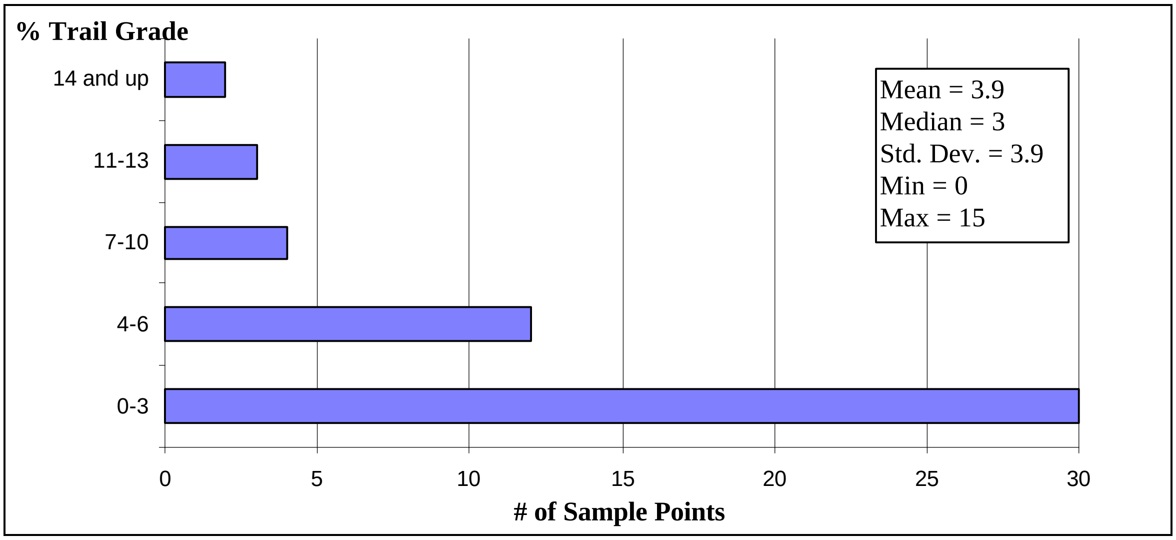

Figure 16. Frequency distribution and descriptive statistics for trail grade in percent.

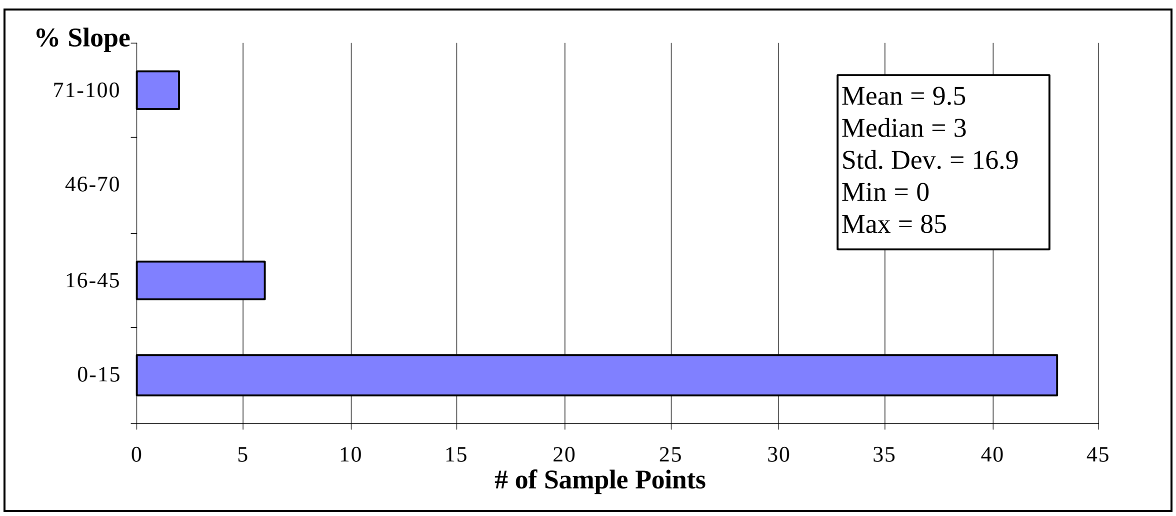

Figure 17. Frequency distribution and descriptive statistics for slope of landform in percent.

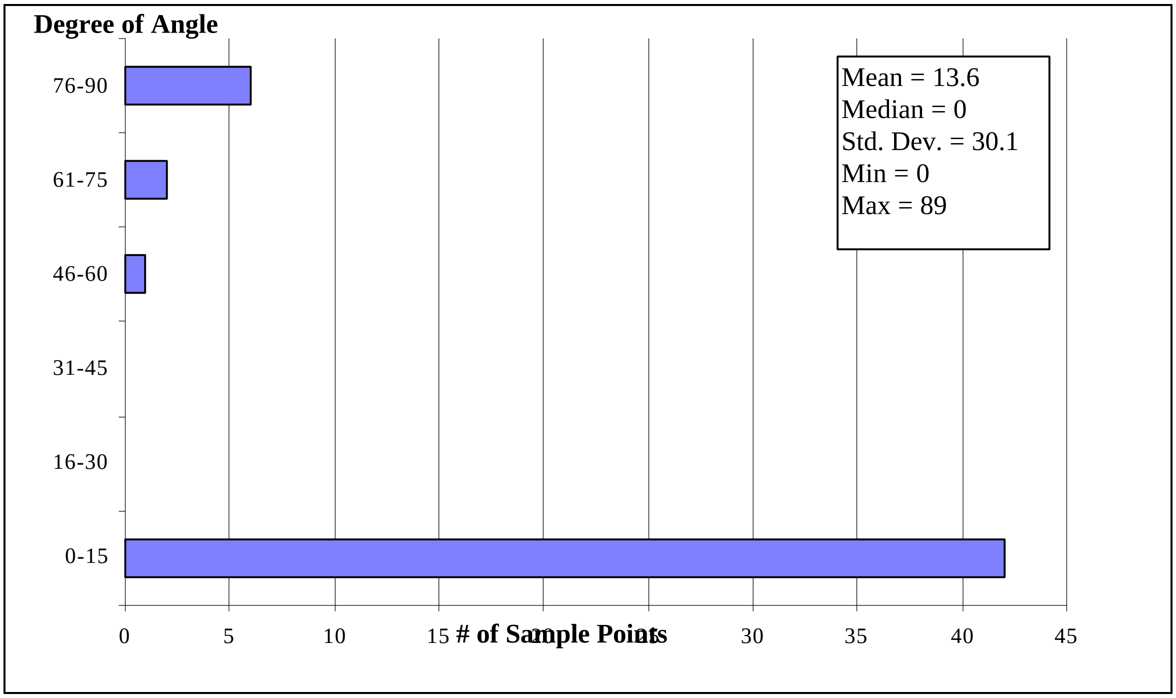

Figure 18. Frequency distribution and descriptive statistics for slope alignment angle in degrees.

