The Effect of Management on Erosion of Civil War Battlefield Earthworks

by

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(ABSTRACT)

Since 1936 National Park Service has been charged with preserving Civil War Earthworks while allowing public access. Soil erosion, both natural and human-induced, is a major concern facing the preservation of the earthworks. Currently, the National Park Service is committed to preserving these earthworks for future generations by determining which maintenance activities cause the least soil erosion. This study was undertaken to determine which management practice; burned, mowed, park-forest, forested, or trimmed, best minimized soil erosion. A secondary objective was to determine how several empirical formulas (e.g. Universal Soil Loss Equation) and one field estimate (e.g. erosion pins) compared soil erosion trends for the 5 treatments. A third objective of this study was to gather information regarding the soil development which has occurred during the 135 + years since the earthworks were constructed.

Earthworks managed by prescribed burning suffered the greatest erosion rates while the forested earthworks eroded the least. The trimmed and mowed management regimes were not significantly different and would provide adequate erosion protection while the forested treatment had significantly less erosion. Based on the empirical models, erosion was primarily a function of ground cover; on the other hand, rain intensity was highly influential for erosion as measured by the erosion pins. All of the erosion estimation methods concurred that the burned treatment should be avoided due to the high erosion rates while the erosion pins indicated that the park-forest treatment could potentially have erosion problems as well. Soil profile descriptions from the earthworks revealed that A horizon depths on the earthworks were not significantly different then the A horizons found on the relatively undisturbed adjacent forest floor and that subsurface soil structure has begun to develop on earthwork soils.

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1. Introduction

During the American Civil War, 1861-1865, earthworks served as primary defensive structures. Earthworks, also known as field fortifications, breastworks, entrenchments, and field works were made of soil and timbers and were initially engineered for relatively short-term duration during battles. Earthen forts, however, were often highly engineered, constructed more slowly and carefully, and developed for longer periods of time then field earthworks. The basic earthwork is made up of the parapet and ditch. A parapet is the earthen mound that was engineered to protect the soldier from the enemy's artillery and enable them to use their weapons effectively. Soil used to build the parapet was taken from the ditch located in front of it. Some earthworks also had several lines of sharpened timbers called palisades, pickets, and abattis for additional protection (Mahan 1863). An example of a basic earthwork can be seen in Figure 1.

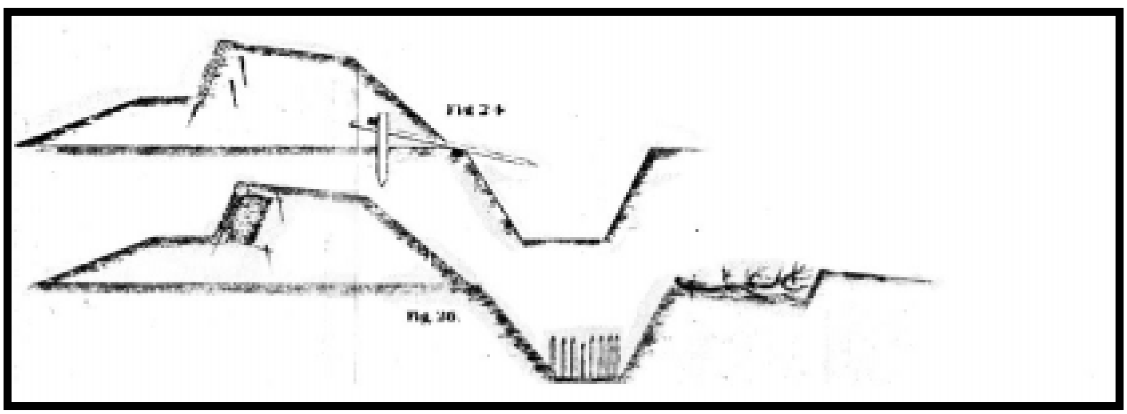


Figure 1. Basic earthwork design from Mahan, 1863.

Earthworks constructed around Richmond, Virginia were of special importance as they were constructed to defend the Confederate Capital. Today many of the earthworks and forts constructed around the City of Richmond are part of the 305-hectares Richmond National Battlefield Park.

This study was conducted at the Fort Harrison and Fort Gilmer sites, which are within the Richmond National Battlefield Park. Confederate soldiers constructed these two forts in 1862 with walls as high as 8.4 m and 4.7 m wide in Fort Harrison (U.S.

Department of the Interior, 1999). On September 29, 1864 the Union army captured Fort Harrison and added to the earthworks (U.S. Department of the Interior 1997).

Additional earthworks were also examined at Colonial National Historical Park in Yorktown. Most of these earthworks were originally constructed during the Revolutionary War, then modified and used during the Civil War. Repair of the earthworks in Yorktown has also taken place since the end of the Civil War.

Currently, the National Park Service is mandated to preserve these earthworks for future generations. Therefore, the National Park Service is committed to determining which management activities will result in the least soil erosion. Several management regimes and vegetation communities are currently being used to minimize erosion and maximize earthwork views. An earlier study by Lakel et al. (1998), found that bare soil on earthworks had the highest erosion rate and that all current management practices generated some levels of bare soil. The purpose of this project is to develop more detailed information regarding soil erosion under the following management regimes: prescribed burning, mowing, park-forest, forested, and trimming and to evaluate the appropriateness of direct and indirect estimates of soil erosion.

Justification

In 1936 the United States Congress established the Richmond National Battlefield Park. Since 1936 it has been the mission of the National Park Service, at the Richmond National Battlefield Park, to preserve the earthworks while allowing public use. The official Mission Statement of the Richmond National Battlefield Park is as follows: "It is the mission of the National Park Service in perpetuity to protect, maintain, and provide for the enjoyment and understanding of the historic resources associated with the Civil War Battlefields fought in the vicinity of Richmond, VA".

The Organic Act of 1916, which created the National Park Service, and the Historic Sites Act of 1935 mandate that the National Park Service preserve public historic sites, buildings, and objects of national significance as well as providing for future enjoyment. Because the National Park Service has to preserve the earthworks while allowing for public use, they must address several problems:

- Earthworks are somewhat unstable due to:
    1. natural soil erosion from wind and water and
    2. human induced erosion from trails and maintenance.
- Public access may cause problems because of human foot traffic because:
    1. trails expose bare soil on the earthworks and
    2. clearing of vegetation from the earthworks to provide better views may accelerate soil erosion.
- The National Park Service is uncertain about how to best minimize erosion in logistically feasible and socially acceptable ways. Currently, they use a wide variety of activities ranging from allowing natural forest succession to annually burning the vegetation from the earthworks. Our goal is to examine the erosion from the various vegetation management regimes in order to determine which treatments are most desirable.

The overall general null hypotheses to be tested are:

Ho_1: Vegetation management does not affect soil erosion on earthworks.

Ho_2: Empirical formulas and field estimates used for estimating soil erosion provide comparable trends in estimated soil erosion between management activities on earthworks.

Additionally, this project investigates 135+ years of soil development on earthworks. Soil profile descriptions were conducted on earthworks and on adjacent, less-disturbed soils. The overall goal of this sub-project was to determine if these highly disturbed soils had regained important characteristics such as A horizon depths and soil structure within the past 13 decades. The null hypotheses tested for this sub-project are:

Ho_3: Earthworks have A horizon depths equal to those of adjacent, less disturbed soils.

Ho_4: Earthworks have soil structure the same as adjacent, less disturbed soils.

2. Literature Review

2.1 Soil Erosion and Controlling Factors

2.1.1 Soil Erosion Process

"Erosion is defined as the amount of soil delivered to the toe of the slope where either deposition begins or where runoff becomes concentrated" (Dissmeyer and Foster 1984). However, soil erosion is not necessarily synonymous with soil loss. Soil loss refers to material that is actually transported from a particular topographic position on a microtopographic scale. Soil loss is commonly less than total erosion due to on-site deposition caused by slope breaks, surface roughness, and litter accumulations (Toy and Foster 1998).

Erosion due to wind and water begins with weathering processes such as freeze-thaw and wet-dry events. These cycles loosen soil aggregates, destabilize the soil structure, and make it more vulnerable to the detachment and transport soil particles in overland flow. In general, the potential for soil erosion increases as the amount of bare soil and the percent slope increase. Surface cover, such as vegetation litter, slash, logs, or rocks, can drastically reduce the erosion potential. As the amount of bare soil decreases, infiltration rates can exceed the rainfall intensity, which drastically reduces the erosion rate (Dissmeyer and Foster 1984). In forests it is possible to have virtually no surface runoff when there is 100% ground cover, assuming that soils and litter are not saturated before the event occurs.

In the Coastal Plain of Virginia, rainfall is the primary agent of erosion. The factors that influence erosion include rainfall duration and intensity as well as climate, soil type, topography, and vegetative cover. Falling raindrops are primarily responsible for the dislodgement of soil particles at the soil surface. Once detachment takes place, runoff transports the soil particles down slope. This type of erosion is caused by raindrop splash (Hewlett 1982).

Soils are particularly susceptible to raindrop splash in areas with sparse vegetation (Brooks et al. 1997). During a large storm event there is enough energy released to splash more than 200 metric tons (Mg) of soil into the air per hectare. The individual soil particles can be splashed more than 0.5 meters high and 1.5 meters sideways (Brooks et al. 1997). Heavier rainstorms may not only cause large amounts of erosion, but also compact the soil as the raindrops hit the bare ground. Soil particles can also become lodged in surface macro-pores and impede infiltration, further adding to the overland flow.

After raindrop splash causes the detachment of soil particles upon impact, surface runoff causes rill and sheet erosion. Surface runoff occurs when the rate of rainfall exceeds the infiltration rate. The energy of runoff is dependent upon the velocity, depth of runoff, and the roughness of the surface. Increasing the steepness and length of a slope causes an increase in water velocity. As these conditions progress, eddies form on the soil surface and begin the soil erosion process attributed to runoff. An increase in velocity also increases the turbulence of the water causing additional soil detachment.

Soil detachment leads to suspended sediment, which has an abrasive action on the soil surface, dislodging soil and adding to the sediment load. Additional increases to the sediment load are attributed to the impact of raindrops in shallow runoff, which increases the rate of erosion by increasing the turbulence of the flow.

Once the process of soil detachment and transport begin, rill erosion forms very small but well-defined, visible channels or streamlets where there is concentration of overland flow. Water also flows in between these channels in sheets, known as sheet erosion, although the channels are being formed and eroded almost as fast as they form. Sheet erosion is the most deceptive type of soil erosion because losses are more uniform and not readily visible. Sheet erosion is found most often on uniform slopes with evenly distributed surface runoff.

Gully erosion is the third type of surface erosion caused by water. Gullies generally form in highly erodible soils where human activity has removed the vegetation. As the runoff flows down hill, a concentrated area called a nickpoint is formed in areas where there is an abrupt change in slope and elevation. Once this process starts, the flowing water headcuts the hillside and eventually downcuts it, moving the gully in the downslope direction (Brooks et al. 1997). Gullies also develop where subsurface flow emerges on the hill-slope causing the water to headcut and downcut the hillside. There are two types of gullies that can form under these processes. The first are V-shaped gullies, which form in shallow or uniformly erodible soils while a U-shaped gully is formed in soil that is less erodible overlying a more erodible soil (Hewlett 1982).

2.1.2 Soil Site Factors

Soil site factors are a combination of both physical and chemical soil properties as well as topography, soil type, climate, and vegetative cover. Generally, soils that are high in silt and fine sand content are more erodible than soils high in organic matter and clay. Slope length and steepness also contribute to the amount of soil loss. El-Hassanin et al. (1993) found that soil loss doubled and runoff was 1.6 times higher when the slope gradient increased 15 to 30%. They also found that runoff decreased by 53% while soil loss doubled when the slope length decreased from 5 to 20 m. Horton (1949) found that the two most important general soil characteristics affecting erosion are those related to available soil moisture and those related to soil stability. The amount of available moisture is indicative of the infiltration rate of a soil. Factors affecting infiltration rates include organic matter content, soil texture, soil depth, degree of swelling of colloids, and pore space (Fisher and Binkley 2000). Soil stability affects erosion by determining the degree of resistance of soil particles to the beating action of rain and runoff. Organic inputs such as fine roots, fungal hyphae, and microbial biomass as well as inorganic work to stabilize the soil aggregates (Pritchett and Fisher 1987). Martinez-Mena et al. (1998) found a significant correlation between aggregate stability and saturated hydrologic conductivity. This correlation suggests that aggregates are more stable where there is a higher proportion of large pores and planar voids. The larger pores increase infiltration and reduce surface runoff.

2.1.3 Vegetative Effects on Soil Erosion

Vegetation provides a protective cover between the atmosphere and soil. Rainfall induced erosion can be reduced a hundredfold by maintaining a dense cover of sod, grasses, or herbaceous vegetation (Gray and Sotir 1996). El-Hassanin et al. (1993) found that forest cover, combined with herbaceous cover, was the most effective cover against soil loss and runoff. Beneficial effects provided by woody and herbaceous vegetation in preventing rainfall erosion include interception, soil restraint, soil retardation, and infiltration.

Interception is the retention of precipitation by the aerial part of vegetation, which is then either evaporated or absorbed. Interception may not prevent all water from reaching the surface, eventually a portion reaches the surface through leaf drip or stem flow (Pritchett and Fisher 1987). Interception reduces soil erosion because plant foliage captures a portion of the rainfall and absorbs the rainfall energy thereby reducing soil detachment. The amount of interception depends upon the type of vegetation and itsvegetation's storage capacity. In general, coniferous evergreen vegetation is more effective at interception than broadleaved deciduous species.

Soil restraint is caused by the physical binding of root systems, which restrain soil particles. Roots with diameters of 1-12 mm are most capable of physically restraining soil particles from gravity, raindrop impact, surface runoff and wind. The most effective roots of these sizes are ones that spread laterally (Coppin and Richards 1990). An important feature of tree roots is their ability to not only bind the surface soil with their fine roots and fungi but also anchor the soil mantle to the substrate due to the penetration and strength of the larger roots (Swanson and Dyrness 1973).

Another integral part of soil restraint is the shear strength of the soil. Ghidey and Alberts (1997) found a significant increase in soil shear strength with species that have high rates of root turnover (organic matter additions) and root length. Their study identified an approximate 22% increase in soil shear strength with the root systems of alfalfa (*Medicago spp.*) and bluegrass (*Poa spp.*) vs. corn (*Zea may*) and soybean (*Glycine max*).

