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Factors that Control Trail Conditions in the College Woods

Ryan Scott McKinney
College of William and Mary

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Student: Ryan Scott McKinney
Advisors: Greg Hancock, Heather Macdonald, Tim Russell, and Rick Berquist

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During its nine-year history (1933-42) the Civilian Conservation Corps (CCC) made a significant contribution to the wilderness areas of the United States. The CCC was instrumental in providing countless hours to reforestation efforts, fire fighting, and opening large areas of virgin forests by development of needed trail systems and roadways. Although the program was designed to help the unemployed of the United States during the great depression, the contributions the program made to America’s wilderness and recreation areas are being appreciated today more than ever (Williams, 1994). The 70-year-old trails provide easy access into wilderness areas throughout the country. Over the last decade national, state, and local recreation areas that make use of CCC trails have experienced a tremendous increase in visitation. Since the early 90’s the popularity of “extreme sports” like trail running and mountain biking have contributed to a significant increase in trail use. Between 1992 and 1997 the National Park Service estimated a 63% increase in total visitation nationwide, while state parks saw similar trends (McLean, 2002).

The significant increase in the number of users and the age of the trails has lead to less than satisfactory trail conditions in the majority of recreation areas. Parks from coast to coast are now face increasing pressures on all the resources of their wilderness areas, both natural and manmade (i.e. trails). The CCC trail systems were developed during a time when “extreme sport” enthusiasts were a rarity and the American public was not nearly as mobile as it is at present. Today the majority of the trails built by the Civilian Conservation Corps are significantly degraded despite the fact that they were well designed when they were constructed (Williams, 1994). Since the late 70’s the National Park Service has funded dozens of investigations to identify the factors that control trail conditions. A field study of Great Smokey Mountains National Park identified slope and water erosion as the most important factors in trail degradation (Bratton, 1979). Another study identified foot traffic as the most devastating factor (Garland, 1990), while a more recent study identified poor trail construction and a lack of maintenance as the most damaging factor (Bocco, 1991). In each of these studies and dozens of others there is no one factor that was a consistent reason for trail degradation. Despite the differences in conclusions, nearly every study did include climate, geology, topography, soil, and vegetation as the environmental factors that influence trail conditions. The studies also identified use-related factors such as user type, and user intensity as the significant human related influences on trail conditions. User type describes what activity the trail user is performing on the trail. For example, a trail user that is riding a bike would be considered user type, “bicyclists”. User intensity describes how often the trail user is on the trail. A final factor that nearly all the studies look at is user behavior. User behavior is an intermediate because it is influenced by user type, use intensity and environmental factors like topography, soil, and vegetation. The role each of these factors play in trail deterioration differs considerably from park to park. This is significant because one park may have more overall relief than another, in which case slope would play a more significant role in trail degradation, while in another park water erosion may be the most significant factor because of heavy rains. As a result of the variety of influences from one location to the next it is difficult for the National Park Service to develop an effective prescription for trail remediation. Environmental quality and trail user satisfaction suffer as a consequence (Garland, 1990).

Degraded trails significantly affect ecological and social environments. Trail degradation can result in aquatic systems disturbance, excessively muddy trails, widening of trails, tread incision and multiple treads that lead to the proliferation of unintended trails (McLean et. al, 2000). Unintended trails can have pervasive environmental effects through alteration of natural drainage patterns, erosion and deposition of delicate soils, trampling of unique flora, introduction of exotic vegetation, and increasing human-wildlife conflicts. Degraded trails also threaten the quality of visitor experiences by making travel difficult or unsafe, or by diminishing the visitors’ ability to enjoy his or her surroundings. Trails that are degraded may have significant amounts of exposed roots, which can decrease the functional utility of the trail and pose a threat to the user.

Additionally, the scars left by degraded trails may be considered a visual impact and adversely affect the visitors' experience (Garland, 1990).

Trail degradation is a serious problem in this country. As human population growth steadily increases the number and size of wilderness areas decrease. For most these wilderness areas provide a setting that improves their quality of life, and the trails are the pathways that make the experience possible. Understanding the processes that influence trail conditions will help find develop better ways to construct and repair the trails. Improved trails will increase the accessibility of the few wilderness areas that are available today and therefore increase the quality of life for those that enjoy them.

The William & Mary community is experiencing this countrywide problem first hand. In 1925 the college purchased Lake Matoaka and 500 acres of land now known as the College Woods from the Hickory Land Corporation. During the depression the Civilian Conservation Corps landscaped the area, building trails in what was designed to be a wildlife sanctuary for the campus community (Kolman, 1994). Today the College Woods Trail System (CWTS) provides more than 10 miles of trails for students, faculty and community members to enjoy (Fig. 1) (Map). Lake Matoaka and the College Woods enrich College and community life, not only with beauty but with their research, educational and recreational uses. The lake and woods serve as a picturesque entrance to the College and Colonial Williamsburg, and provide enjoyment to thousands of visitors each year (Kolman, 1994).