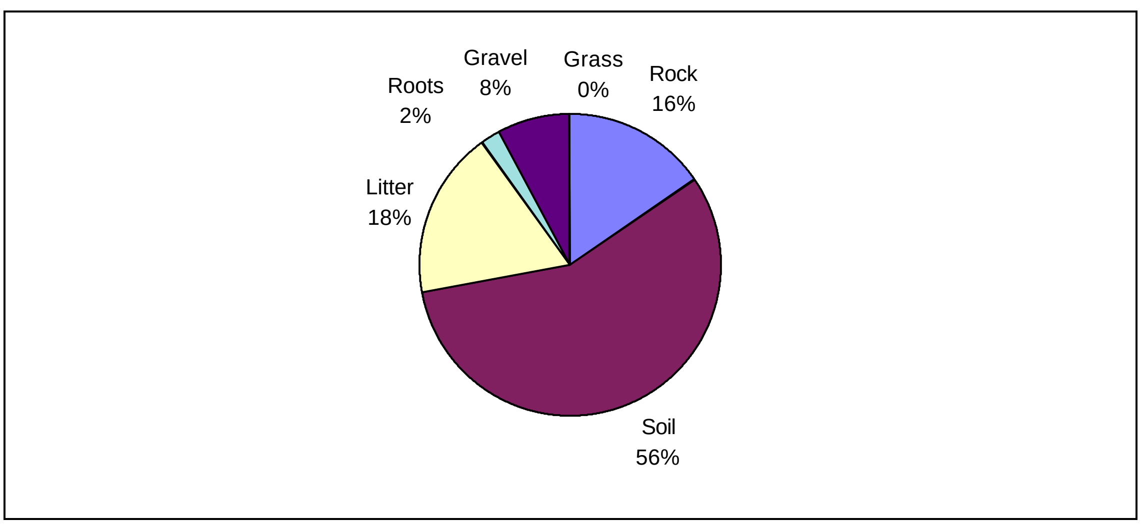

Figure 19. Average percent of trail tread composition.

Office Design Results

Each trail was rerouted using the office design methods previously discussed. The Pretty Hollow Gap and Palmer Creek trails were routed further up the slope from the wet creek valley bottoms where the original trails were located. The Cataloochie Divide trail was routed off the ridge top where the existing trail is located. The Caldwell Fork Trail's original approximate slope was ~ 2%. This trail was rerouted to at least 5%, making it more probable that future maintenance features, such as water bars and drainage dips will be effective. The Sterling Ridge Trail was only slightly altered from its original alignment. The Beech Gap Trail's original tread was excessively steep, > 15% for the majority of the trail. Its alignment was significantly altered in an effort to create a more moderately graded trail tread.

Office Evaluation Results

Dr. Mike Aust, an expert in forest road construction, evaluated each existing trail and potential trail route trail according to design characteristics. Evaluations were based mostly on the grade of the trail and its topographic alignment. His numerical rankings of each trail from 1 to 4, 1 being the best design, are shown in tables 10 - 12. Reasons for each trails rank are included in the table. Maps of each trail and reroute are included in appendices F - H.

Table 10. Office Evaluation Results for Pretty Hollow Gap.

Trail Design	Rank	Reason
Existing trail	3	The trail grade is excessive, the alignment follows and crosses a drainage system which will cause problems for erosion and wet soils.
Office design	1	The trail is located out of the drainage system, the grade is accpetable, but the trail is longer due to excessive curves in cover areas.
GIS User - assisted	2	There is a slight improvement over the existing trail, there will be fewer problems with wet soils. The grade is excessive in some areas.
GIS cost - path analysis design	4	Poor ridgetop location, grades exceed 60%, the trail would be steep and poorly drained.

Table 11. Office Evaluation Results For Cataloochie Divide Trail.

Trail Design	Rank	Reason
Existing trail	3	Ridgetop location will tend to make it wet. There is excessive grade in a few locations.
Office design	1	Location and grade is improved. The length is increased especially for coves and nose slopes (curves).
GIS user - assisted	2	Location and grade is improved, but it is longer than the office design.
GIS cost - path analysis design	4	Longer than the existing trail, but the location is not improved. There is an increase in ridgetop location which will cause more problems with wet soil.

Table 12. Office Evaluation Results for Caldwell Fork Trail.

Trail Design	Rank	Reason
Existing	3	The grade is good, but the location in drainage system and frequent stream crossings may make the trail wet.
Office design	1	The grade and location is good, but the length is excessive in cove areas.
GIS user - assisted	2	The location is better than the existing trail, but there are some areas where trail grade is excessive.
GIS cost - path analysis design	4	The grade is excessive, location is on steep sideslopes, and the ridgetop location will cause wet soils.

In five out of the six trails that Dr. Aust was asked to evaluate, he identified the same trail problems that the field surveys revealed. For Palmer Creek Trail the field surveys revealed that the main problem was running water on the trails tread. Dr. Aust predicted drainage problems in flat areas. Dr. Aust stated that there may be wet soils on the Cataloochie Divide Trail due to a ridgetop design, field surveys revealed the main problem to be wet soils. Dr. Aust's examination of the Caldwell Fork Trail predicted wet soils in drainage draws. Drainage draws are where many of the stream crossings are located. The field survey identifies wet soils as the most prevalent problem on this trail, especially at stream crossings. Dr. Aust stated that grade was a problem for both Sterling Ridge Trail, and Beech Gap Trail. Field Surveys identify borderline excessive grade for Sterling Ridge Trail and an excessive grade for over 50% of Beech Gap Trail.

GIS Design Results

GIS User Assisted Design

Trail reroutes developed using the AML program created trails with a rougher profile than the original trail designs. The cumulative slope for the reroutes were, in each instance, higher than the cumulative slope of the existing trails.

Cost - Path Analysis Design

Each trail the computer rerouted using the Cost - Path Analysis Design placed the new trail alignment parallel to the slope of the landform. The slope alignment angle of the cost - path analysis designs in most sections of the trail is low. All computer designed reroutes were located on ridgetops. The midslope and valley bottom trails were realigned to the nearest ridgetop. The new trail alignments were characteristic of the alignment displayed previously in Figure 4.

Comparison of Alternate Methods for Designing Trails

The GIS was used to generate statistics for the existing trails and the potential or rerouted trails designed by each of the three methods, office, GIS user assisted, and GIS cost path analysis. Tables 13 through 15 give the length, surface length, and cumulative change in grade for each trail. The length indicates the length of the line representing a trail, from beginning to end, in two dimensions on the computer screen. The surface length of the line is that same line's length in three dimensions. The surface length is a more accurate representation of the length of a trail. The surface length accounts for the changes in elevation of a trail. The change in elevation for every ten meters of trail is summed for the cumulative change in trail grade.