Soil retardation is the decrease in the velocity of runoff caused by increasing slope surface roughness from vegetation stems and foliage (Gray and Sotir 1996). Today vegetated filter strips in high erosion areas are being used for this purpose. Robinson et al. (1996) found that using 3 m wide grass filter strips helped reduce the runoff velocity as well as the sediment concentrations.

Infiltration is the entry of water into the soil from the soil surface (Fisher and Binkley 2000). Infiltration rates are determined by the permeability of soils and subsoils, moisture content, internal characteristics of the soil, vegetative cover, intensity and duration of the rainfall, and the temperature of the soil and water (Novotney and Olem 1994). Litter from the surrounding vegetation helps maintain infiltration rates by storing a portion of the rainfall, increasing infiltration, reducing the impact of raindrops, preventing agitation of the mineral soil particles, and discouraging the formation of surface crusts (Wooldridge 1970).

2.1.4 Soil and Litter

In a vegetative community the litter layer forms a protective layer over the soil surface. The vegetative litter found on the soil surface consists of dead plant remains, which protect the soil surface from raindrop impact and surface runoff. In general, as the litter cover increases, soil loss decreases exponentially (Coppin and Richards 1990). Gutierrez and Hernandez (1996) found that increases of surface organic matter lead to decreases in sheet erosion in arid to semi-arid rangelands.

Fisher and Binkley (2000), define a forest soil as "any soil that has developed under the influence of a forest cover." The upper horizons of a forest soil are usually composed of litter layers, decomposing organic material, and mineral soil. These layers are critical for many reasons, including erosion control. The litter found on the soil surface helps protect the soil surface from raindrop impact and surface runoff.

Following soil disturbances, such as a prescribed burn, organic matter accumulation resumes, allowing areas of bare soil to be covered again. The amount of organic matter accumulation on the forest floor is related to the annual litter input, the rate of decomposition, and the elapsed time since the last fire or disturbance (Pritchett and Fisher 1987). The amount of litter input depends on latitude, type of vegetation, and tree species among other influences. Bray and Gorham (1964) found an annual return of 2.5 to 7.4 Mg/ha for most conifers and hardwoods in cool temperate regions.

Ideally, as trees mature, the amount of litter production stabilizes to equal the rate of decomposition on the forest floor, but the age of maturity varies. The amount of litter accumulation/production depends on several factors including tree species, age, and tree density. Biomass production has been found to equilibrate after 10 years in a mature stand of southern pine that has been protected from fire (Heyward and Barnette 1936). However, Gholz and Fisher (1982) found that slash pine plantations were still accumulating organic matter after 35 years in the same geographic region as the previous study.

Organic matter also accumulates in the soil mineral profile due to the death and regrowth (turn-over) of roots, particularly fine roots. Trees, shrubs, and herbaceous plants can have a greater annual turnover of organic matter below ground then above ground litter production (Kimmins 1987). Giese (2001) found that annual root production in upland hardwood forests of the coastal plain of South Carolina was approximately equal to annual litter production.

The soil texture and the type of organic matter influence the incorporation of organic matter in the soil surface. Fine textured soils usually accumulate larger amounts of organic matter than do coarser textured soils. As the layers of organic matter increase on the forest floor so does the water holding capacity, hydraulic conductivity, and infiltration (Fisher and Binkley 2000). These textural and organic properties act in concert to affect the water holding capacity and infiltration.

2.1.5 Fundamentals of Forest Soil Erosion

Regardless of soil erosion control measures, it is inevitable that some erosion will eventually occur. Even undisturbed forests having complex canopies and almost total canopy and litter coverage will have slight erosion rates (generally > 0.07 - 0.11 Mg/ha/yr) (Patric 1976). However, management can have very dramatic effects upon the degree or rate of erosion. For example (Yoho 1980) reported that bare soil associated with road construction could have erosion rates >336 Mg/ha/yr and poorly managed pastures might lose 17.5 - 96.5 Mg/ha/yr.

Two water related factors that cause soil erosion are rainfall and runoff. Mature forests prevent these factors from breaking soil particles free and carrying them down stream. Rainfall impact is reduced as compared to bare soil because of a dense litter layer and canopy cover. Without these two factors the rainfall impact would detach soil particles. In an evaluation of battlefield earthworks, Andropogon and Associates, Ltd. (1989), found that a dense native forest managed to maintain multi-aged and multi-layered structure was one of the best cover types to control erosion on earthworks. Patric (1976) states that even young forests can be virtually erosion-proof if dense overstory, understory, and litter cover are present. In addition, a non-saturated soil with a high porosity and organic matter content can usually absorb rain as fast as it falls. Kirkby and Chorley (1967) found that on fully-vegetated, deep soils, overland flow only occurs during the most extreme storms. This seems reasonable considering that well managed forestland will seldom exceed erosion rates of 0.22 Mg/ha/year (Patric 1976).

The USDA Natural Resources Service estimates allowable soil loss tolerances of 1 to 5 tons/acre/year for sustainable productivity of many agricultural soils (Patric 1976). Erosion from forests is a fraction of that due to agriculture because forests provide protection from rainfall by canopy and litter interception and increased infiltration rates.

Rainfall interception from the canopy of woody vegetation can have either positive or negative effects. Interception spreads the time of the event over a longer period and can reduce net precipitation if the intercepted water is evaporated. Typically the canopy of a temperate broad-leaved forest will intercept 15-25 % of the gross precipitation and a temperate coniferous forest intercepts 25-35% of annual rainfall (Coppin and Richards 1990). There are three forms of rainfall that affect soil underneath vegetation:

1. throughfall, which is rainfall that falls untouched by the vegetation
2. stemflow, which is rainfall that runs down the stems or trunks of the vegetation
3. leaf-drip, which occurs as droplets form and fall from the leaf surface.

Leaf-drip is a potential problem associated with the collection and fall of water drops subsequent to rainfall interception. Raindrop velocities falling from vegetation can have a significant effect on soil breakdown. Vegetation that is low growing has lower raindrop velocities than trees with higher canopies, simply due to the acceleration of gravity. 70% or more cover gives near maximum protection from raindrop impact (Coppin and Richards 1990). Leaf droplets, 5-6 mm in diameter, falling from a canopy at least 1 m high can have more of an impact on soil detachment than that of natural rainfall on bare soil because the droplets are larger than raindrops (Coppin and Richards 1990). Leaf size also influences the erosion potential because of its influence on droplet size. Vegetation with large leaves intercepts more rainfall per leaf allowing larger droplets to be formed on the leaves before leaf drip occurs. When these large droplets are released their impact may be much larger than that of natural rain. For canopies 2 m and higher the amount of bare soil loss increases as the percentage of cover increases. This increase in soil loss is due to an increase in leaf drip velocity as the height of the canopy increases (Coppin and Richards 1990). However, canopies that are less than 0.5 m in height decrease soil erosion exponentially as percent cover increases (Coppin and Richards 1990). It is important to understand that the forest litter layer has the potential to offset the leaf drip problem. Only areas of bare soil have a serious potential to erode due to canopy drip erosion.

The role that forest litter layer plays in reducing soil erosion is paramount. The soil litter layer and organic matter can increase soil infiltration rates to equal the rainfall intensity. When infiltration rates are equal to rainfall intensity no overland flow is observed. Attributes of vegetation such as roots, holes from root decay, increased surface roughness, and lower densities and better structure of surface soils allow for increased infiltration. Wood et al. (1989) found that infiltration rates were significantly lower in a forest that had been seedtree harvested and site-prepared as compared to a stand that had minimal disturbance from thinning. This occurred because the site-prepared area had lost most of its litter layer, which plays a key role in infiltration. The upper-horizon L and F layers, which consist of leaves and other decomposed material, protect the soil from raindrop impact and slow moving water. The H layer, occurring just below the L & F layers, has a water holding capacity of more than 200% by weight (Brooks et al. 1997). Both of these layers help detain water until the soil's natural infiltration has time to absorb it.

Trees may not be appropriate for control of all types of soil erosion problems. Some problems include the length of time for establishment and expense. Two other problems associated with trees on structures such as earthworks are windthrow and root decay. Windthrow is caused by external loading in high windstorms or icestorms, which causes uprooting and may be the most destabilizing mechanism in slope stability (Warrillow 1999). When a tree is uprooted on a slope, it can cause slope destabilization, which leads to erosion. However, removal of trees before windthrow occurs could lead to destabilization because of root decay from the removed tree (Gray and Sotir 1996). Lakel et al. (1998) evaluated the forested earthworks at the Richmond National Battlefield Park and concluded that windthrow of larger, older trees had caused significant damage to earthworks and that the National Park Service should attempt to identify and remove at-risk trees.

2.1.6 Fire Induced Erosion

Fire, in controlled situations known as prescribed burning, is another potential option for maintaining grasses and some forests. The use of fire to promote biological change is a natural cycle in some communities as well as one that can be manipulated by humans. For thousands of years natural and Native American-caused fires have played a dominant role in maintaining species diversity and in shaping the composition of forests (Pritchett and Fisher 1987). Some plant species, such as longleaf pine (*Pinus palustris*) and wiregrass (*Cynodon dactylon*), actually require fire to naturally reproduce.

In the United States, fire was traditionally used to provide better access, improve hunting, and get rid of brush and timber for agricultural activities, but uncontrolled wildfires left millions of acres of forest land in the south without trees (Wade and Lunsford 1989). Today land managers use prescribed fire to manage pine plantations as well as range and other agricultural purposes because there are few alternatives that are as effective and inexpensive (Wade and Lunsford 1989).

In a forested environment, prescribed burning has many useful attributes that include the following (Wade and Lunsford 1989):

Reduce hazardous fuels
Prepare sites for seeding and planting
Dispose of logging debris
Improve wildlife habitat
Manage competing vegetation
Control disease
Improve forage for grazing
Enhance appearance
Improve access
Perpetuate fire-dependent species
Cycle nutrients
Manage endangered species

In order to obtain the burning objectives, sites are burned when conditions promote high intensity fires, but low severity impacts. For prescribed burns such as a fell and burn treatment, a burn of light severity to the ecosystem and the forest floor is the goal of managers (Swift et al. 1993). The degree of soil moisture, fuel moisture, and weather determines the containment of the fire to a predetermined area and at an intensity of heat and rate of spread required to accomplish the objectives (Pritchett and Fisher 1987). Vose (1994) summarized Swift's et al. (1993) guidelines to achieve a low severity fire: 1000-hr fuels > 25% moisture, 1-hr fuels dry but forest floor (>50% moisture), 10-hr fuels between 10-12% moisture, and 10-hr fuels in uncut areas > 14% moisture. Another factor that must be predetermined is the time of year to burn. Swift et al. (1993) suggested burning in the southern Appalachians in August rather than late September because ground cover was able to establish itself before winter.

Fires that burn at low intensities generally do not consume the duff layer, and therefore have only slight effects on the nutrient recycling process, soil pore space, and infiltration rates. Sweeney and Biswell (1961) studied four test fires in ponderosa pine (*Pinus ponderosa*) in California and found that only 23 percent of the duff horizons were consumed. Ottmar and Vihnanek (1991), found that a prescribed burn classified as light, in a southern Appalachian pine-hardwood stand, that had received a fell and burn treatment had a mean reduction of duff thickness ranging from 67% to 30% over the study sites. The physical properties of a soil are usually unaffected if duff remains after a burn (Wade and Lunsford 1989).

The moist organic matter directly adjacent to the mineral soil is normally unaffected by a burn, but burning when fuel and/or soil moisture conditions are extremely low can cause elevated temperatures which may ignite organic matter and alter the structure of soil clays (Wade and Lunsford 1989). These extreme temperatures usually happen where large concentrations of debris or logs burn for an hour or more resulting in soil damage denoted by small spots of soil baked red (Smith 1986). The loss of the organic cover following intense fires can decrease rainfall interception, increase soil detachment, decrease infiltration rates, and increase sheet erosion.

For wildfires or poorly conducted prescribed burns, sediment transport may be increased due to the loss of standing biomass and litter, and under the right circumstances, hydrophobic conditions (Hester et al. 1997). The objective of a study by Hester et al. (1997) was to assess the influence of prescribed burning on the infiltration and sheet erosion of vegetation types dominated by live oak (*Quercus virginiana* Mill), Ashe juniper (*Juniperus ashei* Buchh), bunchgrass (*Sporobolus wrightii*), or shortgrass (*Hilaria cenchroides*). Their data indicated that prior to the burn, oak and juniper infiltration rates were significantly higher than the bunchgrass, which was significantly higher than shortgrass. Sheet erosion prior to the burn followed a similar trend. They concluded that burning caused a decrease in infiltration rates and an increase in sheet erosion, causing an increase in sediment yield. One exception was that the fire caused hydrophobic conditions under the oak vegetation type, substantially decreasing infiltration rates and increasing erosion, but it still yielded less sediment than did the bunchgrass or shortgrass. They also found that infiltration rates of the burned oak and juniper vegetation types were still higher than that of the unburned grassland. These results show that greater organic matter cover and the improved soil structure under the trees resulted in higher infiltration rates and decreased sheet erosion as compared to grassland.

2.1.7 Mowing

Maintenance of grass varies with the species selection. A low maintenance grass requires less frequent mowing but will be less vigorous. More frequent mowing stimulates tillering, which results in a dense sward but at the same time reduces the depth and density of the roots (Coppin and Richards 1990). Grasses used for surface erosion control should be medium in height, 150-300 mm, and be cut 1 to 3 times per year. These grasses should, however, be cut more frequently if tussock grasses develop and could even be burned to control shrubs (Coppin and Richards 1990).

Mowing can cause grass failures. In situations where turf is the ground cover, the preferable clipping height is 5 cm. Mowing closer than 3.8 to 5 cm does not allow enough leaf surface to build, which hinders vigorous root development. Poorly developed roots will result in poor ground cover and lead to the invasion of low-growing weeds. If mowing needs to be closer than 3.8 cm, bent grasses, the Bermudas grasses, and the zoysias should be used (Conover 1977).