Since the 1930's trail use has steadily increased while very little maintenance has been done to repair the trail system. As a result several sections of the CWTS are severely degraded and pose a threat to both the environment and to trail users. A 1996 study determined that years of neglect and heavy use left many of the dirt paths in serious disrepair. Mathes et al., 1996 reported that during rain, water often flowed directly down the paths into Lake Matoaka. The study determined that heavy use by mountain bikers and motorcyclers were particularly destructive and was a major contributor to trail degradation. They even identified ditches 3 feet deep that had developed in some areas as a result of these activities (Mathes et al., 1996).

Today trail users complain that the CWTS conditions are not satisfactory. Students and community members refuse to use the CWTS because the poor condition poses a threat to their safety (personal interview, 2002). Others worry about the environmental impacts the deteriorated trails have on Lake Matoaka.

To control and restore trail quality it is necessary to understand the factors that influence trail conditions in the CWTS. A number of questions will need to be answered to better understand the factors that influence trail conditions.

1. Where are the trails of the CWTS?
2. Where are the CWTS trails degraded?
3. What factors appear to control the degraded areas in the CWTS?
4. How can the impact of the degrading factors be reduced?
5. What can be done to eliminate future degradation problems in the CWTS?

Methods

Map Construction

To identify the location of the trails in the College Woods Trail System (CWTS), a map was constructed. The Williamsburg Quadrangle Topographic map 1984, and the Williamsburg Quadrangle Geologic map 1984 were chosen as the two base maps. The maps were imported into ArcView GIS 3.2 and projected in both UTM and State Plane projection. ArcView GIS 3.2 is the program used to manipulate and construct all of the maps involved in this study. Field data was collected using Trimble's GeoExplorer 3, global positioning system (GPS) unit. Field data was downloaded into Trimble's GPS Pathfinder Office, version 2.8. Data points that were not accurate were deleted in Trimble's GPS Pathfinder Office. To transfer the field data to ArcView GIS 3.2 it was necessary to create "shape files" in Pathfinder Office. A shape file contains three file extensions, shx, dbf, and shx. These extensions are necessary for the data to be projected correctly in ArcView GIS 3.2. Once the shape files were created they were opened and manipulated in ArcView GIS 3.2.

To ensure the accuracy both the topographic and geologic maps were rectified to the field data. To rectify the base map to points gathered in the real world, eight waypoints were chosen based on how easy they were to locate on the map and in the real world (Fig. 2). The data collected at the intersection of Berkeley Rd. and Mill Creek Rd. was not used because of interference from power lines. The seven waypoints used include

-Lake Matoaka spillway across Jamestown Rd.
-Intersection of Jamestown Rd./Rte. 5
-Intersection of Moticello Ave./Compton Rd.
-Intersection of Strawberry Plains Rd./Midlands Rd.
-Lake Matoaka Amphitheater
-Berkley High School Radio Towers
-Intersection of Compton Rd./Brooks Rd.

100 points were collected at each of the seven waypoints using the Trimble GeoExplorer 3. This data was collected during a time of high satellite coverage with PDOP values >6, and SNR values <4 for optimal accuracy and the first standard deviation was 1 meter.

Image rectification in Arc View 3.2 is the process of transforming an image from a file coordinate system (seven waypoints gathered in real world) into a map coordinate system (Topographic and Geologic base maps). Rectification is accomplished by matching corresponding image and map points. These points are then used to compute the best-fit polynomial transformation to align the image to the target map or image (Arc View, 1998).

The following is step-by-step description of methods used in ArcView 3.2 to rectify the images used. Careful attention is paid to this step because it is the base for the final map. The file names correspond to those used in the production of the final map.

Change projection

Opened ArcView GIS 3.2 and began a new view
Type of projection was changed to UTM 1927 or State Plane 1927 by clicking “View” and highlighting “Properties”.

In the “View Properties” window, “Projection” was selected.
A “category” box appeared with a pull down arrow to the right. The ideal category and zone were selected (Zone 18 was used for UTM in this project).
It was necessary at this point to click “View” at the top of the screen; highlight “Properties” and use the arrows to change the distance units to feet.

Add a theme

Theme “wmbgdrg.tif” (base map) was added by clicking the add theme icon in the upper left, searching the “c:/” drive in geology library computer, opening the “berquist” folder, opening the “tim” folder, opening the “arcview” folder, and opening the “original images” folder. No file options were available because the “data source types” in the bottom left of the window was set on “feature data source”. It was necessary to change the “data source types” to “Image Analysis Data Source” for “wmbgdrg.tif” to appear so it could be selected.

Once selected nothing appeared on the screen but “wmbgdrg.tif” with several classes listed below it. It was necessary to check the empty box to the left of “wmbgdrg.tif” for the map to appear.