Table 13. GIS evaluation results, Pretty Hollow Gap.

Design Method	Length (m)	Surface Length (m)	Cumulative Grade (m)
Existing Trail	6,452	6,567	1,042
Office Designed Trail	10,974	11,213	1,969
GIS User Assisted	8,249	8,516	1,811
GIS Cost - Path Analysis	6,343	6,503	1,284

Table 14. GIS evaluation results, Caldwell Fork Trail.

Design Method	Length (m)	Surface Length (m)	Cumulative Grade (m)
Existing Trail	4,743	4,887	597
Office Designed Trail	6,007	6,079	777
GIS User Assisted	4,678	4,737	639
GIS Cost - Path Analysis	4,879	4,993	811

Table 15. GIS evaluation results, Cataloochie Divide Trail.

Design Method	Length (m)	Surface Length (m)	Cumulative Grade (m)
Existing Trail	9,304	9,431	1,347
Office Designed Trail	9,596	9,685	1,133
GIS User Assisted	10,070	10,164	1,179
GIS Cost - Path Analysis	9,277	9,426	1,443

Discussion

Field Survey Procedures

The field surveys of existing trails provided two types of information. The systematic point measurement surveys provided general data about surrounding environmental features and trail tread characteristics. The problem assessment survey yielded information on number and effectiveness of trail maintenance features. The problem assessment survey also provided specific locations of problem areas on the trail tread. This data was useful in characterizing the general condition of each study trail. Statistics generated from the survey data is later used to compare with statistics generated from potential new trail alignments developed using the various methods of trail design previously discussed.

Further research using the survey data was performed by Leung et al. (1997). Leung et al. found that the point measurement "effectively characterizes mean trail conditions, but may miss trail problems that lie between sample points. ... The problem assessment method yields more complete data on the number, extensiveness, and location of trail impact problems." In assessing existing trails, trail managers can refer to this work when choosing the appropriate sampling method for field data collection. The type and detail of data they wish to collect will determine which sampling method will be most effective.

In general, field surveys gave more detailed information about an existing trail's condition than either office or GIS examination. Inputting the field survey data into the GIS system made the data much easier to visualize. Using dynamic segmentation to place survey points along the line representing a trail in the GIS added a useful spatial aspect to the field data by revealing the approximate geographic coordinates of each survey point.

Further opportunities for research lie in statistically examining the correlation between various environmental attributes and the occurrence of trail degradation.

Office Design and Evaluation

The office design method was quick, the materials were inexpensive, and the new tread locations were never above or below acceptable trail grades. Due to the numerous occurrences of existing trails exceeding acceptable trail grades, it did not appear that they were originally constructed using this method.

GIS Design and Analysis

A previous study done by Lu et al, (1994) approached the application of GIS to trail siting and design by using the computer to generate, ranked polygons of suitable areas, then trail alignments between points of interest. Although insightful, this study failed to address two key concerns in trail planning. One is that the computer fails to determine the difference between the grade of the trail and the slope of the land. Without an existing trail or line feature crossing a TIN or group of pixels, the computer can only compute the slope of the land. Many trails are located on side slopes, the grade of a trail may only be 5 %, but it could be located on a hillside whose slope is 30 %. When constructing a trail, the grade of the trail should not exceed 15% for extended distances, but the sideslope of the hill can be up to 45 %. The second consideration that Lu et al, (1994) failed to address is the location of the trail on the landform. The literature review revealed that valley bottom and ridgetop trails are likely to have problem areas due to the difficulty of draining water off the trail treads.

GIS analysis for this thesis showed that computer designed trails using a cost - path and cost distance analysis resulted in trails routed inappropriately in ridgetop positions. The ridgetop alignment resulted from the low pixel values representing slopes on the tops of well rounded Appalachian Mountains. To address the limitations of GIS generated trail alignments, this research approaches the use of GIS from a different angle. The trail planner draws the potential trail on the screen of the computer. Once the planner draws the trail, the capabilities of GIS are used to generate statistics about that trail and any existing or hypothetical trails the planner wishes to compare with the new trail. This incorporates the essential human element of design with computer generated statistics.

There were several limitations to the user assisted GIS trail design. One limitation of the Arc/Info GIS programs capabilities is the system will not allow the user to set the scale of a profile. Therefore, it is unlikely that two trails will be viewed at the same scale, limiting the amount of knowledge gained from this exercise. Another limitation to GIS user design is the resolution of the data. The secondary data acquired from the USGS was too coarse to provide the detail needed to completely design a trail with the computer. However, it can be used to identify various prospective trail alignments, which can then be examined more carefully with field reconnaisence. Thus while, the GIS may be effective in evaluating numerous potential trail corridors, it does not replace the final alignment of a trail in the field.

Alternate Solutions

As technology improves, and trail designers and planners can input desirable design characteristics into the algorithm, future cost - path analysis may become more effective. The IDRISI GIS program incorporates an additional file for the computer to adjust cost values according to direction of travel across a slope. Downhill travel will accumulate less cost than uphill travel. Further research of this new algorithm may end in improved cost - path analysis design results.

The new ArcView version 3.0a has a user friendly interface that will allow trail designers with limited GIS knowledge to determine the length of a line segment while drawing on the computer screen. This combined with the new scanned Digital Raster Graphic topographic maps will simulate the office design procedures and incorporate the data management advantages of GIS. If a Digital Elevation Model is purchased from the USGS, the ArcView program also allows users to generate a profile of the newly designed trail and manipulate the vertical exaggeration of the profile. The ability to maintain profile scale and vertical exaggeration allows quick, effective comparison of alternate trail routes.

Chapter 7
Conclusion

This study sought to evaluate four different methods or approaches to trail siting and design. Each method was implemented to the fullest extent of its capabilities. The methods were then compared through office evaluation and GIS statistical evaluation. Evaluations revealed some benefits and limitations of each approach.

Field reconnaissance and field surveys of the existing trail yielded a detailed inventory of existing trail conditions. After the inventory had been entered into a database, statistical analysis made the information much more useful. The collection of field data took two people approximately one week to collect. This was time consuming, but the equipment is not expensive. The data was then used as a comparison for hypothetical trail routes generated by other design methods.

An expert forest road designer, Dr. Aust, was able to evaluate the same trails at a scale of 1:24,000 on a topographic map and predict dominant trail tread problems and conditions. When compared to the field data collected, the office evaluation by Dr. Aust gave an accurate description of the overall condition of a trail in a very small amount of time at very little cost. The office method of designing a trail cost less, was less time consuming, and yielded better alignments that any other design method. Overall, the office method of evaluation and design was most efficient.