2.2 Soil Erosion Estimation, Measurements, and Solutions

2.2.1 Estimation of Soil Erosion

Up until 1954 soil erosion estimates were made with technologies based on local data. These small data sets made it difficult to accurately estimate soil erosion with any type of a national standard. In order to create a national standard, the National Runoff and Soil-Loss Data Center was established in 1954 by the United States Department of Agriculture, Agricultural Research Service (Toy et al. 1999). These efforts lead to the development of the Universal Soil Loss Equation (USLE) released in 1965 and revised in 1978 (Wischmeier and Smith 1965, 1978). The Universal Soil Loss Equation was adapted for forest land by (Dissmeyer and Foster 1984).

The original USLE is an empirical equation originally designed to estimate rill and sheet erosion from agricultural lands. More than 10,000 plot years of data from natural runoff plots were used to derive this equation. The USLE is as follows:

A=RKLSCP

Where A = the estimated annual soil loss per unit area.

R = the rainfall and runoff factor for a specific area expressed in terms of average erosion index (EI) units.

K = the soil erodibility factor, which accounts for the soil erodibility by evaluating a combination of the soil's texture, organic matter, structure, and permeability.

L = the slope-length factor, which is defined as the "distance from the origin of overland flow to the point where either the slope gradient decreases enough that deposition begins or the runoff becomes concentrated (Dissmeyer and Foster 1984)."

S = the slope-steepness factor, which is the gradient of a uniform slope.

C = the cover and management factor, which is the ratio of soil loss from an area with specific cover and management.

P = the support practice factor, which is the ratio of soil loss with a support practice such as contour disking (Dissmeyer and Foster 1984).

Dissmeyer and Foster (1984) modified the USLE to predict sheet and rill erosion on forestland. Modifications were made to the cover and management factor C by including nine subfactors that provide more flexibility for different forest conditions.

amount of bare soil

canopy

soil reconsolidation

high organic content

fine roots

residual binding effect

onsite storage

steps

contour tillage

Today, the original USLE has been revised for improved uses with newer technology and data for additional sites, allowing for soil loss estimations from undisturbed lands, disturbed lands, and newly established reclaimed lands using a computer program. The Revised Universal Soil Loss Equation (RUSLE) is the 3rd major version of the USLE since 1965. It was created using the same equation structure of the USLE, but each of the factors has been updated with newer data or new relationships have been derived from the modern theory of erosion (Soil and Water Conservation Society 1993). The most current version is the Guidelines for the Use of the Revised Universal Soil Loss Equation (RUSLE) version 1.06 on Mined Lands, Construction Sites, and Reclaimed Lands (Toy and Foster 1998).

The most significant changes to the USLE have been made through improvements to its factors and the use of a computer-based program to calculate the factors. The R factor has been improved by including many more weather stations that are able to give localized climate values through the RUSLE CITY database. K values have been modified by the inclusion of time-of-year erosion differences and the multivariate influence of rock-fragment cover within soil profiles and surfaces. The LS factor has been refined for improved accuracy and to include steeper hillslope gradients. The C factor has added 5 additonal subfactors, which include prior land use (PLU), canopy cover (CC), surface cover (SC), surface roughness (SR), and antecedent soil moisture (SM). Only the first four are used in the eastern portion of the United States. In addition, the C factor takes into account multivariate influence of rock-fragment cover within soil profiles and surfaces as well as biological changes over time. The RUSLE contains a VEGETATION database to help users characterize various plants for the C factor computations. It also provides the OPERATIONS database to characterize effects of various soil-disturbing activities. The P factor has been developed to accommodate a wide range of site-specific practice conditions and can estimate sediment yield for concave hillslopes (Toy and Foster 1998).

2.2.2 Soil Erosion Measurements

Soil erosion can be measured directly in the field by several different methods. The most commonly used are soil erosion plots and erosion pins. Erosion plots measure soil erosion rates by measuring the amount of soil that washes from the plot. These plots range in size from 1 m^2 to 1.9 m x 22 m. The edges of the plot are made of plastic, sheet metal, plywood, or concrete with a collecting trough located along the width of the lower boundary. Runoff from the plot empties into the collecting trough which then empties into a container, or tank, to get a runoff and sediment measurement (Brooks et. al. 1997). Erosion pins are another method of erosion measurement. The erosion pins consist of a long metal rod inserted flush into the ground and is measured by the distance between the head of the nail and the soil surface. As erosion occurs the distance between the head of the pin and the soil increases. The typical length of the erosion pin is 300 mm with a width of 5 mm (Hudson 1993).

2.2.3 Slope Stabilization

Stabilizing bare slopes such as cut and fill slopes along roadsides, dam embankments, or earthworks are based on the same principles: unprotected soils are susceptible to soil erosion. The impact to a bare slope from rainfall and overland flow is dependent upon the slope length, slope gradient, climate, soil type, and the time of year.

Rill, sheet, gully, and mass wastage are all forms of erosion that can be found on bare slopes. On steep dry slopes that have unprotected soil, erosion can also take place by dry ravel. Dry ravel is the process of soil rolling down steep hillsides, usually steep roadsides, because the water that held the soil particles together completely evaporated, allowing gravity to pull the soil particles down hill (Berglund 1978).

Potential slope stabilization options include armoring with options such as riprap, earth-crete stabilizers, gabions, surfacing geotextiles, and vegetation (Lakel et al. 1998). For situations where aesthetics are important, establishment of vegetation is the most natural and attractive method of controlling erosion. Vegetation can help stabilize exposed soil on steep hillsides by shielding the soil from raindrop impact and holding it in place with a well-anchored root system (Adams 1983). Berglund (1978) found that in order to reduce soil erosion on steep slopes you need 40 to 50% plant cover and approximately 70 to 80% plant cover to control the erosion. Vegetation has its limitations depending on the soil loss circumstances. In the event of embankment failures vegetation has little control. Causes of slope failure include: removal of support material from the toe of slope, overloading or over steepening slopes, and excess water levels in the slope (Gray and Leiser 1982).

Commonly a mixture of grass and legumes are used to control erosion on cut banks. These mixtures usually contain 5 different plant species and legumes to fix nitrogen in the soil (Berglund 1978). Depending upon the type of site preparation, several techniques of vegetation establishment can be used. On cutbanks and fillslopes, a combination of seeding, fertilization, and mulching should be used. Slopes that are 1 to 1 or less should be fixed with seed sowing devices while steeper slopes will require a plaster technique to seed, fertilize, and mulch (Berglund 1978). These plastering techniques can be performed with a hydroseeder, which has specific hydroseed formulas based on soil type, condition, acidity, amount of vegetation required, and climate (Hayden 1984). It is important to use plant species that are local to the soil and climate as well as planting during the spring and fall when temperatures are moderate and the moisture is sufficient (Adams 1983).

3. Materials and Methods

3.1 General Location

This project consists of three study areas located at Fort Harrison and Fort Gilmer within the Richmond National Battlefield Park and Colonial Battlefield (Figure 2).

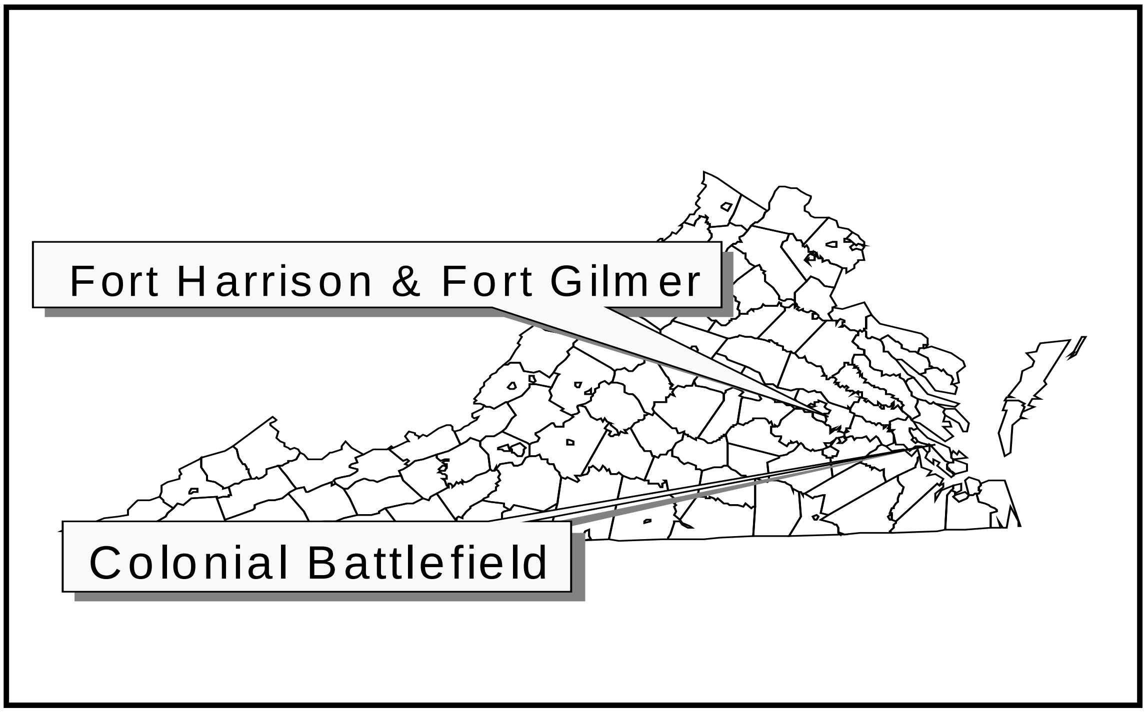


Figure 2. Project study areas in Virginia.

Due to the logistical contraints of the National Park Service, this study was designed to take advantage of the locations where the various management options were being administered.

Fort Harrison, part of the Richmond National Battlefield Park, provided the best location to test prescribed burning, trimming, and a forested treatment. Fort Gilmer, part of the Richmond National Battlefield Park, is located approximately one mile to the north of Fort Harrison and this area provided a park-forest treatment. Colonial Battlefield was used to examine the mowed treatment on earthworks, because areas of mowed earthworks were limited at the Richmond National Battlefield Park and the National Park Service wished to include more administrative units. Sampling was performed on two types of earthworks, breastworks and forts (Figure 3). In general, the breastworks in the study were significantly smaller in size then the forts. They were developed to form long defensive lines around cities while the forts were used to defend strategic areas with large cannons. In general, the breastworks are of less interest to visitors so they are typically managed in a less intensive fashion than are forts.

Figure 3. Example of a breastwork (left) and a fort (right).

3.2 Site Description

3.2.1 Fort Harrison

Fort Harrison is located adjacent to State Highway 5, approximately 13 kilometers southeast of Richmond, in Henrico County, Virginia within the Coastal Plain physiographic province (Figure 4). Recorded climatic data was obtained from Byrd Air Field, Richmond, Virginia. The average temperatures range from 12.8^0 to 15.6^0 C with a maximum temperature of 32.2^0 C and a minimum temperature of 0^0 C. The county averages 1.1 meters of annual precipitation. Based on air temperatures, the average growing season for the county typically lasts from March 11 until November 23 (U.S. Dept. of Agriculture 1975).

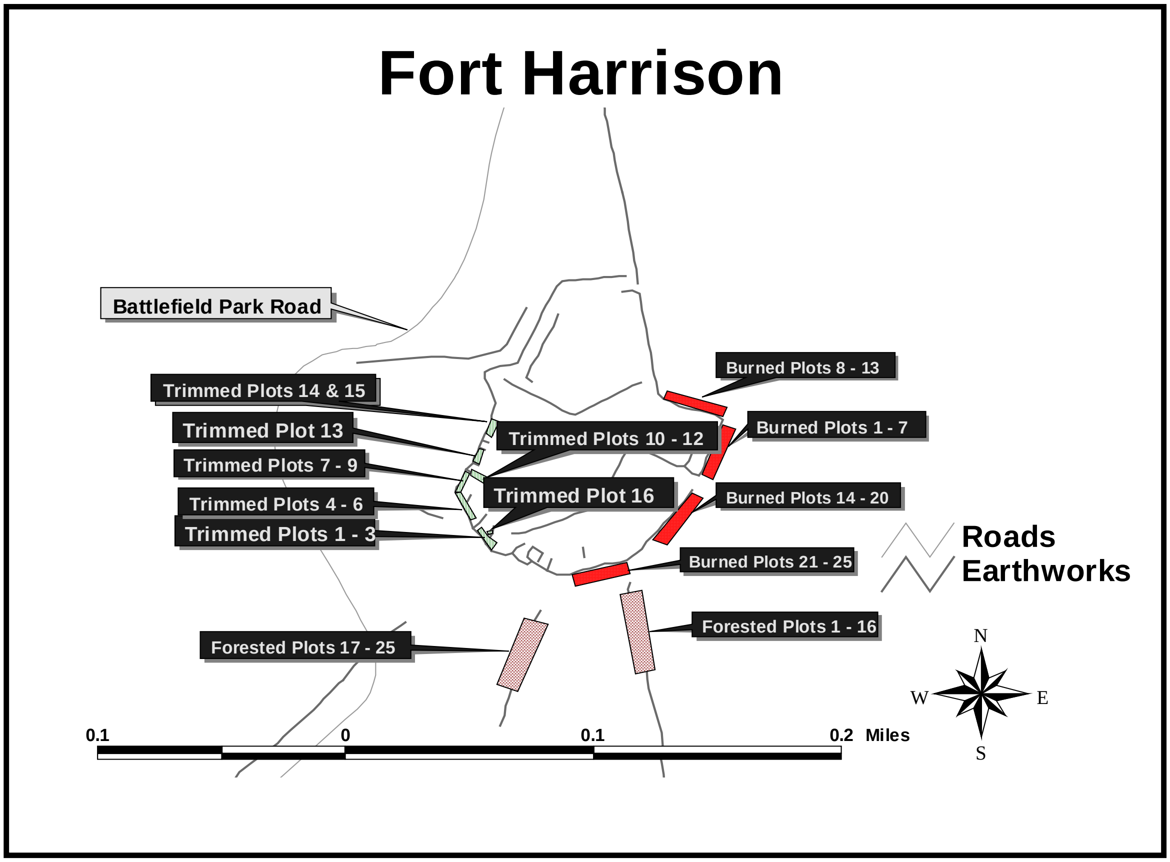


Figure 4. Fort Harrison study site with plot locations.