Theme “reference.shp” (seven points) was added by clicking the add theme icon in the upper left, searching the “c:/” drive in geology library computer, opening the “berquist” folder, opening the “tim” folder, opening the “arcview” folder, and opening the “points” folder. No file options were available because the “data source types” in the bottom left of the window was set on “Image Analysis Data Source”. It was necessary to change the “data source types” to “Feature Data Source” for “reference.shp” to appear so it could be selected.

Once selected nothing appeared on the screen but the existing “wmbgdrg.tif”. It was necessary to check the empty box to the left of “reference.shp” for the points to appear.

Base topographic map file -	wmbgdrg.tif
Base geologic map file-	wmbggeo.tif
Seven pre-determined points from GPS unit-	reference.shp

Note that the “wmbggeo.tif” file was not been opened at this point.

Aligning the themap

With both “wmbgdrg.tif” (topo map) and “reference.shp” (geo map) open it was possible to rectify the images. The align tool icon was used with “wmbgdrg.tif” as the active theme which place both images and points on the same area.

With the align tool icon highlighted one of the six points to be rectified was identified on the “wmbgDRG.tif” (base map) and the left click was used to mark it. Once the left click had established at that point, the corresponding point collected in “reference.shp” was also clicked on. The computer matched the two and this process was repeated six separate times. These six points are called the control points.

The topographic and geologic maps are similar and display many of the same points. Once the topographic map was rectified using to the real world points “reference.shp”, it could be used to rectify the geologic map “wmbggeo.tif”. This was done in both UTM and State Plane. Four points that were easy to identify on both maps were chosen.

-Bench Mark on Duke of Glouster Street
-Lake Matoaka Spillway across Jamestown Rd.
-Northern most corner of Williamsburg Community Hospital
-Intersection of Strawberry Plains/Midlands Rd.

Aligning map to map involved no reference points. Matching one place with another was sufficient to rectify the map.

Aerial photos of the CWTS were taken by the Department of Agriculture in 1937 are used in this report to identify trail migration over the last 65 years. The photos were aligned to the rectified topographic map by matching points that were on both the photos and the map. The points include

-Intersection of Mill Creek Rd/Jamestown Rd
-Intersection of Burns Rd/Jamestown Rd
-Intersection of Wythe Ave/Richmond Rd
-Intersection of Brooks St/Richmond Rd
-Intersection of Berkeley Rd/Mill Creek Rd.

As control points were created, root mean square (RMS) error was calculated and reported in image pixels. RMS error is the distance between the input location (or from point) and the rectified location (or to point) after applying the current transformation. For this project an RMS error of <3 is acceptable. This is based on the following formula and the USGS 40ft error cushion.

1:24,000
1”=24,000”
1”=2000’
2000feet / 250pixels = 8 feet/pixel
error = RMS x 8 = ___ft
error = 3 x 8 = 24ft

RMS errors for each of the rectified base maps and aerial photos are listed below. Notice that all are well within the USGS 40ft error cushion.

Topographic map	wmbgdrgutm	RMS = 2.60	2.60 x 8 = **20.8ft**
Topographic map	wmbgdrgstpl	RMS = 2.26	2.26 x 8 = **18.08ft**
Geologic map	wmbggeoutm	RMS = 0.21	0.21 x 8 = **1.68ft**
Geologic map	wbrggeostpl	RMS = 0.76	0.76 x 8 = **6.08ft**
1937 Aerial Photo	1937a_gray_	RMS= 2.26	2.26 x 8 = **18.08ft**

Identifying trail location and condition was the next step. This was done by carefully plotting field data on the rectified base maps. The collection of field data using the Trimble GeoExplorer 3 was done at one second time intervals during a time of high satellite coverage with PDOP values >6, and SNR values <4 for optimal accuracy. A data dictionary called "condition class" was developed and installed on the GeoExplorer 3 to store data on trail location and condition. The condition class method (Jewell et. al, 2000) is a rapid assessment method that involves a series of six condition descriptions determined by disturbance of organic litter, pulverization of trail tread, and amount of soil erosion (Fig. 3). Using this classification scheme, the CWTS was sampled by foot. Trail segments of 5 meters or longer were classified according to the predetermined condition classes. This information was loaded into to ArcView GIS 3.2, and the actual lines were traced over to ensure quality presentation and accuracy of the map (Fig 4.)

A data dictionary called "Slope" was developed and installed on the GeoExplorer 3 to store field data on trail slope. The collection of field data for slope was done using the Trimble GeoExplorer 3 at one second time intervals during a time of high satellite coverage with PDOP values >6, and SNR values <4 for optimal accuracy. Slope of the trail surface, "trail slope," was measured parallel to trail direction using a Brunton compass level. Trail segments of 5 meters or longer that fell within pre-determined slope categories were collected in the field and then loaded into ArcView GIS 3.2 and plotted on the base map. The actual lines were traced over to ensure quality presentation and accuracy of the final map. The pre-determined slope categories are as follows.