The GIS was useful in managing the data collected in the field, but yielded limited information in evaluating trail conditions. Custom programming provided a user friendly interface for a trail planner, but did not provide the planner enough on - screen data to enable him/her to effectively design trails. At best, a very general trail corridor could be outlined with the GIS, but follow - up office design and field reconnaissance would be essential. The cost - path analysis GIS design of trails yielded highly inappropriate trail alignments. It is expected that special programming could overcome these limitations or that future improvements and options in GIS software may allow improved GIS based trails routing. Use of the GIS system for trail design was both expensive and time consuming. The strengths of the GIS system at this time lie in its ability to handle large amounts of spatial data. The most efficient use of the GIS system for this study was data management.

During field reconnaissance a global positioning system (GPS) was taken into the field to record coordinates locating survey points and to map a more precise alignment of the existing trail. The rugged terrain of the Great Smoky Mountains prevented the receiver from maintaining satellite communications making it virtually useless. In the future As GPS technology improves and the number of satellites increases, this may change.

The methods of trail design revealed that designing a trail in the office using topographic maps yielded the best potential new trail routes. The GIS user - assisted design methods were less effective. The GIS cost - path analysis design of trails was ineffective due to the routing of trails in ridgetop alignments. Further research opportunities exist in evaluating GIS as a recreational trail management tool. Overall, the office methods of trail siting and design proved to be significantly less expensive, less time consuming, and yielded the best potential new trail routes. At this time, GIS may serve recreational trail design and management best as a data management tool.

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Appendix A
Glossary of Terms

Cross Slope - the slope of the tread of a trail perpendicular to the trail itself. This can also be termed side slope, cut slope, and fill slope.

Cumulative Slope - The amount of change in slope along a trail and added to any previous change in slope.

Grade-refers to the slope of the trail itself or for a given segment of trail. The grade of a trail can be calculated by finding the (maximum elevation-minimum elevation) / distance.

Resistance-refers to the ability of vegetation to resist the initial impact of trampling.

Resilience-refers to the ability of vegetation to regenerate over time after damage by trampling.

Sideslope-the slope of the terrain perpendicular to a trail.

Sidehill design-aligning a trail along the side of a hill, perpendicular to the slope of the hill.

Slope-refers to the slope of a hillside or landform. Often the terms slope and sideslope, and grade are used interchangeably.

Switchback-the change of direction in a sidehill design trail, usually in an attempt to gain elevation.

Tolerance-refers to the ability of vegetation to withstand repeated cycles of trampling.

Slope alignment angle - The angle between the direction of a landform's slope and the direction of a trail. In geologic terms, the angle between the direction of dip and direction of the trail.

Trail Erosion-refers specifically to assessments of tread incision and soil loss. (Leung et al in press)

Trail Degradation-focus on the effects of trail use on the tread surface. (Leung et al in press)

Trail Deterioration-includes trail impacts and proliferation and vegetation assessments. (Leung et al in press)

Trail Impact-general term comprising all physical, ecological, and aesthetic impacts resulting from the construction and use of trails including elements related to the depreciative behavior of visitors. (Leung et al in press)

Tread-refers specifically to the trail's surface.

Appendix B
Trail Location and Design
Systematic Point Measurement Survey Procedures

A survey crew of two people will collect data at a sampling interval of 250 feet starting at the beginning of a study trail segment. The crew will hike the trail with a measuring wheel to ensure a 250 foot interval between points. To accurately map each trail and the data collected at the sample points, a GPS unit will be carried along the trail during the survey and coordinates will be manually recorded in the field chart for each sample point. Below is a list of equipment that will be used in the field to collect and record data.

Equipment List

USGS topographic maps
Data from previous 1993 survey
Measuring wheel
GPS receiver
Several batteries for the GPS   Notebook computer
Tape measure
Clinometer
Compass
Survey procedures manual
Clipboard
Pencils
Field form (some on waterproof paper)

Systematic Point Measurement Survey Form Procedures

1) **Trail Code:** Record the trail segment code from the attached trail listing sheets.

2) **Trail Name:** Record the trail segment name from the trail listing sheets and trail name from park map if different.

3) **Page Number:** In the space provided record consecutive page numbers for the trail segment beginning with page 1 for each new trail segment.

4) **TG - Trail Grade:** Two field staff will position themselves about 10 feet from the sampling point in opposite directions along the trail. A clinometer will be used to determine the grade (% slope) by siting a spot on the opposite person at the same height as the first person's eyes. Record the measurement in the TG column of the field form.

5) **LS - Landform Slope:** Use the same procedure for trail grade, but position each person about 10 feet from the sampling point along the prevailing landform slope. If there is no cross-slope, position the two people perpendicular to the trail. Record this measurement in the LS column of the field form.

6) **TA - Trail alignment angle:** Using a compass, shoot an azimuth straight along the trail pointing in the direction that you are traveling. If the trail is very curvy, aim for the nearest vanishing point along the trail. After this is completed, shoot another azimuth directly up the slope of the prevailing land form. Record these two compass bearings in the trail and landform spaces under TA.

7) **SM - Soil Moisture:** In an adjacent, undisturbed, off - trail area, remove enough of the litter from the soil to determine the typical soil wetness if necessary. Also, take into account current landform position, aspect, and overstory type and density. Use the following codes to record your description:

D - dry **M** - moist **W** - wet **S** - saturated

8) **TP - Trail Position:** Use the descriptions below to determine the trail position of the sampling point. Record the corresponding letter code in the TP column.

V - valley bottom: The trail is within 60 feet (3 1:24000 topographic lines) vertically from the lowest area in the closest valley bottom.

M - midslope: The trail is located at least 60 feet above the closest valley bottom and 60 feet below the crest of the closest ridge or mountain.

R - ridge top: The trail is located within 60 feet of the crest of a ridge or mountain.

9) **OB - Off Trail Obstructions:** Within 50 feet of the sampling point along the trail, observe any off-trail obstructions that may deter hikers from leaving the trail tread. Examples may be dense or thorny vegetation, steep slopes, excessive rockiness, or wet soils. Use the following categories and ratings and record the corresponding code in the OBST column of the field form:

1 - high expansion potential: few obstructions present to deter hikers from leaving the trail tread.

2 - Moderate expansion potential: trailside terrain is moderately unsuitable for off-trail travel due to steep slope, rockiness, dense vegetation and/or poor drainage.

3 - Poor expansion potential: trailside terrain is completely unsuitable for off-trail travel.