Because the construction techniques used to build earthworks mixed and inverted the soil horizons, it is important to realize that the soil descriptions only provide general characteristics of soils on the earthworks. In general, the subsurface horizons formed the original earthwork surfaces. Specific soil data needed from surface layers was gathered in the field and determined through lab analysis. Chapter 6 will provide detailed information concerning a limited number of soil profiles that were conducted on the earthworks.

Undisturbed soils located near Fort Harrison consist of Turbeville fine sandy loam (Clayey, mixed, thermic Typic Paleudults) on 2 to 6 percent slopes. The soils are deep, well drained, and found on somewhat broad, slightly convex ridges formed in alluvial material. Small areas of well-drained Kempsville soils (Fine-loamy, siliceous, thermic Typic Hapludults) and areas of gravelly soils can be found associated with Turbeville soils. The typical profile consists of a surface layer that has a brown fine sandy loam texture 18 cm thick. The subsoil is 190 cm thick, consisting of a yellowish-red sandy clay loam in the upper 13 cm and dark-red clay to 190 cm. Soils found between 208 to 277 cm + are red, brownish-yellow, and light-gray clay. These sandy loam - sandy clay loam textured soils have a medium water holding capacity and a moderate permeability in the subsoil. The runoff potential is medium with a moderate erosion hazard if the soil is disturbed and left without plant cover.

Fort Harrison had the burned and trimmed treatments located within its boundaries. Additionally, breastworks extending perpendicular to Fort Harrison's southern walls were used as the forested treatment (Figure 4). Vegetation located on the burned plots consisted of a variety of turf grasses, lawn weeds, native grasses, wildflowers, and small saplings. These plots had been planted with native tall grasses several years ago with minimal success. The most common species found were little bluestem (*Andropogon scoparius*), weeping lovegrass (*Eragrostis curvula*), Downy chess (*Bromus tectorum*), fescue species (*Festuca spp.*), Japanese honeysuckle (*Lonicera japonica*), and sweet gum (*Liquidambar styraciflua*). Vegetation on the trimmed plots consisted of a variety of fescue species, Japanese honeysuckle, and Reed canary grass (*Phalaris arundinacea*). The forested treatment plots consisted of a mixed age oak/pine forest cover type. Scarlet oak (*Quercus coccinea*) was the dominant tree in the overstory with a mixture of Virginia pine (*Pinus virginiana*), sweet gum, flowering dogwood (*Cornus florida*), American holly (*Ilex opaca*), and an occasional hickory (*Carya spp*).

The physical dimensions of the three treatment plots differed greatly, indeed, physical dimensions are often used by managers to determine which treatment to apply. The burned plots had slope lengths from 4.5 m to 8.7 m while the trimmed plots ranged from 1.1 m to 4.1 m and the forested plots 2 m to 3.1 m. Burning is attractive on these longer slopes where mowing or trimming are more difficult. The percent slope also differed with the burned plots ranging from 36% to 80%, the trimmed ranging from 46% to 100+%, and the forested ranging from 31% to 68%. The greater slope percentages of the trimmed plots are one of the factors that may preclude mowing.

3.2.2 Fort Gilmer

Fort Gilmer is located in the Richmond National Battlefield Park approximately 1.6 kilometers north of Fort Harrison on Battlefield Park Road in Henrico County, Virginia (Figure 5). Physiographic and climatic characteristics of this site are identical to For Harrison.

Undisturbed soils located at Fort Gilmer consist of Kempsville very fine sandy loam, clayey substratum 0 to 2 percent and Ruston fine sandy loam (Fine-loamy, siliceous, thermic Typic Paleudults) 2 to 6 percent slopes. The Kempsville soils are deep, well drained, and found on broad ridges formed in coastal plain sediments. Included in these soils are small areas of moderately well drained Atlee soils in small depressions and small areas of well-drained Caroline (Clayey, mixed, thermic Typic Paleudults) and Faceville soils (Clayey, kaolinitic, thermic Typic Paleudults). The typical profile consists of a brown fine sandy loam surface layer 28 cm thick. The subsoil is 124 cm thick, consisting of a yellowish-brown heavy fine sandy loam in the upper 15 cm. The next 33 cm are a yellowish-brown sandy clay loam followed by a strong-brown sandy clay loam for 58 cm. Depths below 127 cm from the soil surface may also have a clay loam and clay texture. The substratum ranges from 152 to 274 + cm consisting of gray material below 183 cm and loamy fine sand below 203 cm. Kempsville soils have a medium available water holding capacity and moderately permeable subsoil.

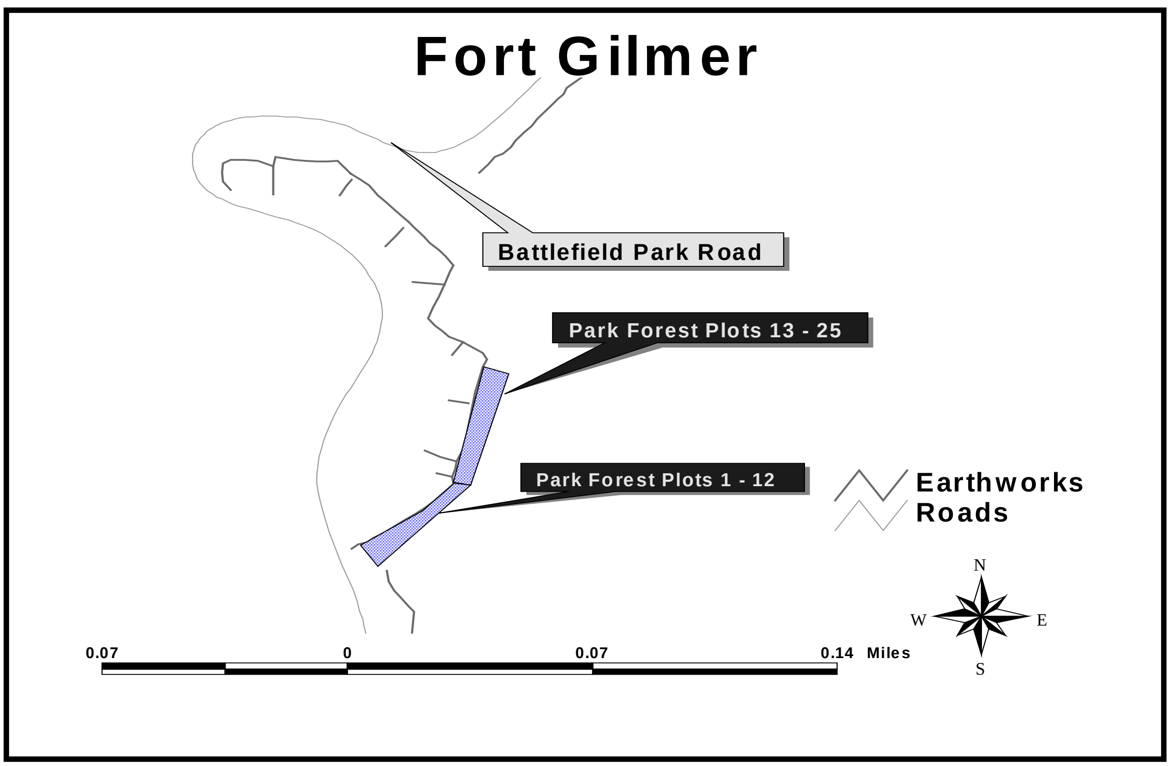


Figure 5. Fort Gilmer study site with plot locations.

Ruston soils are deep, well drained, and found on weakly convex ridges formed in coastal plain sediments. These soils also include small areas of well drained Faceville and Norfolk soils (Fine-loamy, siliceous, thermic Typic Paleudults). A typical profile of these soils consists of a surface layer that has a grayish brown to yellowish-brown fine sandy loam in the upper 28 cm. The subsoil is 226 cm thick with a strong-brown sandy clay loam in the upper 18 cm, a yellowish-red-brown clay loam in the next 135 cm, and a red and reddish-yellow light clay loam in the lower 76 cm. The substratum begins at 254 cm and continues to a depth of 361 cm +. It consists of a mottled red, gray, and olive-yellow clay loam. The Ruston soils have a high available water capacity and medium permeability. These soils also have a medium runoff potential with a moderate erosion hazard (U.S. Dept. of Agriculture 1975).

The park-forest plots were located on the outer wall of Fort Gilmer near the visitor parking location. The vegetation consisted of mature (60 - 100 year old) Virginia pine, white oak (*Quercus alba*), and southern red oak (*Quercus falcata*). The slope lengths ranged from 2.5 m to 7.1 m and ranged in slope steepness from 36% to 100%. The park-forest condition is maintained here because it provides enhanced viewing of this relatively small battery, with less effort and expense than some of the other options that favor views.

3.2.3 Colonial Battlefield

The Colonial Battlefield in the Colonial National Historical Park is near the intersections of Colonial National Historical Parkway and VA Route 238 in York County, Virginia (Figure 6). Colonial Battlefield lies in the Atlantic Coastal Plain physiographic province in an area locally called the "Peninsula." The temperature and precipitation was recorded in the period of 1951 to 1976 in Williamsburg, Virginia. Mean annual temperatures range from 5^0 C during the winter to 24.4^0 C during the summer with a daily minimum of -1.1^0 C and a maximum of 30.6^0 C respectively. York County has an average annual rainfall of 1.1 meters, of which approximately 55% occurs in April through September. The typical growing season lasts from March 14 to November 22.

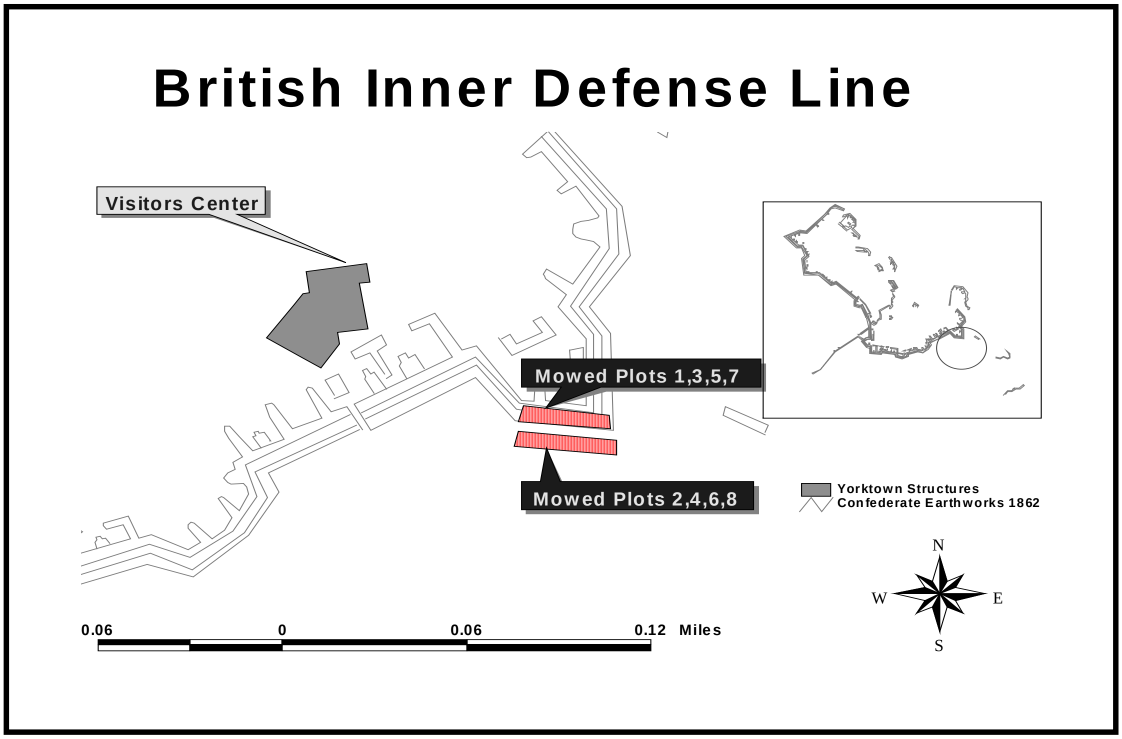


Figure 6a. Colonial Battlefield study site with plots 1 - 8.

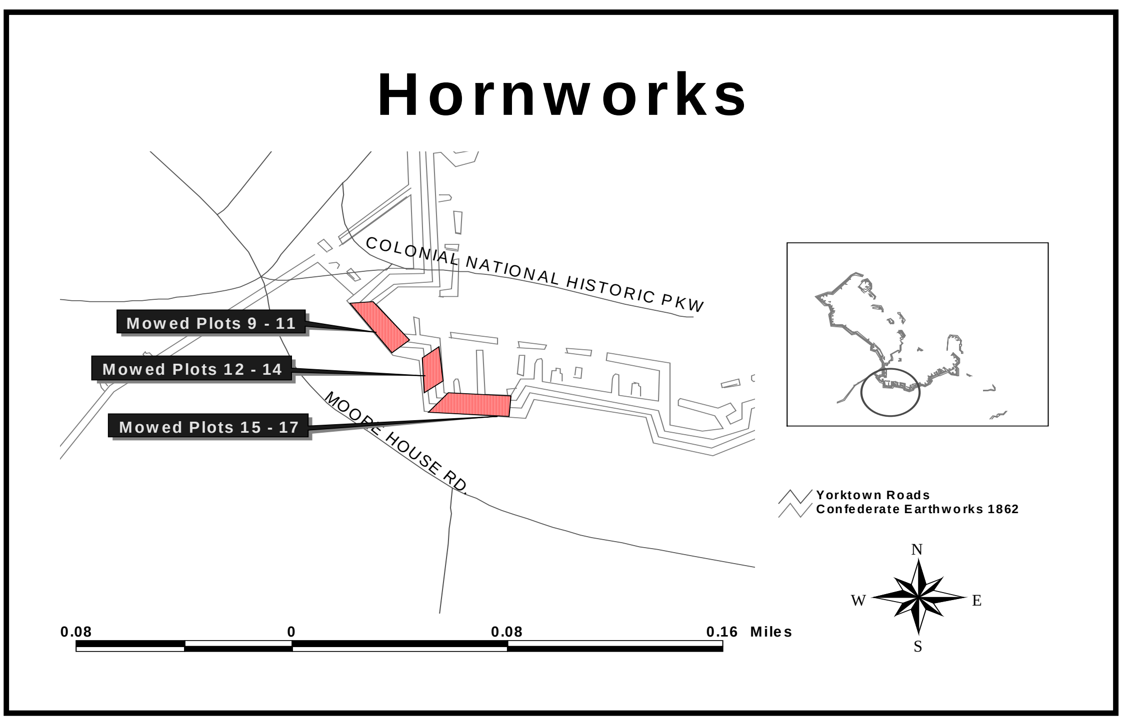


Figure 6b. Colonial Battlefield study site with plots 9 - 17.