0-5 degrees trail slope
6-10 degrees trail slope
11-15 degrees trail slope
16-30 degrees trail slope
31-45 degrees trail slope
46-60 degrees trail slope
61-75 degrees trail slope

Notice that the first three categories are broken up by five degrees of trail slope, while the last four are broken up by fifteen degrees of trail slope. This is because a majority of the trail slope within the CWTS is less than fifteen degrees and these categories better represent the actual slope. There are few slopes in the CWTS that are greater than fifteen degrees, but those that are vary significantly. This categorization increases the accuracy of the map and makes it easier to interpret (Fig. 5). Notice that slope data was not collected for the trails north of Monticello Avenue.

Geologic formations were traced in ArcView GIS 3.2 using the rectified geologic map. Contacts were confirmed by field observation, but no GPS data was used to reconstruct a geologic map (Fig. 6).

The rectified topographic map was used to create a land use map of the area surrounding the college woods (Fig. 7). The topographic map was also traced to plot roadways, and identify many buildings on the final map. Due to its recent construction, the Keck Environmental Field Laboratory was plotted using actual data collected using Trimble's GeoExplorer3.

Trail type was divided up into three categories, main for the trails developed by the CCC in the 1930's, secondary for trails developed after the 1950's, and the fitness trails located on the east side of Lake Matoaka. These trails were plotted on the base map using data collected with Trimble's GeoExplorer3.

Trail length was calculated by retracing sections of trail on the map using the ruler tool provided in ArcView GIS 3.2. Total trail length was calculated for each of the main, secondary, and fitness trails. Measurements were done in meters and converted to Km, and then to miles. For each of the trail types, the amount of trail that was in a certain class, had a particular slope, and the geologic formation it is within were calculated by tracing each section and dividing by the total distance of the trail type. The amount of slope within each trail class category was calculated by overlying the slope and class line shape files in ArcView GIS 3.2 and measuring the sections with the ruler tool. The average width of each trail type was calculated by taking two measurements at locations of maximum trail width, two measurements of at locations of minimum trail width, and five measurements at locations that represented the average trail width. All the measurements were averaged to yield the average trail width.

Trail Use

Trail users were counted on random days between the dates of June 12, 2001 and February 4, 2002 while simultaneously collecting data for map construction. Trail type (main, secondary, fitness), and user type (foot, bike) were recorded. User type is broken down into two categories, foot and bike because these are the main types of use in the CWTS. Trail use is reported in terms of user per hour. For example, if over the course of two hours, eight trail users were counted at any point along the main trail, then four users/hour would be reported on the main trail (Fig. 8).

67 Students and 15 faculty of the College of William and Mary as well as 18 residents of Williamsburg were asked if they used the trail. If the subject answered yes then they were also ask the following questions (Fig. 8b).

-How many times a week do you use the CWTS?
-At what time of the day do you use the CWTS?
-What type of activity do you participate in during your time on the CWTS?
-Do you think the trails pose a threat to your health and the health of Lake Matoaka?
-Do you use the main, secondary, or fitness sections of trail?

Transect Data

An approximate erosion rate was calculated using Leonard, Whitney and Cole's *cross sectional area method* (Fig. 9). Three sampling locations were chosen in Class 5 areas with a slope of approximately 14 degrees (Fig. 10). At each of the three locations two fixed objects were driven into the ground on either side of the trail. A taught line of kite string was stretched from poll to ensure a straight line across the trail. A tape measure was then stretched across the trail parallel to the kit string to provide a means of measurement. A second tape measure was then used to measure the distance of the kit string from the contours of the trail surface. This process was done on October 4, 2001 and January 13, 2002. The location of the measurement at ST-3 on January 13, 2002 may have changed slightly due to a trail user removing the fixed objects on either side of the trail. The data was then compared by overlying the measurements in Microsoft Excel, and creating difference graphs.

Results

The College Woods Trails are located on the Virginia coastal plain in Williamsburg, Virginia in Zone 18 of NAD 1927 Universal Transverse Mercator projection. The 10 miles of trails are surrounded by approximately 500 acres of the College of William & Mary's western campus. This area is temperate forest that is comprised mainly of Loblolly Pine, and Tulip Poplar trees. This forest is known as the College Woods, and is surrounded by an encroaching urban setting (Fig 11).