10) **ST - Tread Soil Texture:** Follow the field method described by Foth (1990) to determine the soil texture of the trail tread. Record the number code corresponding to the soil texture identified.

a) Moisten a sample of soil the size of a golf ball but don't get it very wet. Work it until it is uniformly moist; then squeeze it out between the thumb and forefinger to try to form a ribbon.

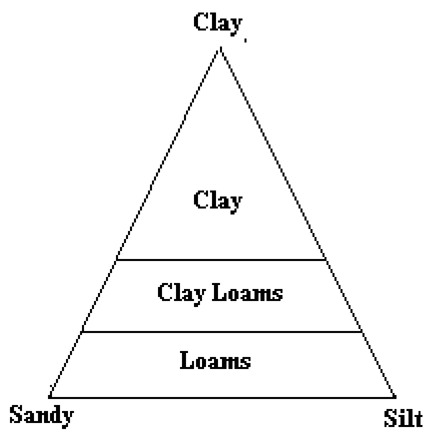
b) First Decision: If the moist soil is:

* 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.

c) The second decision: Add an adjective to refine the description.

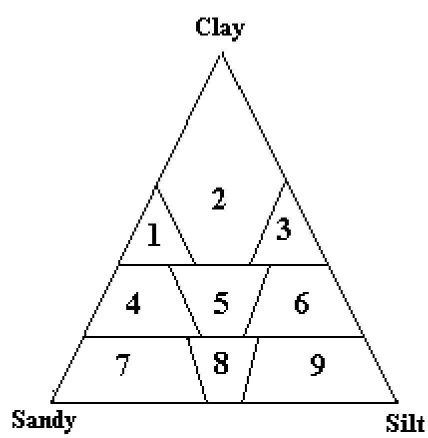
If the soil feels:

* Very smooth, it is silt or silty.
* Somewhat gritty, use no adjective.
* Very, very gritty, it is sandy.



* Use the following codes to record the proper 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



11) **FOR - Forest Type:** Use the classification codes described by Bratton (1979) adapted from Whittaker (1956).

FS - Forest Succession: Enter the succession code under the FS section of the FOR column and the type under the FT column. Use the following classification system:

FS - Successional codes

V - Virgin **M** - Mature **S** - Second growth **E** - Early successional (usually after farming or fire)

FT - Forest type codes

1. Spruce-fir (yellow birch)

1RF - Red spruce-Fraser fir (yellow birch)

1RFH - Red spruce-Fraser fir-Hardwood or hemlock

1YB - Yellow birch (mature)

1HB - Heath bald (rhododendron or mountain laurel)

2. Northern hardwoods

2B - Beech (gray beech gap)

2M - Mixed northern hardwoods (sugar maple, beech, yellow birch, buckeye, serviceberry)

2S - Successional northern hardwoods (yellow birch, fire cherry, red maple)

3. Mesic types

3MCH - Mixed cove hardwoods (tulip tree, silverbell, buckeye, basswood, beech, sugar maple, white ash, birches, oak, magnolia)

3HH - Hemlock-hardwood cove (same species as 3-1 with hemlock codominant)

3MH - Mesic hardwood flats (tulip tree, sweet gum, sycamore, birch, walnut)

3SC - Successional cove (tulip tree, silverbell, red maple, fore cherry)

3MSH - Mixed submesic hardwoods (silverbell, black gum, magnolia, tulip tree, predominance of oak)

3T - Tulip tree (dominated by small tulip trees with successional associates)

3H - Hemlock cove

4. Xeric types

4MS - Mixed subxeric hardwoods (red, oak, hickories, black locust, and some more mesic associates)

4MO - Mixed oak (chestnut oak, red oak, black oak, white oak, sourwood, black gum)

4WO - White oak

4MOP - Mixed oak-pine (including red maple-pine, and sourwood-pine, etc)

4MP - Mixed pines (Virginia, pitch, Table Mountain)

4WP - White pine

5. Balds, burn scars, pastures

5GB - Grassy bald

5 BS - Burn scar (no canopy)

5P - Pastures, old fields, and artificial clearings

5ESS - Early successional shrubs (fire cherry, serviceberry, hawthorn, blueberry)

5ESH - Early successional heath (mostly erecads)

12) **VC - Vegetation Cover:** Assess the percentage of grassy/herb/shrub type of ground cover in adjacent undisturbed areas. record the appropriate code for each vegetation type, follow the categories listed below. Each category code will be entered into the appropriate section of the GC column on the field chart. H - herb cover, G - grass cover, and S - shrub cover: **1**) 0 - 5% **2**) 6 - 25% **3**) 26 - 50% **4**) 51 - 75% **5**) 76 - 95% **6**) 96 - 100%

13) **USE - Frequency of Use:** Estimate the frequency of use at each sampling point along the trail. Record the appropriate code from the classification system adapted from Bratton (1978) in the USE column of the field form.

VH - Very High, more than one group almost every day throughout the season.
H - High, the site receives almost continual use through the season.
M - Side us regularly used, but rarely supports large numbers of people.
L - Lightly used, site largely used on weekends, groups tend to be small.
R - Rarely used, groups tend to be small
MH - Site is moderately visited, but groups tend to be large.

14) **COND - Tread Condition Characteristics:** Assess the tread condition at each sampling point. Identify the boundaries of the trail corridor by pronounced disturbances in vegetation cover, composition, or organic litter. Imagine a line transect perpendicular to the trail tread which connects these boundaries and the sampling point. Along this transect estimate to the nearest 10% (5% if necessary) the lineal distance occupied by any of the following tread surface categories. Be sure that your estimates sum to 100%.

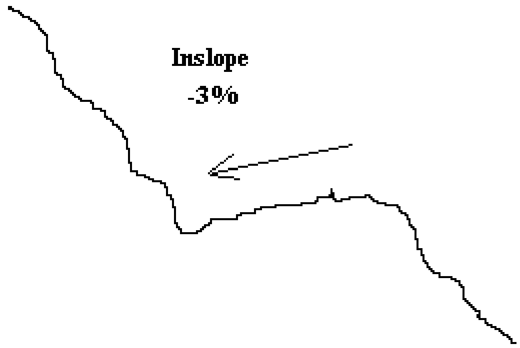
Bedrock	**R**ock	**G**ravel	**S**oil	**W**et/Muddy Soil
Standing Water	**R**unning Water	**R**oots		**V**egetation Cover
Other (explain)				

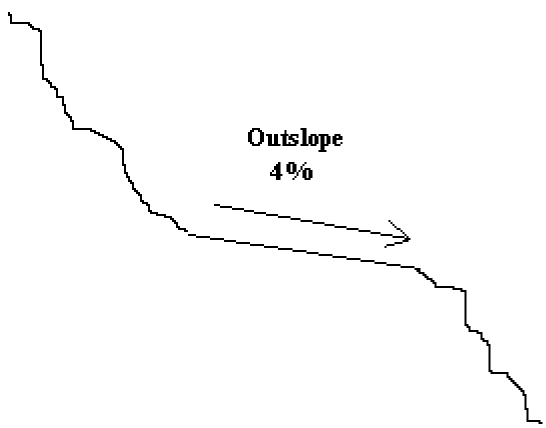
15) **TCW - Trail Corridor Width:** vegetation disturbance: measure and record the total trail corridor width based on the boundaries identified above.