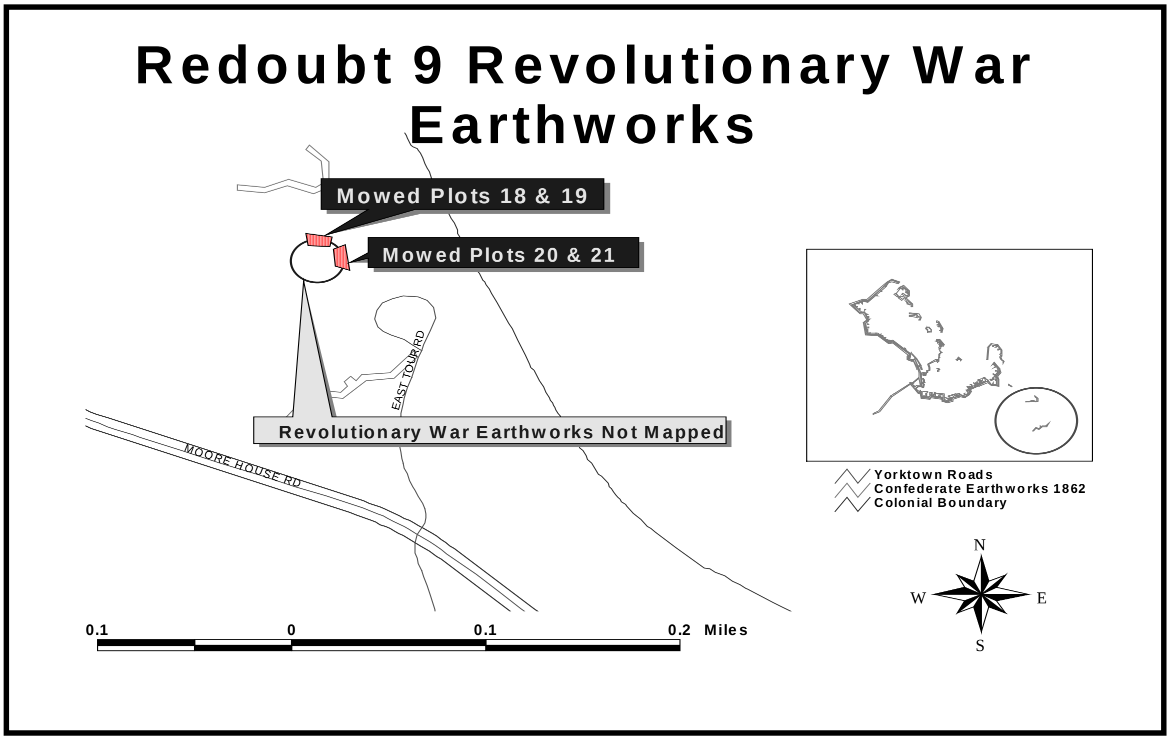


Figure 6c. Colonial Battlefield study site with plots 18 - 21.

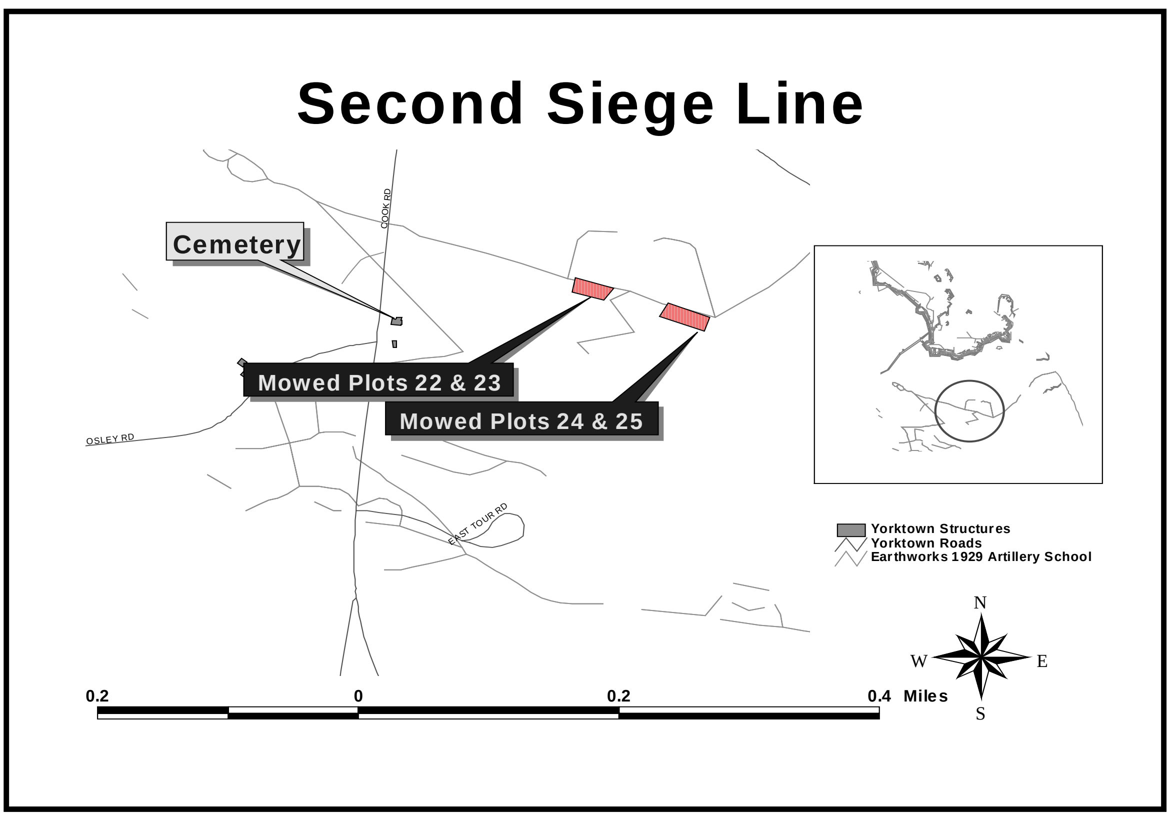


Figure 6d. Colonial Battlefield study site with plots 22 - 25.

The undisturbed soils located in and around the earthworks at Colonial Battlefield consist of Slagle fine sandy loam (Fine-loamy, siliceous, thermic Aquic Hapludults) 0 to 2 percent slopes and 2 to 6 percent slopes, Pamunkey soils (Fine-loamy, mixed, thermic Ultic Hapludalfs) 2 to 6 percent slopes, and Craven-Uchee complex (Clayey, mixed, thermic Aquic Hapludults)-(Loamy, siliceous, thermic Arenic Hapudults) 6 to 10 percent slopes.

The Slagle soils are deep and moderately well drained. They are found on upland terraces, slight depressions, broad flat uplands, and upland side slopes. These soils typically have a brown fine sandy loam surface layer about 10 cm thick. Their subsurface layer is a light yellowish-brown fine sandy loam 13 cm thick. Subsoil with a clay loam and sandy clay loam textures extends to a depth of 127 cm and is mostly mottled yellowish-brown. Below a depth of 127 cm is a substratum, which is a mottled sandy clay loam. Small areas of Emporia, Kempsville, Uchee, Izagora (Fine-loamy, siliceous, thermic Aquic Paleudults), Peawick (Clayey, mixed, thermic Aquic Hapludults), Yemassee (Fine-loamy, siliceous, thermic Aeric Ochraquults) and Bethera soils (Clayey, mixed, thermic Typic Paleaquults) are included in this mapping area. The soil permeability ranges from moderate in the upper horizons to slow in the lower part. They have a moderate available water holding capacity, slow to medium runoff, and a slight to moderate erosion hazard.

Pamunkey soils are deep, gently sloping, and well drained. These soils can be found on broad high terraces. The typical profile is a dark grayish-brown sandy loam about 10 cm thick with a brown sandy loam subsurface layer 25 cm thick. Subsoil extends to a depth of 109 cm and is a yellowish-brown sandy loam and dark brown sandy clay loam. The substratum extends to at least 190 cm and is strong brown loamy sand and sand. Bojac (Coarse-loamy, mixed thermic Typic Hapludults), Altavista (Fine-loamy, mixed, thermic Aquic Hapludults), Dogue (Clayey, mixed, thermic Aquic Hapludults), and Tetotum (Fine-loamy, mixed, thermic Aquic Hapludults) soils are found associated with Pumunkey soils in small areas. Pumunkey soils have a moderate available water holding capacity, moderate permeability, medium surface runoff, and a moderate erosion hazard.

The Craven-Uchee soils complex is moderately well drained for Craven soils to well drained for Uchee soils. These soils are deep, strongly sloping, and found on side slopes and narrow ridge tops. Craven soils are typically composed of a dark grayish-brown fine sandy loam surface layer 10 cm thick, a pale olive fine sandy loam subsurface layer 13 cm thick, and a yellowish-brown clay to a sandy clay loam with mottles in the lower part of the subsoil to a depth of 107 cm. A fine sandy loam to loamy fine sand can be found to a depth of 190 cm or more. Uchee soils are typically composed of a dark grayish-brown loamy fine sand surface layer 13 cm thick, a light yellowish-brown and very pale brown loamy fine sand subsurface layer 23 cm thick, and a strong brown sandy clay loam to a mottled clay subsoil at a depth of 142 cm. A sandy loam and sandy clay loam can be found to at least 165 cm. Caroline, Emporia (Fine-loamy, siliceous, thermic Typic Hapludults), Kempsville, and Slagle soils are included in small areas with these soils. Permeability for this complex ranges from slow to moderate with a moderate and low or moderate available water holding capacity. Surface runoff is rapid and the erosion hazard is severe (U.S. Dept. of Agriculture 1985).

The mowed treatment plots were located in the Colonial National Historical Park. The vegetation consisted of a mixture of grasses and wildflowers, which included sweet vernalgrass (*Anthoxanthum odoratum*), Downy chess, velvet grass (*Holcus lanatus*), and a figwort species (*Scrophularia spp*.) Plots slope lengths ranged from 2.6 m to 10.35 m with percent slopes of 57 % to 100% +.

3.3 Treatments

A total of five management regimes were used as treatments for this study because they reflected the major current management regimes used by the National Park Service for Civil War Earthworks. These five management regimes/treatments were prescribed burning, mowing, park-forest, forested, and trimming. Ideally these treatments would have been applied to uniform earthworks on uniform sites and replication would have occurred on all sites. However, the National Park Service has logistical and historical constraints, which precluded true replication. Therefore, treatments were applied where and how they would normally have been applied.

3.3.1 Burned Treatment

Burning of earthworks is a relatively new management technique for the Richmond National Battlefield Park, but it is being examined as a method that could be used to maintain native herbaceous species in a logistically feasible manner. The principal disadvantages of burning are due to the inherent need for caution, the unpredictability of good burning days, and the need for trained fire personnel.

The Richmond National Battlefield Park has recently used prescribed burning as a management technique every 2-5 years to promote the regeneration of native grasses, control woody plants, and control other invasive species along the earthworks in Fort Harrison. A total of 25 plots measuring 5 m wide by the length of the slope were installed along the eastern outer wall of Fort Harrison (Figure 4). Officials from the Richmond National Battlefield Park and the Shenandoah National Park used a prescribed burn at Fort Harrison on March 15, 2000. All of the earthworks at Fort Harrison were burned except for a section along the inner western wall where trim plots had been installed (Figure 4). As depicted in Figure 7, herbaceous and woody vegetation were successfully burned. The burn treatment plots were also trimmed on June 8, 2000.

Figure 7. Herbaceous vegetation during and after fire at Fort Harrison.

3.3.2 Mowing Treatment

The mowing treatment tends to be used in situations where earthworks are highly visited and grass/herbaceous cover is desired. Mowing is fast, efficient, and maintains desired vegetation in many areas. However, mowing may actually traffic earthworks and may not be suitable for some desired native herbaceous plants. Lakel et al. (1998) found that mowing of earthworks at Cold Harbor Unit may occasionally actually remove the tops of smaller, individual soldier type earthworks.

The mowing treatment was located at the Colonial National Historical Park. A total of 25 plots measuring 5 m wide by the length of the slope were installed (Figure 6). From September 25 through October 6, 2000 plots were mowed to an approximate height of 15 cm with a boom arm mower that was able to cut the grass on the earthworks without driving the tractor on them (Figure 8).

Figure 8. Example of boom arm mower cutting earthworks at the Colonial National Historical Park.

3.3.3 Park-Forest Treatment

This treatment is used in areas that have high visitor visibility or in areas that had a somewhat open forest during the time of Civil War battles, such as Cold Harbor. This treatment has significant display advantages yet may not provide ideal cover in all situations. Specifically, the park-forest treatment maximizes the disadvantages of increased canopy drip from greater heights while minimizing the advantages of canopy layer and the litter layer.

The park-forest treatment was located along the outer wall of Fort Gilmer at the visitors parking lot (Figure 5). A total of 25 plots measuring 5 m wide by the length of the slope were installed. Maintenance activities were performed on June 15, 2000 and consisted of trimming the woody understory with triple blades and line fed weed eaters to an approximate height of 10 cm (Figure 9). The trimming of the understory gives the earthworks a park-like setting (Figure 9).

Figure 9. Maintenance personal trimming (left) to give the park-like setting (right).

3.3.4 Forested Treatment

This treatment is typically used in areas having less dramatic historical associations or in more remote areas. In some areas, such as the Petersburg Battlefield, this is actually the most common type of management. The forested treatment stabilizes the earthworks naturally, however it restricts visitor views and large trees of older ages can significantly damage earthworks during windthrow events.

The forested treatment had no maintenance activities performed and was located on the southern breastworks of Fort Harrison (Figure 4). Figure 10 depicts a typical example of the forested earthworks.

Figure 10. Example of the forested treatment earthworks.

3.3.5 Trimmed Treatment

Trimming is used on areas that are inaccessible by a mower, but where grass or herbaceous vegetation is desired. The advantage of trimming is that it provides visibility and maintains the vegetation on steep terrain. However, trimming is very labor intensive and does require traffic on the earthworks. Additionally, trimming on steep slopes was personally observed to displace litter and soil as worker's boots slipped on steep side slopes.