The three trail types within the CWTS include the main, secondary, and fitness trail. The main trail was constructed by the Civilian Conservation Corps in the early 1930's, and is one of the oldest sections of trail in the CWTS. A rectified aerial photo that compares the main trail of today to the main trail from 1937 shows the path of the main trail has not changed significantly for more than 65 years (Fig. 11b). The main trail has four trailheads that intersect a roadway. The south trailhead is at the intersection of the main trail and Mill Creek Rd. The west head is where the main trail intersects Strawberry Plains Rd. The north trailhead is where the trail intersects Monticello Ave., and the east head is where the trail intersects Compton Rd. The total distance of the main trail is 5.2 km (3.1 miles) (Fig 11). The average width of the trail is 1.5 meters. 9% of the trail is class category 2, 70% is class category 3, 14% is class category 4, and 7% is class category 5 (Fig. 12a). 76% of the trail has a slope between 0-5 degrees, 7% has a slope of 6-10 degrees, 15% has a slope of 11-15 degrees, and the remaining 2% has a slope of 16-30 degrees (Fig. 12b). 43% of the main trail is within Bacon's Castle and Windsor formations while 8% is in the Yorktown and 6% is in the Sedley formations. The Yorktown formation is described as shelly, clayey fine-grained sand. The Sedley Formation is described as clayey silt with very fine grained sand grading downward to muddy fine to coarse-grained sand with granules: glauconite common. The Bacon's Castle formation is interbedded sand silt and clay, massively bedded and lenticular to flaser bedded, basal pebbly to coarse sand common. The Windsor formation is clayey, fine to coarse-grained sand with pebbles. The main trail gets 2.12 users per hour. 1.89 of those users are on foot and .23 users are on a bike (Fig. 12d). Relative to the other trail types the main trail gets the second most use.

The percentage of slope within each condition class of the main trail shows that 100% of the trail that is classified as class category 2 is between 0-5 degrees (Fig. 12e). In class category 3, 94% of the trail is 0-5 degrees, 4% of the trail is 6-10 degrees, and 2% of the trail is and 11-15 degrees (Fig. 12f). Class category 4 yields 1% of the trail is 0-5 degrees, 58% of the trail is 6-10 degrees, 28% is 11-15 degrees, and 15% is 16-31 degrees (Fig. 12g). Class category 5, 0% of the trail is 0-5 degrees, 4% of the trail is 6-10 degrees, 93% is 11-15 degrees, and 3% is 16-31 degrees (Fig. 12h).

The age of the secondary trails is difficult to pinpoint. Word of mouth attributes the construction of the secondary trails to mountain bikers riding off the main trail. Mountain bikes began to be mass-produced in the early 90's, giving the trails a maximum age of twelve years. For this study the secondary trails have been broken into two distinct sections, secondary south and secondary north. The secondary trails south of Monticello Ave. are considered secondary south, and those north of Monticello Ave. are considered secondary north. The secondary trails south trails branch off of the main trail in four locations and have two trailhead locations where they intersect Berkeley Rd. and Mill Neck Rd. Two short sections of trail that do not branch off the main trail connect Compton Rd. with Matoaka Ct. Another short section of trail stretches from the art school to the amphitheater (Fig. 11). The total length of all of the secondary trails south of Monticello Ave. is 1.7 (2.8km) miles with an average width of .7 meters. 5% of the secondary south trail is class category 1, 42% is class category 2, 31% is class category 3, 15% is class category 4, and 8% is class category 5 (Fig. 13a). 54% of the secondary south trail has a slope between 0-5 degrees, 13% has a slope of 6-10 degrees, 13% has a slope of 11-15 degrees, 17% has a slope of 16-30 degrees, 2% has a slope of 31-45, and the remaining 1% has a slope 45-60 degrees (Fig. 13b). 20% of the secondary south trail is within the Windsor formation, 55% of the trail is within Bacon's Castle formation, 11% is within the Sedley and 5% is within the Yorktown. The secondary south trail gets .34 users per hour. .26 of those users are on foot and .08 users are on a bike (Fig. 13d). The trails secondary trails south of Monticello Ave. get next to the least amount of use.

The percentage of slope within each condition class of the secondary south trail shows that within class category 2, 75% is 0-5 degrees, 16% is 6-10 degrees, and 9% is 11-15 degrees (Fig. 13e). In class category 3, 58% of the trail is 0-5 degrees, 11% of the trail is 6-10 degrees, 9% of the trail is and 11-15 degrees, and 22% of the trail is 16-30 degrees (Fig. 13f). Class category 4 yields 11% of the trail is 0-5 degrees, 12% of the trail is 6-10 degrees, 25% is 11-15 degrees, 33% is 16-31 degrees, and 19% is 31-45 degrees (Fig. 13g). Class category 5, 0% of the trail is 0-5 degrees, 3% of the trail is 6-10 degrees, 10% is 11-15 degrees, 82% is 16-30 degrees, and 5% is 31-45 degrees (Fig. 13h).

The secondary trails north of Monticello Ave. have one accessible trailhead on the north side of Monticello Ave (Fig11). Two other trailheads are at the northern most extent of the trail system but are not accessible to the public because these trailheads are on private property. The total length of all of the secondary trails north of Monticello Ave. is 3.9miles (6.5km), with an average width of .45 meters. 5% of the secondary north trail is class category 1, 42% is class category 2, 31% is class category 3, 15% is class category 4, and 8% is class category 5 (Fig. 14a). No slope data was collected on the secondary north trail. 28% of the secondary north trail is within the Windsor formation, 65% of the trail is within Bacon's Castle formation, 3% is within the Sedley and 4% is within the Yorktown (Fig. 14b). The secondary north trail gets .34 users per hour. .26 of those users are on foot and .08 users are on a bike (Fig. 14c). Relative to the other trail types the secondary trails north of Monticello Ave. get the least amount of use.