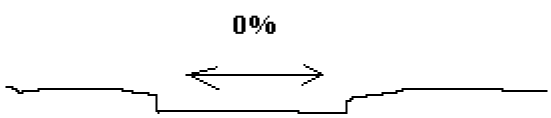
16) **WID - Trail Tread Width:** measure and record the width of bare soil.

17) **INC - Incision:** measure the maximum incision from the estimated original post-construction tread surface.

18) **OUT - % Outslope:** Measure the % outslope of the tread. If there is none, record a 0%, if there is an inslope, record the measurement as a negative, if there is a berm, record an "na" for not applicable. Following are shown several typical situations to look for.







19) **Photographs:** Take several photographs to characterize each distinct portion of each trail segment based on changes in trail position or condition. The photos are to be in vertical format with a closer view of the trail in the bottom foreground and more distant view of the corridor. Additional photographs may be taken of good and poorly designed trail segments or good and bad trail conditions.

Appendix C
Trail Location and Design

Problem Assessment Survey Procedures

A survey crew of two people will collect information about resource impacts along the survey trails using standardized methods developed by Dr. Jeffrey L. Marion, Research Scientist/Unit Leader of the Virginia Tech Cooperative Park Studies Unit. The crew will record the beginning and ending distance of any evidence of trail degradation and the distance from the beginning of the trail to any evidence of design, construction, or maintenance features. Below is a list of equipment that will be used in the field to collect and record data.

Equipment List

USGS topographic maps
Data from previous 1993 survey
Measuring wheel
GPS receiver
Several batteries for the GPS   Notebook computer
Tape measure
Clinometer
Compass
Survey procedures manual
Clipboard
Pencils
Field form (some on waterproof paper)

Problem Assessment Survey Form Procedures

1) **Trail Code**: Record the trail segment code..

2) **Trail Name**: Record the trail segment from the trail listing sheets.

3) **Page Number**: In the space provided record consecutive page numbers for the trail segment beginning with page 1 for each new trail segment.

All other parameters are recorded in the tabular section of the form. For each parameter record the capitalized 2 or 3 letter code in the Code column of the Trail Survey Form. In the Dist1 (Distance 1) column record the cumulative trail distance (nearest 1 foot) from the measuring wheel. Parameters which start with a "B" require "beginning" and "ending" distances; for these you will record the beginning distance under Dist1 and the ending distance under Dist2 (ending distance). Finally, some parameters require you to write additional comments. These should be brief, yet concise and complete. If comments require additional lines leave the first three columns blank. Each code, associated distance(s) and comment(s) must be an independent entry.

Whenever you record a code starting with the letter "B", record a dash adjacent to the code in the left margin. These will serve as a visual aid to remind you to be looking for the "end" of this parameter. When you complete this entry by recording the "ending" distance in Dist2 make the dash into a plus. Parameters with beginning distances must have ending distances or the data will be incomplete and unusable in our analyses. Avoiding such missing data will require your undivided attention to this task, particularly to remembering which parameters are currently "incomplete" so that you will spot the locations where they end.

4) **NEW** - New Trail Segment: This parameter must be included beginning on the top line of a new form each time a trail segment is started. Record the code "NEW" in the Code column, a "0" in the Dist1 column, and all of the following information in the Comments columns.

Trail Code: xx	Trail Name: xx	Date: xx
Inventoried by: xx	Elevation: xx	Begin Wheel: xx

Trail Code and Trail Name: As for Parameters 1 and 2 above.
Date: Month, day, and year the trail segment was evaluated (eg. June 12, 1993 = 06/12/93).
Begin Wheel: Select a location near the beginning of the trail segment, which is easily identifiable for future reference. Begin the wheel at this location and write a brief description.

5) **REF** - Reference Point: Record the code and distance for this parameter periodically when you come across a permanent feature which can be used by future workers to compare and/or recalibrate their wheel readings to those you record. Under comments describe reference points with sufficient detail that someone else could relocate the precise point and reset their wheel reading to coincide with your own. Also try to select locations, which can be identified on maps, for example: stream crossings and trail intersections.

Resource Problems

These parameters provide information on the condition of the trail as influenced by human use, environmental, and design/construction/maintenance factors. All parameters are of the begin/end type so be extremely careful to watch for and record ending distances. Record only those problems, which exceed a lineal distance of 10 feet.

9) **BE1 -> BE2** - Soil Erosion (begin/end): The intent of these two parameters is to identify trail sections, which have experienced substantial soil erosion 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 while tops were likely at the original trail surface but, through subsequent erosion, have been exposed more fully. Two soil erosion parameters are defined:
BE1 - Soil Erosion 1: 1 - 2 feet of soil lost since construction
BE2 - Soil Erosion 2: > 2 feet of soil lost since construction

10) **BRE** - Root Exposure (begin/end): Record for trail sections exhibiting severe tree root

exposure such that the tops and sides of many roots are exposed.

11) **BW3 -> BW6** - Excessive Width (begin/end): 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. Two expansion widths (actual expansion width, excluding normal trail width are defined:
BW3: 3 - 6 feet wider than normal
BW6: > 6 feet wider than normal

12) **BWS** - Wet Soil (begin/end): Record for trail sections, which exhibit temporary, seasonally, or permanently wet or boggy soils. Wet soils typically occur on low areas, depressions, or are associated with hillside seeps. Mudholes and other situations with standing water should be assessed with this parameter. If actual overground water flow is present record parameter BWT - 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 or 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.

13) **BWT** - Water on Trail (begin/end): Record whenever water from a large seep or small stream runs on the trail tread, potentially causing soil erosion and tread rutting. Some degree of water flow must be present, otherwise record BWS - Wet Soil. Use your judgment as described for parameter 12 to record begin/end distances that reflect normal soil moisture conditions.

14) **BMT** - Multiple Tread (begin/end): 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.

Design, Construction, and Maintenance Features

One objective of this survey is to evaluate relationships between resource problems and trail design, construction, and maintenance. This will be accomplished by examining relationships with individual maintenance actions and a general maintenance intensity index that takes cumulative trail elevation gain and loss into account (calculated by examining topographical maps)

15) **BEG** - Excessive Grade (begin/end): Record for trail sections with grades exceeding 15

percent (a 15 - foot rise in 100 lineal feet). Using a clinometer, position your partner at the opposite end of the slope in question and sight on a feature of your partner that is the same height above ground as your eyes. Read and record the percent slope under comments. Only record this parameter when the slope exceeds 15 percent.