The trimmed treatment was located on the inner western wall of Fort Harrison (Figure 4). A total of 16 plots measuring 5 m wide by the length of the slope were installed. The trimmed treatment plots were trimmed twice during the duration of the study. Trimming was performed with a triple blade that is capable of removing woody vegetation up to 4 cm in diameter and a line fed weed eater to remove grass down to approximately 10 cm (Figure 11). Trimming was performed on June 8 and October 6, 2000.

Figure 11. Picture of a triple blade and of maintenance personnel trimming earthworks.

3.4 Field Sampling

3.4.1 Erosion Estimates

Empirical Formulas

Erosion estimates from each of the five management regimes were obtained using the Revised Universal Soil Loss Equation (RUSLE), version 1.06, on Mined Lands, Construction Sites, and Reclaimed Lands as well as a variation of the RUSLE based on seasonal variations of the K factor, which was called the Seasonal Revised Universal Soil Loss Equation (SRUSLE) for this project (Toy and Foster 1998). The RUSLE was compared to another version of the USLE, A Guide for Predicting Sheet and Rill Erosion on Forest Land, which was referred to as the Dissmeyer and Foster for this project (Dissmeyer and Foster 1984).

Both the Dissmeyer and Foster and RUSLE estimation methods are modifications of the Universal Soil Loss Equation, which is an empirical formula, based on 10,000 plot years of runoff and soil loss data (Wischmeier and Smith 1978). Both of these models predict erosion based on an original unit plot 22 meters in length with a uniform 9 percent slope continuously in clean-tilled fallow. In the case of earthwork slopes, none were much longer than 5 m and the earthwork slopes ranged from 60 - 100%, which was greater than these models were designed to predict.

The Dissmeyer and Foster method was designed to predict soil erosion from forested land while the RUSLE was suited to predict soil erosion from cropland and construction sites. The Dissmeyer and Foster is somewhat adapted to estimating soil erosion on pasture-type land because the C factor and subfactors could be interpreted to use the ground vegetation.

The RUSLE was more difficult to adapt. In order to determine a C factor for each plot, knowledge of the plant species root biomass in the upper 10 cm of the soil and the root decomposition rate was required. Due to the variety of plant species on each plot, this was not possible. The Natural Resources Conservation Service did, however, have a C factor chart for areas in permanent pasture called "Pasture C Factors for All Virginia Climate Zones" (USDA Natural Resources Conservation Service 1999). Though the burned, mowed, and trimmed treatments were not exactly permanent pasture, the C factor chart was used. The RUSLE was not used to estimate soil erosion on the forested treatments because the vegetative C value for forest species is not available. The RUSLE did however, have the advantage of being computerized, which speeded calculations. It also allowed the operator to change the K factor for seasonal variability in the soils. The estimated erosion from the seasonal variability in the K factor was compared to the basic RUSLE and the Dissmeyer and Foster.

The RUSLE/USLE are composed of the following factors (Dissmeyer and Foster 1984):

Where A=RKLSCP

A = Average annual soil loss in tons/ac/year

R = the rainfall and runoff factor

K = the soil erodibility factor

L = the slope-length factor

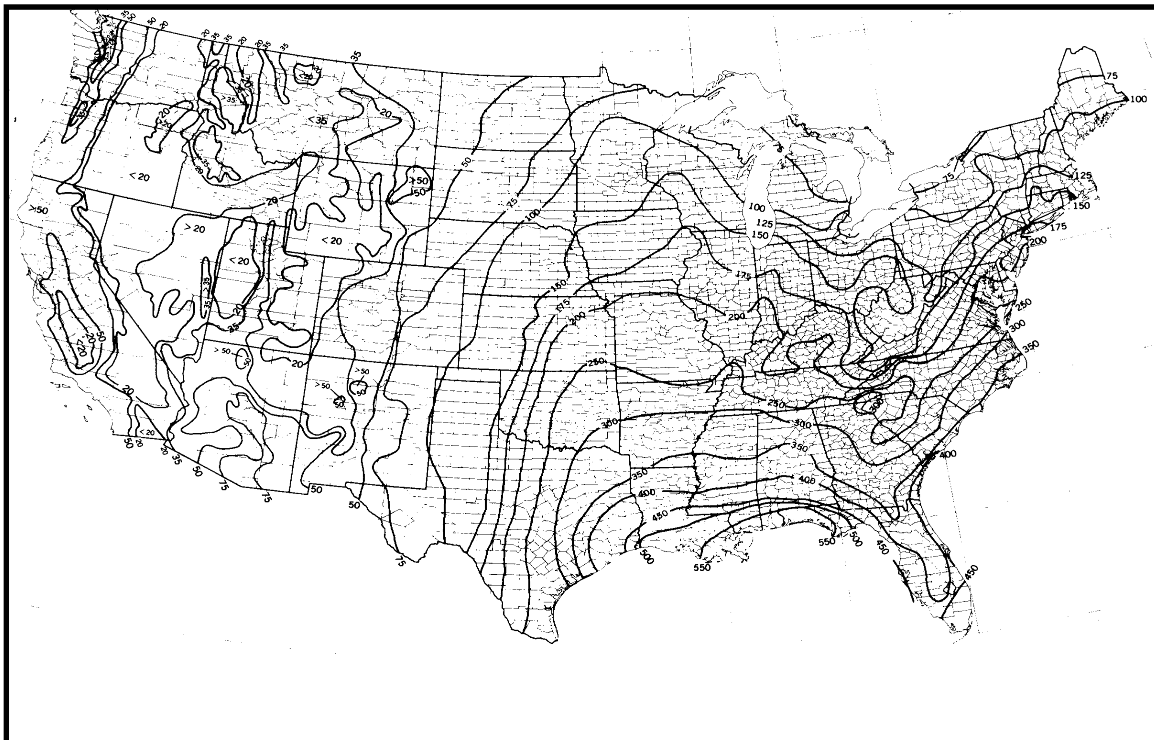
S = the slope-steepness factor

C = the cover management factor

P = the support practice factor

Each of these factors were measured as follows

Rainfall and Runoff Factor (R) -The RUSLE program calculated the R factor for both the RUSLE and Dissmeyer and Foster methods. The R-values from the RUSLE came from its CITY database that stores climatic data for numerous locations. Specifically, the R-value for the Richmond National Battlefield Park was 220 EI units/yr and 250 EI units/yr for the Colonial National Historical Park. These same R-values could be extrapolated from the isoerodent map shown in Figure 12.



[1]Measured in EI units—(100 foot tons/acre) (inches/hour). Wischmeier and Smith (7).

Figure 12. Isoerodent map of the United States. (from Dissmeyer and Foster 1984)

Soil Erodibility Factor (K) - Usually the K factor is provided by the local soil survey or NRCS office but because we were not sure how accurate the soil survey K values were on earthworks, the individual K subfactors had to be calculated. These subfactors consisted of determining the soil's sand % (0.01 - 2.0 mm), organic matter %, structure, and permeability. Once these subfactors were determined, they were hand entered into the RUSLE program, which calculated the K factor for the RUSLE and Dissmeyer and Foster methods. It should be noted however, that the RUSLE program calculated an additional factor for climate into the K value (Toy and Foster 1998). This additional climatic factor produced a K value 20% smaller for the RUSLE when compared to the same value calculated by the Dissmeyer and Foster nomograph. To compensate for the 20% difference, all K values intended for the Dissmeyer and Foster calculations were increased by 20%. For this study, the RUSLE K value was also adjusted for the seasonal variability in the RUSLE program. This K value was used to calculate the SRUSLE. An example of the soil erodibility nomograph from Dissmeyer and Foster is shown in Figure 13.

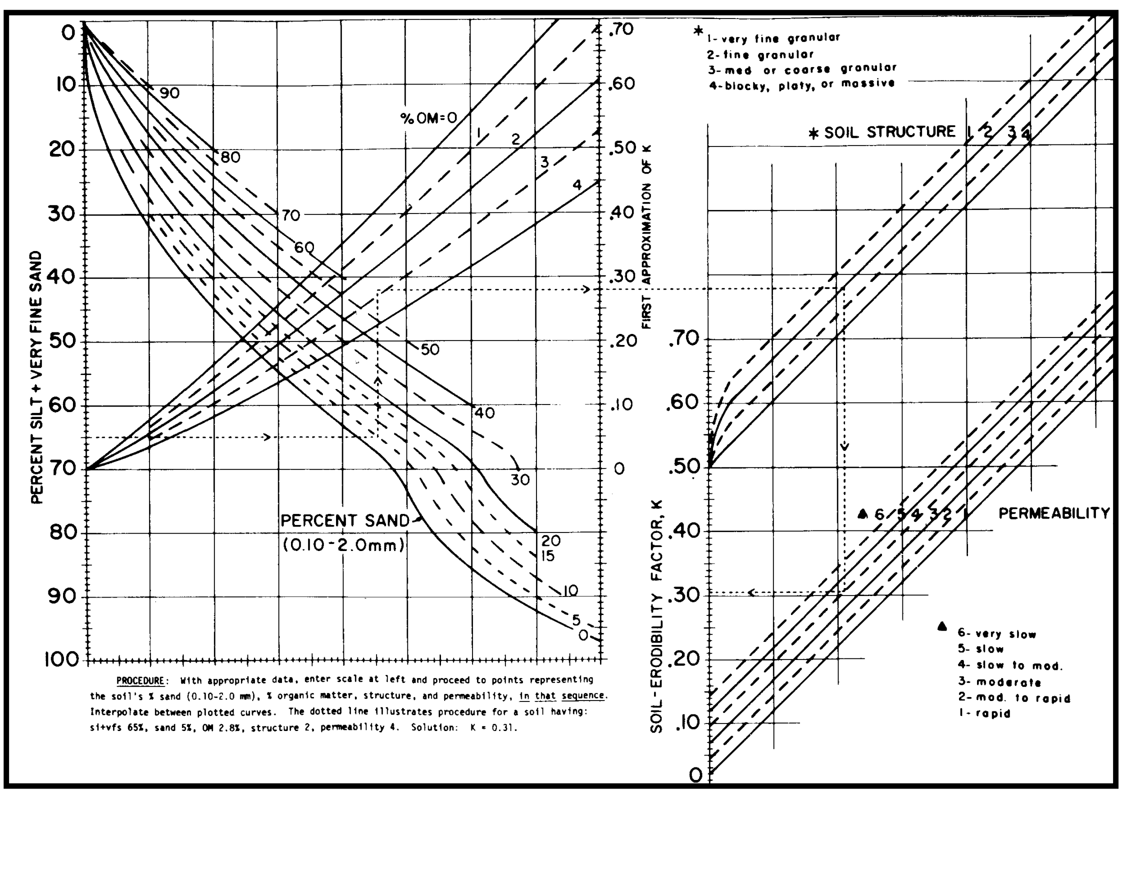


Figure 13. Soil nomograph used to estimate soil erodibility (K). (adapted from Dissmeyer and Foster 1984)

The K factor subfactors were determined by both field and lab techniques. Soil sampling from each plot was performed as follows:

- Five trowel samples were taken to a depth of 5 cm in each treatment sample plot.
- Samples were taken on diagonals starting 30 cm in from the corners. The fifth sample was taken in the center of the plot.
- The five samples from each plot were mixed into one paper bag per plot and labeled.
- Each hole was back filled with similar textured local soil.

These samples were analyzed in the lab to determine the soil texture and % organic matter as explained under Laboratory Methods. The soil structure was determined by field observation and the soil permeability was determined by its soil textural class from table 1 in the RUSLE User's Guide (Soil and Water Conservation Society 1993). It should be noted that one additional step was included in determining the K values and the final erosion estimates for the RUSLE and Dissmeyer and Foster methods. Several plots had organic matter percentages greater then 4%. In calculating the K value, neither the Dissmeyer and Foster nor the RUSLE accept organic matter percentages over 4%. To accommodate for the high organic matter Wishmeier and Smith recommend multiplying the C factor by 0.7 (Wishmeier and Smith 1978). This was done for soils exceeding 4% for both the Dissmeyer and Foster and RUSLE.

Slope Length Factor (L) - The slope length was measured with a metric tape from the point of origin of overland flow to the point where either the slope gradient decreased enough that deposition began or the runoff became concentrated (Dissmeyer and Foster 1984). This measurement was used for the Dissmeyer and Foster and RUSLE.

The following equation was then used to obtain a value for L using the Dissmeyer and Foster method:

$L = (\lambda/72.6)^m$.

Where λ = slope length in feet

And m = 0.5 if the percent slope is 5 or more (Dissmeyer and Foster 1984)

Slope Steepness Factor (S) - The slope steepness was measured to the nearest 1 % using an Abney Level by taking a back site at a rod, at the slope bottom marked at eye level from the top and center of the hill. This measurement was used for the Dissmeyer and Foster and RUSLE. The following equation was used to obtain an S value for the Dissmeyer and Foster method: $S = (65.41\sin^2\theta+4.65\sin\theta+0.065)$. To obtain the final LS factor value for the Dissmeyer and Foster method, both formulas were multiplied together to form the following equation:

$LS = (\lambda/72.6)^m\,(65.41\sin^2\theta+4.65\sin\theta+0.065)$

Where λ = slope length in feet:

Θ = angle of slope in degrees: and

m = 0.5 if the percent slope is 5 or more

(Dissmeyer and Foster 1984)

The LS for the RUSLE was calculated by hand entering the slope length and percent slope into the program.

Cover Factor (C) - The C factor was calculated differently for the RUSLE and the Dissmeyer and Foster methods. Because the RUSLE was only used to estimate erosion on the grass-covered earthworks, a chart prepared by the NRCS called "Pasture C Factors For All Virginia Climatic Zones" was used to determine the C factors (USDA Natural Resources Conservation Service 1999). The percent ground cover and percent canopy cover were used to estimate the C factors from the chart (Figure 14). The C factor was then entered directly into the RUSLE program.

The C factor for the Dissmeyer and Foster method was comprised of 6 individual subfactors that were evaluated in the field and from lab results: ground cover %, canopy cover %, fine roots %, steps%, onsite storage, and organic matter content. Once these 6 subfactor values were recorded, unitless values were derived from Tables 3, 5, and 7 in the Dissmeyer and Foster manual. Multiplying all 6 values together derived a final C factor value. The organic matter content subfactor was only applied to plots that had more than 4% organic matter, which were multiplied by 0.7.