The fitness trail is visible in the 1937 aerial photos, yielding an age of at least 65 years (Fig 11b). The fitness trail is accessible from two main trail heads, one off of Compton Rd. and the other off Dillard Dr., behind DuPont hall (Fig. 11). The trail is also accessible from the Keck Environmental field lab and at different points on Wake drive. Of the three trail sections it is the most accessible trail type to the students and faculty at the College of William & Mary. The total length of the fitness trail is 1.43 miles (2.3km) with an average width of .7 meters. 15% of the fitness trail is class category 1, 6% is class category 2, 36% is class category 3, 24% is class category 4, and 19% is class category 5 (Fig. 15a). 70% of the fitness trail has a slope between 0-5 degrees, 17% has a slope of 6-10 degrees, 7% has a slope of 11-15 degrees, and the remaining 6% has a slope of 16-30 degrees(Fig. 15b). 17% of the fitness trail is within Bacon's Castle formation, 12% is within the Sedley and 75% is within the Yorktown (Fig. 15c). The fitness trail gets 8.85 users per hour. 7.62 of those users are on foot and 1.36 users are on a bike (Fig. 14d). Relative to the other trail sections the fitness trail gets the most use.

Unlike the other trail types, use does vary significantly on one section of the fitness trail. The section is known as "arm" because of its resemblance of an appendage (Fig. 16). Trail use on the "arm" is 0 users per hour. It is necessary to represent the fitness trial without the collected "arm" data. The fitness trail results above include the data collected from the "arm," the following data does not include the data from the "arm" section of the fitness trail. 7% of the no "arm" fitness trail is class category 2, 43% is class category 3, 28% is class category 4, and 22% is class category 5 (Fig. 17a). 75% of the no "arm" fitness trail has a slope between 0-5 degrees, 15% has a slope of 6-10 degrees, 7% has a slope of 11-15 degrees, and the remaining 7% has a slope of 16-30 degrees (Fig. 17b). 4% of the no "arm" fitness trail is within Bacon's Castle formation, 13% is within the Sedley and 83% is within the Yorktown (Fig 17c). These results vary significantly from those that include the "arm."

The percentage of slope within each condition class of the fitness trail shows that within class category 2, 75% is 0-5 degrees, and 25% of the trail is between 6-10 degrees (Fig. 17e). In class category 3, 90% of the trail is 0-5 degrees, 9% of the trail is 6-10 degrees, and 1% of the trail is 16-30 degrees (Fig. 17f). Class category 4 yields 74% of the trail is 0-5 degrees, 24% of the trail is 6-10 degrees, and 2% is 11-15 degrees (Fig. 17g). In class category 5 of the fitness rail, 29% of the trail is 0-5 degrees, 10% of the trail is 6-10 degrees, 30% is 11-15 degrees, and 31% is 16-30 degrees (Fig. 17h).

Trail transect data was recorded at three different locations that were classified as trail class category 5. Transect sites ST-1 and ST-2 are on the main trail while the ST-3 was located on a secondary trail (Fig. 10). Data on trail depth was recorded on October 4, 2001 and January 13, 2002. All measurements from transect ST-1 show a significant loss in soil across the trail (Fig. 18). Measurements from transect ST-2 show both a loss and gain in soil across the trail. When all the measurements are compared in the difference graph there is a net gain in soil of 5.1cm (Fig. 19). Measurements from transect ST-3 yield both losses and gains in soil across the trail. There is a net gain of 1cm when comparing each of the points in the difference graph (Fig. 20). Measurements from transect ST-3 are not as accurate as those from ST-1 and ST-2 because the stakes used for the measurements were removed by a trail user. An approximate location was decided on for the second measurement that may not have exactly matched that of the original measurement.

Discussion

There are environmental and use related factors that control trail conditions in the College Woods Trail System (CWTS). A model of the principal groups of environmental and use-related factors, including interrelationships and the influence of proposed managerial actions, is presented in figure 21 (Fig. 21). Primary environmental factors include climate and geology, which act on each other as well as the intermediate elements of topography, soil, and vegetation. The characteristics of these intermediate elements are important determinates of trail degradation. For example, climate and geology may act to determine topography, but it is the topographic characteristics (slope) that most directly influence the layout of trails and their susceptibility to trail degradation.

Primary use-related factors include user type, frequency of use, and user behavior. User behavior plays an intermediate role because it is influenced by user type, frequency of use, and the three intermediate environmental factors (Fig. 21). All use-related factors are subject to influence by the extent of trail degradation. For example, excessive trail incisions or muddiness can alter user behavior by causing bicyclists and runners to spread laterally in their effort to avoid eroded or muddy and downed trees on sections of trail. This behavior would lead to other forms of trail and wilderness degradation through widening and birth of new trail.