16) **BTC** - Trail Corduroy (begin/end): Trail corduroy is defined as any form of wooden or log bridging designed to traverse areas of wet soil (excluding stream bridges).

17) **DD** - Drainage Dip: A drainage dip is defined as an obvious human-constructed dip or shallow trench, typically with an earthen berm built across the tread, configured in such a way that water is diverted off the trail.

18) **WB** - Water Bar: A water bar is defined as a wooden or rock structure partially buried in the trail tread for the purpose of diverting water off the trail.

19) **LD** - Lateral Drain: A lateral drain or ditch is defined as an obvious human-constructed trench dug along the up-slope side of the trail to collect and carry the water down-slope parallel to the trail until it can be shunted away from the trail at the end of a slope or across the trail at a water bar, drainage dip, or culvert. Record the distance for any point along the trail where the ditch is present.

20) **RW** - Retaining Wall: A retaining wall is defined as an obvious human-constructed wall or cribbing constructed of rocks and/or logs to retain soil, typically on the downslope sides of trails. Record the distance for any point along the trail where this feature is present.

21) **CU** - Culvert: A culvert is defined as a metal, rock, or wooden structure which carries water from one side of the tread to the other; it may be open or enclosed. Be aware that some are buried and may not be easy to see.

22) **ST** - Step: A step is defined as an obviously human-placed rock or wooden structure which facilitates travel up a steep slope and/or prevents the erosion of soil or unconsolidated rock/gravel. Also include soil dams, rocks, or wood embedded in the trail perpendicular to the tread to retain soil, or to cause eroded sections to fill in. Soil dams are distinct from water bars in that they are not angled and configured to shunt water off the tread.

<u>Attraction Features</u>

23) **AF** - Attraction Features: These natural or historical features directly or indirectly lead to increased concentrations of use and subsequent impacts. Record these features whenever they are notable or significant enough to attract the attention of visitors. Typically such "popular" features will have well-defined social trails leading to them. These are point features so record a distance under Dist1 for the point along the survey trail which is closest to the feature (do not wheel off the trail to the feature). Briefly describe the feature under comments eg. Waterfall, vista, cliff, pond, or stone foundation.

Appendix D
Office Methods:

The first step in trail routing was to select a beginning and ending point. The second consideration in routing a trail is the initial trail's grade. To calculate the grade, the difference in elevation between the two points is determined in feet. This is divided by the horizontal distance between the two points measured in feet. For example, if the two points are 1 in. apart on the map, but the map scale is 1 in. = 500 ft., the distance is 500 ft. The distance is then divided by the approximate change in elevation:

difference in elevation / distance = initial % grade

Once the initial grade is determined, a draftsman's instrument known as a divider is used to "step" along the map between the beginning and ending points. The distance at which to set the draftsman's divider is found by dividing the contour interval of the map by the initial % grade. For example a 20 ft. contour interval / 7% initial grade = 285.7 ft. To set the dividers in proportion to the map the following the formula was used.

$$\frac{x \text{ in.}}{\text{distance required for draftsman's divider}} = \frac{1 \text{ in.}}{\text{map scale}}$$

This formula filled in for a map scale of 1in = 400 feet and a divider distance of 285.7 ft. would be:

$$\frac{x \text{ in.}}{285.7 \text{ ft.}} = \frac{1 \text{ in.}}{400 \text{ ft.}} = \sim 0.7\text{in}$$

A draftsman's scale is used to set the distance of the divider to 0.7 in. The divider is used to step from one contour to the next. The divider is set to ensure that the distance between the two divider legs represents no more then 285.7 ft. If the designer steps from only one contour to the next, the change in elevation will never be over the contour interval (in the example, 20 ft.). This constant gain in distance and change in elevation ensures that no section of the trail will exceed 7%. Figure 20 below depicts designing a trail using these methods.

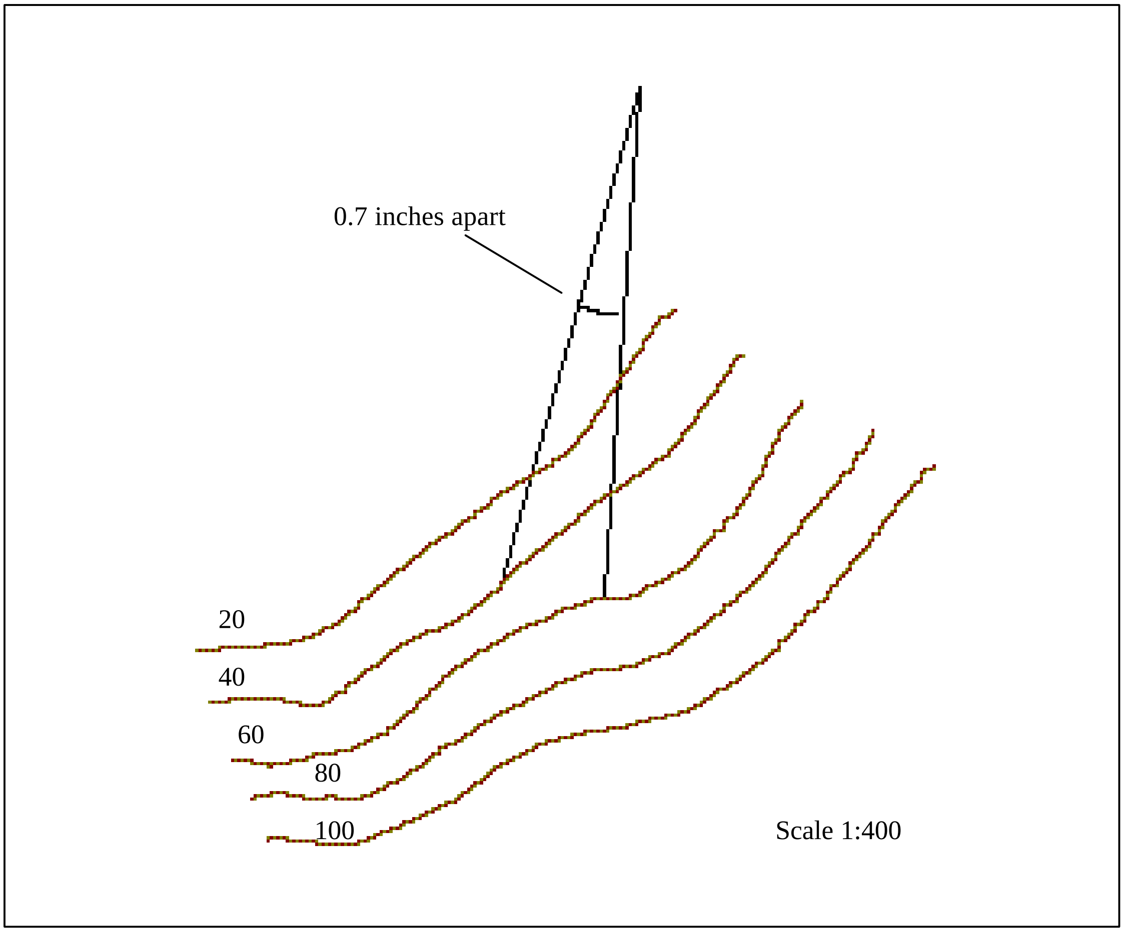


Figure 20. Designing a trail using office methods.