PASTURE C FACTORS FOR ALL VIRGINIA CLIMATIC ZONES

GROUND COVER (%)	CANOPY COVER (%) 0	10	20	30	40	50	60	70	80	90
10-H*	0.016	0.015	0.013	0.012	0.01	0.008	0.007	0.005	0.003	0.002
10-M*	0.045	0.041	0.036	0.032	0.027	0.025	0.02	0.015	0.01	0.005
10-L*	0.152	0.137	0.122	0.107	0.092	0.077	0.062	0.047	0.032	0.017
20-H	0.013	0.012	0.01	0.009	0.008	0.006	0.005	0.004	0.003	
20-M	0.039	0.035	0.031	0.027	0.024	0.02	0.016	0.012	0.008	
20-L	0.119	0.107	0.095	0.083	0.072	0.06	0.048	0.036	0.025	
30-H	0.01	0.009	0.008	0.007	0.006	0.005	0.004	0.003		
30-M	0.03	0.027	0.024	0.021	0.018	0.015	0.012	0.009		
30-L	0.092	0.083	0.074	0.065	0.056	0.047	0.037	0.028		
40-H	0.008	0.007	0.006	0.005	0.005	0.004	0.003			
40-M	0.024	0.021	0.019	0.017	0.014	0.012	0.01			
40-L	0.072	0.065	0.058	0.051	0.043	0.036	0.029			
50-H	0.006	0.005	0.005	0.004	0.004	0.003				
50-M	0.018	0.017	0.015	0.013	0.011	0.009				
50-L	0.056	0.05	0.045	0.039	0.034	0.028				
60-H	0.005	0.004	0.004	0.003	0.003					
60-M	0.014	0.013	0.011	0.01	0.009					
60-L	0.044	0.039	0.035	0.031	0.026					
70-H	0.004	0.003	0.003	0.003						
70-M	0.011	0.01	0.009	0.008						
70-L	0.034	0.031	0.027	0.024						
80-H	0.003	0.003	0.002							
80-M	0.009	0.008	0.007							
80-L	0.026	0.024	0.021							
90-H	0.002	0.002								
90-M	0.007	0.006								
90-L	0.021	0.019								
100-H	0.002									

*H: High level management
M: Medium level management
L: Low level management

November 24, 1999

Figure 14. C factors for the RUSLE. (from USDA NRCS 1999)

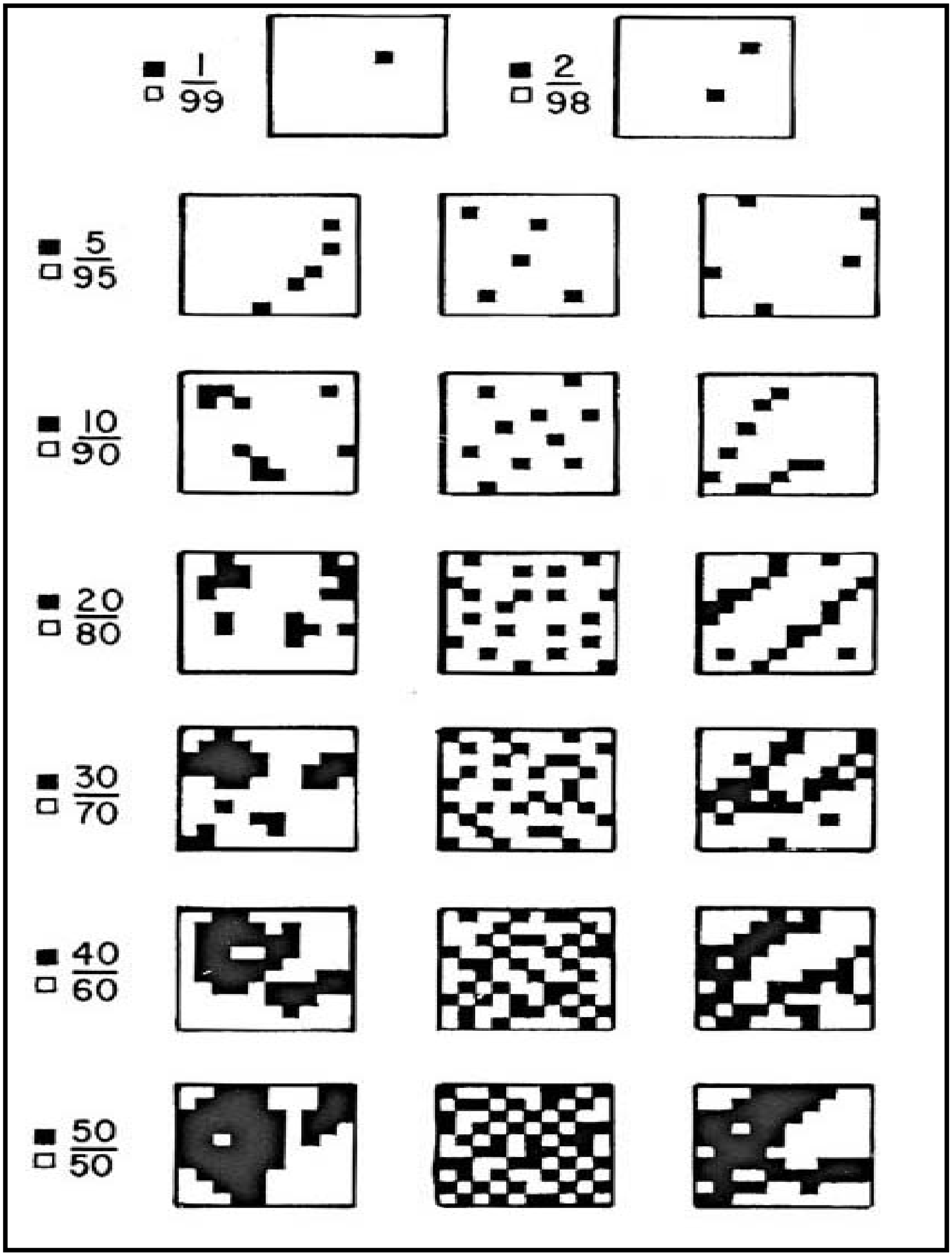


Figure 15. Guide for estimating ground cover %, canopy cover %, fine roots % and steps %. (from Dissmeyer and Foster 1984)

The percent ground cover and percent canopy cover were recorded for both the RUSLE and Dissmeyer and Foster methods using the visual chart in Figure 15. The Dissmeyer and Foster method also required a visual assessment of Figure 15 to determine the % fine roots and % steps on each plot. Illustrations of fine roots and steps can be seen in Figure 16. The onsite storage for the Dissmeyer and Foster method was calculated by a visual assessment of the plot using Figure 17 as a guide while the organic matter content was determined in the lab.

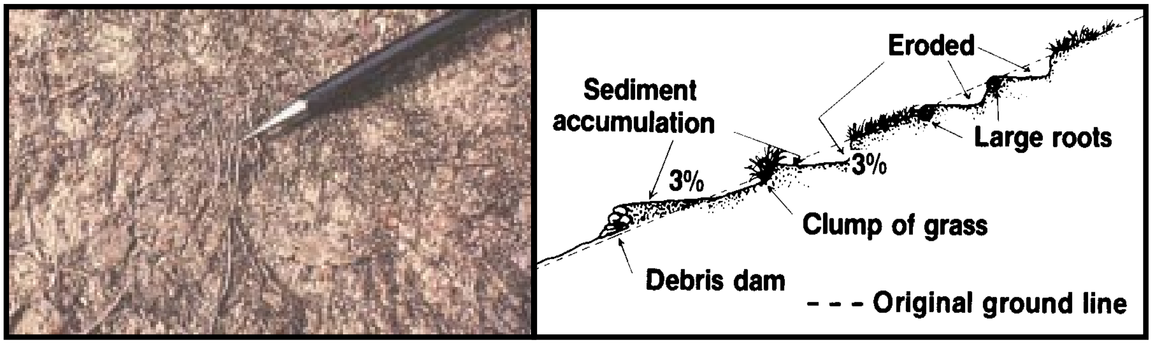


Figure 16. Illustration of fine roots on the left and steps on the right. (from Dissmeyer and Foster 1984)

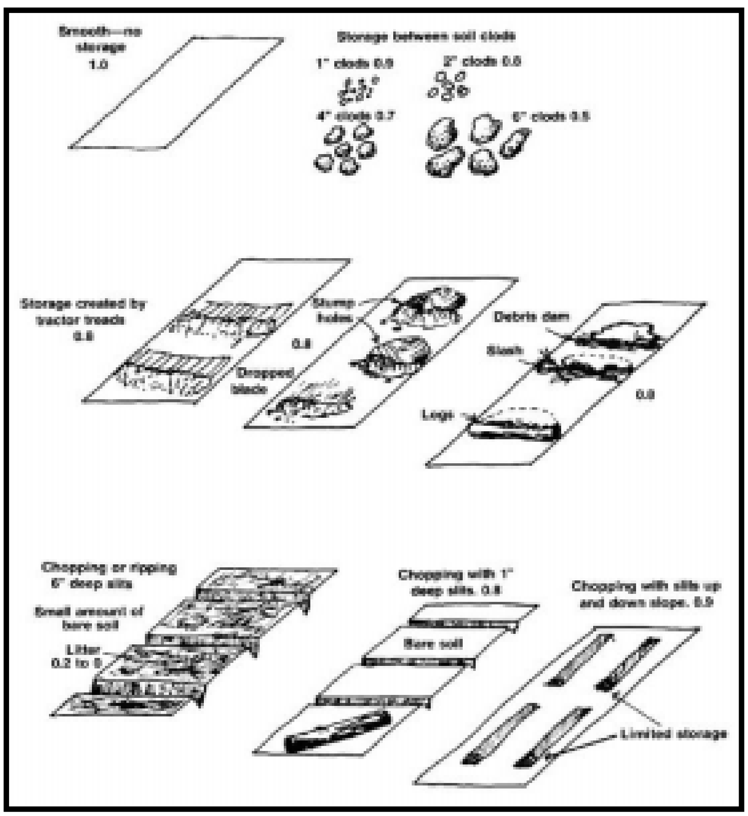


Figure 17. Illustration of onsite storage with subfactor values. (from Dissmeyer and Foster 1984)

Support Practice Factor (P) - The support practice factor was not used because no tillage had been performed within the last 72 months on any of the earthworks (Dissmeyer and Foster 1984).

These factors were estimated in 25 measurement plots within each management regime except where treatment area limited the number. The plots were 5 meters wide by the length of the actual earthwork slope. No space was provided between plots except where natural breaks in the landscape occurred. Steel spikes (25 cm long) were used to mark the corners of each plot. Each corner marker was inserted into the earthwork to a depth of 23 cm in order to prevent interference with normal management techniques. Plot corners were subsequently relocated by use of a pin finder. Each plot center was further located using a CMT Mark II Geographical Positioning System in order to provide the National Park Service with the GPS layer necessary for future coordination. A numeric system was used to name each plot per management regime, e.g., B1 for Burning Management Regime plot 1.

Data collections were performed in the spring, summer and fall, 2000 as well as one to two weeks after maintenance activities for the burned, mowed, and trimmed treatments. Data collection was performed during the spring, summer, and fall for forested and park-forest treatments.

Additional data were collected on tree density, canopy cover, and litter depth in the forested areas as well as general vegetation type in all study areas, to determine if trends within each management regime exist. Tree densities were measured by counting every tree in the forested plots while at the same time the diameter at breast height (DBH) and height of the tree was measured to the nearest 0.5 cm and 0.5 m, respectively. The percent forest canopy cover was also recorded from visual estimates using Figure 15.

General vegetation assessments were made by recording the three dominant plant species in each plot during the plot assessments. Figure 15 was used to visually estimate how much of the plot each plant species covered. The three that were most dominant were recorded with their percent cover.

Litter depths of the L, F, and H layers were measured at 4 random locations in the forested plots by placing a 0.1 m^2 PVC frame on the ground and cutting the litter with a knife. The depths of each litter layer were measured to the nearest 0.5 cm on each of the four faces of the profile. The litter was then removed by layer and bagged for a dry weight analysis. Surface litter from the adjacent forest floor was be used to patch the removed littler samples.

Field Estimate

Erosion pins were selected to estimate soil erosion in the field because it is an accepted, easily measured and installed method and because alternative non-formula based methods, such as erosion plots may cause visitor issues with the National Park Service. Therefore, four erosion pins/plot were inserted and used as another method to estimate soil erosion. The stratified insertion of these pins was based upon the availability of bare soil with an emphasis on trying to place 2 pins toward the top of the slope and 2 toward the bottom.

The erosion pins consisted of a 20 cm steel nail. Each nail was inserted flush into a bare soil patch in the earthwork. Erosion was measured by measuring the distance between the head of the nail and the soil surface to the nearest 1 mm. This was performed on the right and left sides of the nail as well as the upslope side and then averaged. The same person performed these measurements every time with the same ruler.

Because the erosion pins were only installed in bare soil, their erosion rates were weighted by the inverse of the percent ground cover or weighted by the percentage of the bare soil for each plot. Without weighting their erosion rates, the results would show the erosion rates for earthworks with no ground cover, which would be significantly higher then earthworks with ground cover. For this estimate, areas having cover were assumed to have no erosion while bare areas were assumed to be eroding at the same rate as the pins. These estimates were worst-case scenarios and estimated soil loss from around the erosion pin rather then the total soil loss from each plot.

Additional precipitation data was used to interpret the erosion pin data. The precipitation for the burned, trimmed, park-forest, and forested treatments was recorded by the National Weather Service at the Richmond International Airport. The airport was located approximately 7 kilometers NE from the burned, trimmed, and forested treatments and located approximately 6 kilometers NE from the park-forest treatment. Precipitation data for the mowed treatment was recorded at the Williamsburg Water

Treatment Plant in Williamsburg, Virginia. The treatment plant was located approximately 20 kilometers NW of the mowed treatment plots. Both sets of precipitation data were recorded daily but did not include rainfall intensity or hourly duration.