According to the data collected in this study, the most devastating environmental factor acting on the CWTS is slope (topography). The main, secondary, and fitness trails show that as slope increases trail condition class gets closer to class category 5 (Fig. 12e-h, Fig. 13e-h, Fig. 17e-h). The strong positive relationship between trail slopes and soil loss is well documented in this study and others (Bratton et al., 1997; Garland et al., 1990; Sun et al., 1993; Teschner et al., 1979; Weaver et al., 1979). The greater velocity and erosivity of surface runoff on steep slopes is the predominant cause of trail degradation but other influences, such as the slippage of feet and the skidding of off road bicycle tires, are also likely contributors (Sun et al., 1993; Teschner et al., 1979). The presence of gullies (steep-sided eroding water courses that are subject to ephemeral flash floods during rainstorms) on several sections of trail with slope greater than 10 degrees suggest that water erosion induced by steep slopes is the most significant soil transport mechanism. Water erosion occurs if the combined power of rainfall energy and overland flow exceeds the resistance of soil to detachment (McLean et al., 2000). There is a greater occurrence of gullies on trail surfaces where the slope is greater than 10 degrees. Sections of trail with a slope that is less than 10 degrees show no significant occurrence of gullies (Fig. 22).

An interesting trend is evident when the slope and condition maps are overlaid in ArcView GIS 3.2. When the slope trail map is overlaid on the condition class trail map the sections of trail where slope is steeper match up with where trail condition is closer to class 5 (Fig. 23). This trend supports the fact that slope is the most devastating factor acting on the CWTS.

There is no direct correlation between trail condition and geology (soil). The percentages of trail that lie in a particular geologic formation do not match up with the percentages of trail condition class as well as they do with slope (Fig. 12a, 12c; Fig.13a, 13c; Fig. 14a, 14b; Fig. 15a, 15c; Fig. 17a, 17c). On the main and secondary trails trail condition class tends to get closer to class 5 when the trail is cutting through the Yorktown and Sedley formations. Despite this trend, geology on the main and secondary trails is not independent of slope. Meaning that where slope is steep, the geology tends to be either Yorktown or Sedley. We can say that slope is a more destructive factor than geology by looking at the Fitness Trail. 83% of the fitness trail lies in the Yorktown and 13% lies in the Sedley (not including "the arm"), but 50% of the trail is class 3 or below (Fig. 17a, 17c). In the absence of slope, trail that runs through the Yorktown or Sedley formations is not worse than a class 3 a majority of the time (Fig. 24). The section of trail that is greater than class category 3 with a slope less than 5 degrees is perpendicular to a steep slope. Since that slope was measured parallel to the trail, this slope is not accounted for in the data. This and all the other data suggest that slope is a more devastating factor to the trails than geology in the CWTS. A more detailed investigation of slope is recommended. Measuring the maximum slope at a certain section of trail instead of slope parallel to the trail would yield a better idea of total slope and how it affects trail conditions.

Researchers working on other areas where geology tends to be more varied have found that soils with fine and homogeneous textures have been found to have great tread incision. Poorly drained soils contribute significantly to excessive trail widening due to users seeking to circumvent muddy areas. Researchers also point out that wet muddy soils are more susceptible to erosion, especially when trail slopes are steeper (Bratton et al., 1997; Garland et al., 1990; Sun et al., 1993). The differences between the geologic formations found in the CWTS are not significant enough for there to be much of a difference in how they affect trail condition.

In general researchers have found that understory vegetation with high density, resistance to trampling, and resilience, inhibit trail widening. These attributes are less important in reducing soil loss but dense trailside vegetation confines the lateral spread of trail users. In the CWTS the sparse understory vegetation does not play a significant role in keeping trail users on the trail. Many trail users have been observed off trail on bicycles and on foot. In area's where trees have been downed trail users have created new trail. Vegetation does play one significant role in the CWTS. Where

Loblolly Pines are plentiful, fallen needles from the trees tend to protect the trail from the trampling of feet and the treads of bicycles tires. The needles also seem to reduce rainwater splash and slow runoff in areas were slope greater than 10 degrees and Loblolly Pines are present (Fig. 25). This conclusion is based on observation only. No data was collected to support this claim but future research looking at canopy cover over the trails is important for determining how much of role vegetation plays on trail condition.

Use related factors that control trail conditions include user type and frequency of use. On average there is more foot traffic on the trails than there is bicycle traffic (Fig. 12d). This study did not look at how each trail user affects the trail and present studies are inconclusive on whether bicycle or foot traffic is more destructive to trail surfaces (Garland, 1990). Future research is recommended to find out which of the two types of traffic are more destructive to trail surfaces.