Appendix E
AML Programs Developed:

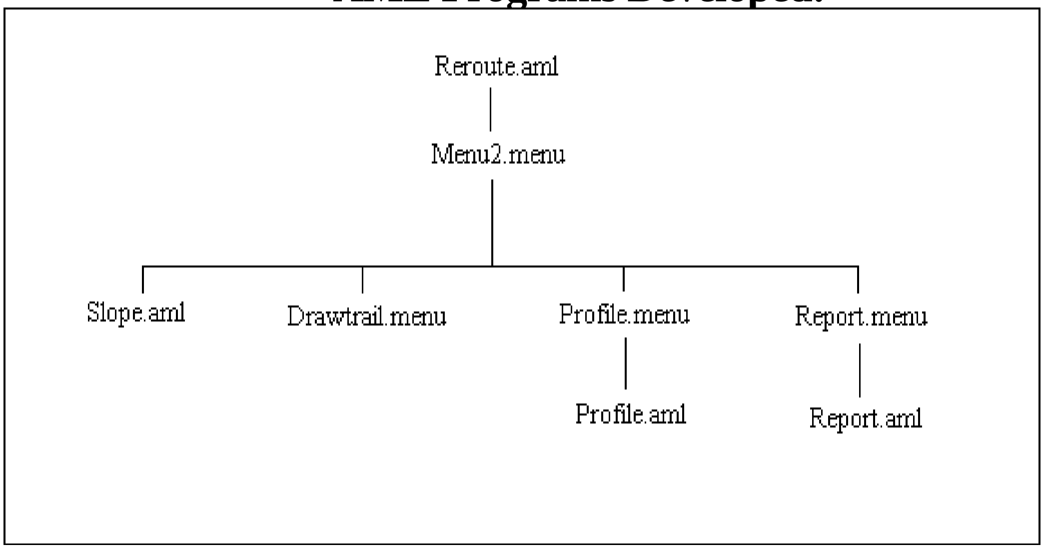


Figure 21. Structure of AML programs.

<u>Reroute.aml</u>

```
DISPLAY 9999
&terminal 9999
arcedit
mapextent BLANK
editcover BLANK
backenvironment arc on
drawenvironment poly
editfeature none
&menu menu2
```

<u>Menu2.menu</u>

```
1 Main Menu
Survey_Data
 Point_Data editcover event2; editfeature label; drawenvironment label on; draw
 Line_Data editcover line_events; editfeature arc; drawenvironment arc on; draw
Slope
 Display_High_&_Low_Slopes &run slope
 Display_Middle_Slopes &setvar low := [response 'Enter the lowest slope you wish shown'];
&setvar high := [response 'Enter the highest slope you wish shown']; aselect percent_slope >
```

%low% and < %high%
Backdrops
 Slope &setvar cover := [response 'Enter the name of the coverage containing poor slopes']; BACKCOVER %cover% 6; DRAW
 Trails BACKCOVER TRAILS2 3; DRAW
 Stream_Buffer_Zone BACKCOVER HYDRO2BUF 4; DRAW
 Streams BACKCOVER HYDRO 4; DRAW
 Roads BACKCOVER ROADS4 2; DRAW
 Contours BACKCOVER CONTOURS 1; DRAW
Reroute &menu drawtrail.menu
Profile &menu profile.menu
Trail_Statistics &menu report.menu
Full_View MAPEXTENT HYDRO; DRAW
Zoom MAPEXTENT *; DRAW
Select
 Select_Point_Attribute EDITFEATURE LABEL; SELECT *; LIST
 Select_Line_Attribute EDITFEATURE ARC; SELECT *; LIST
Clear CLEAR; REMOVEBACK ALL
Quit QUIT

<u>Slope.aml</u>

editcover surfacepolys
editfeature poly
&type 'this program allows you to select the slope classes you wish to avoid while planning a trail. You only need to run this module once. It allows you to create a permanent file that you can use repeatedly.'
&setvar low := [response 'Show slopes < ? (Enter 0 for none)']
&setvar high := [response 'Show slopes > ? (Enter 100 for none)']
&type 'Please wait ...1'
aselect percent_slope < %high% and percent_slope > %low%
delete
&setvar cover := [response 'Enter a file name for poor slopes']
save %cover%

<u>Drawtrail.menu</u>

1 reroute menu
Zoom mapextent *; draw
Draw_Reroute EDITCOVER BLANK; &SETVAR COVER := [response 'Enter a new filename for your reroute coverage']; ~
EDIT blank; editfeature arc; drawenvironment arc; ~
ADD; SAVE BLANK %cover%

Profile.menu

```
7 profile.menu

 Use these scrolling menus to select two coverages to compare

  %datalist1      %datalist2
                                     %button1
%datalist1 INPUT .profcov1 14 TYPEIN NO SCROLL YES ROWS 4 COVER ~
  * -ALL -SORT
%datalist2 INPUT .profcov2 14 TYPEIN NO SCROLL YES ROWS 4 COVER ~
  * -ALL -SORT
%button1 BUTTON KEEP 'Draw two profiles' &run profile.aml
```

Profile.aml

```
quit
kill temp3
copy blank temp3
arcedit
editcover temp3
editfeature arc
get %.profcov1%
get %.profcov2%
save
quit
arcplot
mapextent hydro
surface tin surface
surfaceextent surface
surfaceprofile * temp3 # 1 temp3-id
```

Report.menu

```
7 report.menu



    %datalist1
%datalist1 INPUT .trail 14 TYPEIN NO SCROLL YES ROWS 4 ~
  KEEP ~
  RETURN '&run report.aml' ~
```

```
COVER ~
* -ALL -SORT
```

Report.aml

```
quit
kill temp2
copy %.trail% temp1
intersect temp1 surfacepolys temp2 line
kill temp1
tin
surfacelength surface temp2 # 10
additem temp2.aat temp2.aat difference 16 16 n
additem temp2.aat temp2.aat rise 16 16 n
&popup directions.txt
info
```