Frequency of use is a significant factor in controlling trail conditions. There is a strong correlation between the amount of use and the condition class of a trail. Approximately 20% of the main and secondary trails are category class 4 or higher while the fitness trail, which receives more than 4 times the use, is more than 50% class 4 or above (Fig. 12a, 12d; Fig. 13a, 13d; Fig. 17a, 17d). This suggest that the more use a trail gets the worse the condition is. The “arm” section of the trail demonstrates this point very clearly. This section of trail is at least 65 years old as indicated by its presence in the 1937 aerial photo (Fig. 11b). The observed use on this trail is 0 users per hour and its class category rating is class 1. This “arm” does have approximately 30 meters of trail that has a slope that is greater than 10 degrees (Fig. 26). However, since there is relatively no use of this trail the vegetation is able to cover the trail and reduce overland flow and rainwater splash so that little soil is removed from the trail. Another area that demonstrates this same pattern is the secondary trails north of Monticello Avenue. This section of trail receives less than .5 users per hour and 71% of the trail is class category 2 or less (Fig. 14a, 14c).

The trails north of Monticello Avenue are the only trails that are regularly maintained. The average trail width is less than all the other trails and 71% of the trail is class category 2 or less.

The fact that the trail receives little use compared to the other trails is the primary reason that it is in good condition, but the managerial actions also play a role in keeping the trails in good condition. When a tree is downed vegetation around the site is not disturbed because the tree is removed from the trail surface so that users can pass without having to go off trail. Also, when a section of trail is worn out repairs have been made and bridges have been added to improve the quality of the trail. This section of trail is an important example because it shows that managerial actions have potential for mitigating or modifying the roles of both environmental and use-related factors, with the exception of climate. Humans monitoring the trail for trouble spots, fallen trees, and gullies can reroute the trail or remove the debris that has fallen on the trail so that trail users do not have to disturb the vegetation around the trail.

Through trail layout and design, managers can minimize trail degradation by selecting routes through more resistant and resilient soil and vegetation types and by avoiding sensitive landforms and topography. Through their influence over use-related factors, managers can reduce the amount and type of use or modify visitor behavior that contributes to excessive trail degradation. Finally through trail construction and maintenance actions, managers can harden treads to sustain use while minimizing water erosion that occurs as a result of steep slopes.

Conclusion

In the College Woods Trail System (CWTS) slope is the most devastating factor acting on trail condition because water erosion leads to soil loss, which leads to the exposure of roots and to the formation of gullies. In many sections of trail geology is not independent slope, which makes it difficult to determine how significant geology is, but the fitness trail shows that slope is more significant in shaping trail conditions than geology. The thin understory of the College Woods does not prevent trail users from going off trail, but the Loblolly Pine needles do protect the trail surface in areas where the trees dominate. The affect of trail user types on trail condition was difficult to determine but frequency of use was found to be a very significant factor. Increased trail use removes more of the protective vegetation from the surface of the trail and increase the amount of overland flow and rainwater splash that occurs during storm events. The impact of these degrading factors can be reduced by decreasing the amount of users a trail gets per hour and by establishing a managerial staff to monitor the conditions of the trail and make repairs when necessary. Future degradation problems can be avoided by constructing trails with slopes less than 10 degree, decreasing the amount of users, and increasing the amount of trail repair.

Works Cited

ArcView Image Analysis. GIS by ESRI. Atlanta, GA, 1998.

Bayfield, N.G., and R.J. Lloyd. 1973. An approach to assessing the impact of use on a long distance footpath-the Pennine Way. Recreation News Supplement 8: 11-7.

Bocco, G. 1991. Gully Erosion: processes and models. Progress in Physical Geography 15: 392-406.

Bratton, S.P., M.G. Hickler, and J.H. Graves. 1979. Trail erosion patterns in Great Smokey Mountain National Park. Environmental Management 3: 431-445

Cole, D.N. 1983. Assessing and monitoring backcountry trail conditions. USDA Forest Service, Intermountain Res. Stn., Res. Pap. INT-303, Ogden, UT.

Doucette, J.E. and K.D. Kimball. 1990. Passive trail management in northeastern alpine zones: a case study. USDA Forest Service NE-145 pp. 195-202.

Garland, G.G. 1990. Technique for assessing erosion risk form mountain footpath: an experimental study in the Drakensberg Mountains, South Africa. Applied Geography 7: 41-54.

Price, M.F. 1983. Management planning in the Sunshine area of Canada's Banff National Park. Parks 7(4):6-10

Sun, D., and M.J. Liddle. 1993. A survey of trampling effects on vegetation and soil in eight tropical and subtropical sites. Environmental Management 17:497-510.

Teschner, D.P., G.M. DeWitt, and J.J. Lindsay 1979. Hiking Impact on Boreal Forest Vegetation and Soils in Vermont's Northern Green Mountains. University of Vermont, Recreation Management Program, Research Note SNR-RM 6, Burlington, VT.

Weaver, T., D. Dale, and E. Hartley. 1979. The relationship of trail condition to use, vegetation, user, slope, season and time. USDA Forest Service, Pacific Northwest Region, Publ. R-6-001-1979. pp. 94-100.