3.5 Laboratory Methods

The soil samples taken from each erosion plot were taken to the laboratory, air-dried, and ground to pass a 2 mm sieve. The soil texture was determined using the hydrometer method (Gee and Bauder 1986) after the removal of organic matter by oxidation with H_20_2 (Kunze and Dixon 1986). The percent organic matter was determined by loss-on-ignition (Nelson and Sommers 1982). The leaf litter taken from the forested plots was dried in paper bags to a constant moisture content at 65^0 C for 72 hours. The litter was then weighed to the nearest 0.01 gram and transformed to a Kg/ha value.

3.6 Statistical Analysis

The overall statistical design of this project was an observational study with 5 treatments, 25 pseudo-replications per treatment, except for the trimmed treatment, which only had 16 pseudo-replications, and a total of 116 plots. Due to the nature of the management treatments, true replication within a site was not possible because replications of each treatment were only performed if or when the National Park Service was scheduled to perform that maintenance activity, therefore pseudo-replication was used.

After sampling and laboratory analysis were completed, erosion data were analyzed to determine if there were significant differences in erosion rates between management regimes. The Number Cruncher Statistical System 1997 (Hintze 1997) was used to run the Kruskal-Wallis One-Way ANOVA, a nonparametric test, to determine if there were significant differences in the 5 treatments for the RUSLEs and Dissmeyer and Foster estimates of erosion as well as the erosion pins. The Kruskal-Wallis One-Way ANOVA was used because two assumptions for parametric tests were violated. All of the treatments except for the trimmed treatment had 25 replications. Since the trimmed treatment only had 16 replications sample sizes were not equal. The second violation was that the data was not Gaussian due to multiple outliers.

The Kruskal-Wallis One-Way ANOVA was also used to determine if there were significant differences between the 4 measurement methods. Additional simple linear regression analyses were used to determine which site factors had a significant effect on the erosion rates. Factors included the ground cover %, canopy cover %, % steps, % slope, slope length, K factor, LS factor, C factor, % organic matter, sand %, silt %, and clay %. Treatments were also contrasted using the Kruskal-Wallis Multiple-Comparison Z-Value test. All tests were run at an alpha level of 0.10.

4. Evaluation of Management Treatment Effects on Soil Erosion

4.1 Introduction

A major goal of this study was to determine whether vegetation management affects soil erosion on earthworks. This goal was achieved by comparing soil erosion rates for the 5 treatments used most frequently by the National Park Service in Richmond and Colonial Battlefields.

4.2 Comparison of Earthwork Management Treatments

Soil erosion rates, determined by the Dissmeyer and Foster method, for the 5 treatments, (burned, mowed, park-forest, forested, and trimmed) were found to be significantly different using the Kruskal-Wallis One-Way ANOVA (p=.0001) (Table 1). Results of the Kruskal-Wallis Multiple-Comparison Z-Value test indicated that the burned treatment had the highest soil erosion (Z-value > 1.6449) (Table 1).

Table 1. Estimated average annual soil erosion for the 5 treatments for the period between March 13 and October 12, 2000.

Treatments	Erosion Rate Mg/ha/yr (tons/ac/yr)
Burned	16.5 (7.4) a
Trimmed	4.1 (1.8) b
Park-forest	3.7 (1.7) b
Mowed	3.6 (1.6) b
Forested	2.6 (1.1) c*
Mean	7.3 (3.3)

* Different lowercase letters, within a row, indicate a significant difference at the 0.01 level.

The burned treatments average annual soil loss was 16.5 Mg/ha/yr during the course of the study, while the next highest erosion rates occurred with the trimmed treatment, which averaged 4.1 Mg/ha/yr (Table 1). The forested treatment had significantly less soil loss while the mowed, park-forest, and trimmed treatments had similar erosion rates (Table 1).

In order to explain why the five treatments erosion rates were significantly different, simple linear regressions were used to determine which site factors were most strongly related to erosion. The regressions indicated that the percent ground cover was the most significant individual factor for all 5 treatments with an r^2 of 60%.

After determining that the percent ground cover was the most important site factor relating to erosion, an analysis of variance was performed on the percent ground cover and the treatment effects. The resulting data indicated that there was a significant difference in ground cover between the 5 treatments (p=.0001). A multiple comparisons test was performed, which found that the burned treatment had significantly less ground cover (55%), followed by the mowed (81%), park-forest (83%), forested (86%), and the trimmed (87%) (Z-value > 1.6449) (Figure 18).

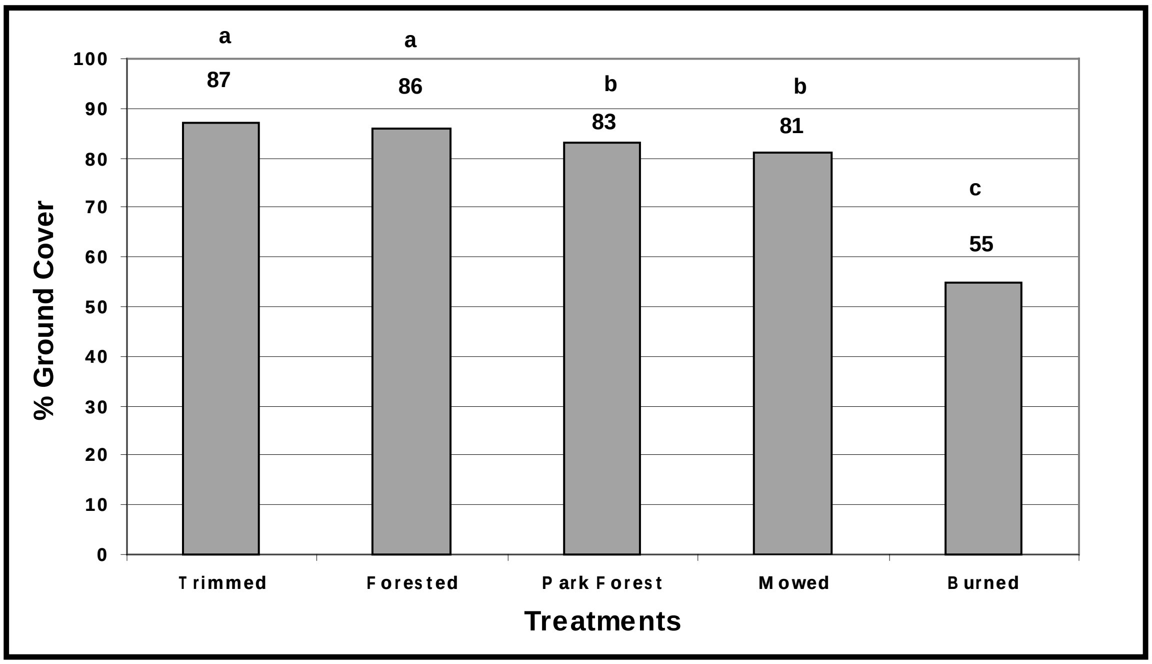


Figure 18. Average % ground cover for the 5 treatments over the duration of the study. The letter above the columns indicates a significantly different mean.

From the results of the multiple comparisons test, the obvious interpretation is that the lack of ground cover on the burned plots allowed the high erosion rates over the duration of the study. Because of this it was important to differentiate how the actual management activities used on the mowed, park-forest, and trimmed treatments differed from the ones used on the burned treatment plots. This was done to explain the high erosion rates for the burned treatment plots versus any of the other treatments by measuring erosion rates before and after maintenance activities.

All treatments except the forested treatment had active maintenance performed at some point during the duration of the study. Table 2 shows the before and after effects of the maintenance activities and the erosion rates associated before and after the data collection.

Table 2. Erosion rates before and after maintenance activities.

Treatments	Maintenance Activity	Erosion Rates Before Mg/ha/yr (tons/ac/yr)	Erosion Rates After Mg/ha/yr (tons/ac/yr)	% Change Following Treatments
Burned	Burned	17.7 (7.9) a*	31.6 (14.1) b	78.5%
	Trimmed	14.4 (6.4) a	18.0 (8.2) a	27.8%
Mowed (Only plots 1-17)	Mowed	1.8 (0.8) a	3.5 (1.6) b	94.4%
Park-forest	Trimmed	3.0 (1.3) a	5.5 (2.5) a	83.3%
Trimmed	Trimmed # 1	3.8 (1.7) a	5.1 (2.3) a	34.2%
	Trimmed # 2	2.7 (1.2) a	4.6 (2.1) a	70.3%

* Different lowercase letters, within a row, indicate a significant difference at the 0.01 level.

The erosion rates from before and after the maintenance activities varied greatly between the treatments. The net increase in erosion rates for each treatment after management activities took place are provided in Figure 19.

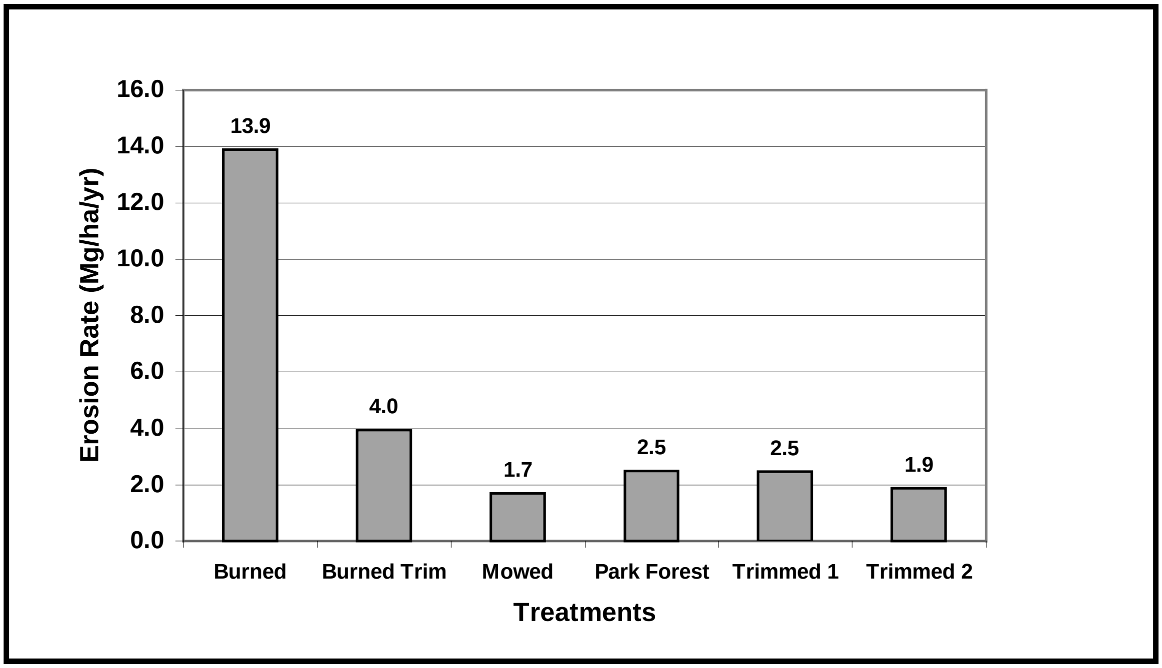


Figure 19. The net increase in erosion rates after major management activities.

The burned treatment had the largest net increase in erosion (13.9 Mg/ha/yr), which was approximately 3.5 times higher then the net increase in erosion after the same plots were trimmed. The trim that followed the burn did not increase the erosion rate significantly but still had a net gain higher then any of the other treatments. The significant increase in soil erosion after the burn was due to the removal of the ground cover and canopy. When comparing the grass ground cover of the burned, mowed, and trimmed treatments after their maintenance activities, it can be seen why there was a huge increase in soil erosion after the burn (Figure 20).

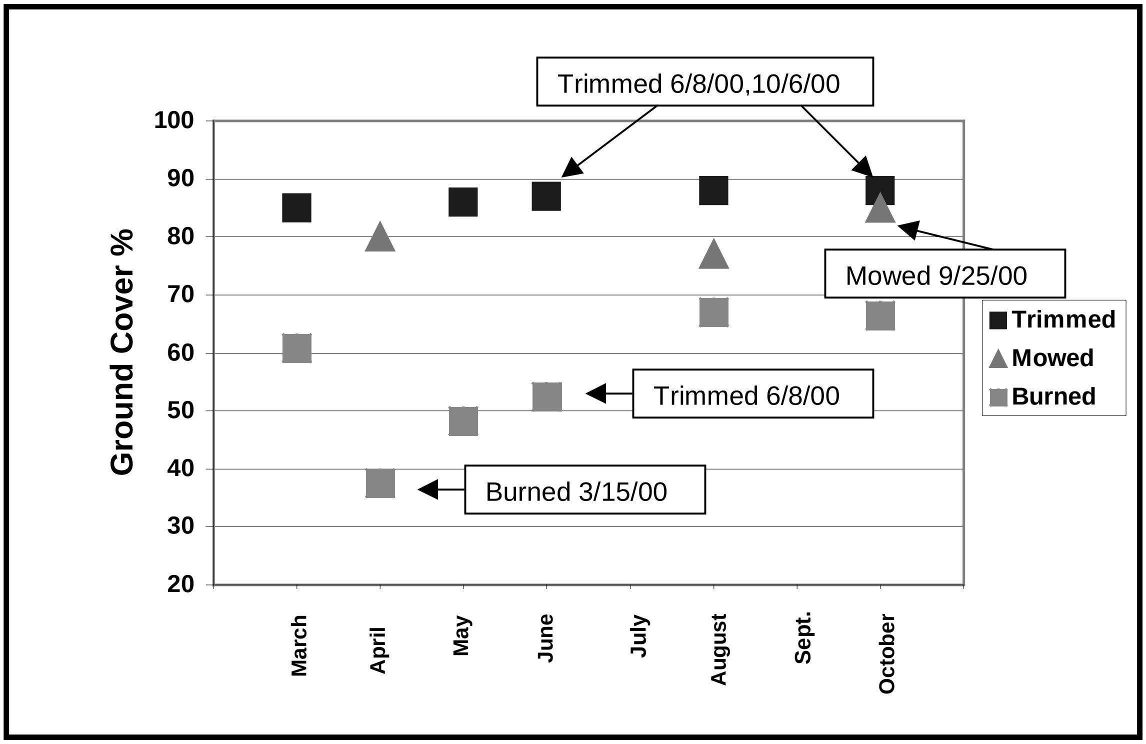


Figure 20. Change in ground cover over time for the three treatments that had a grass ground cover.

Figure 21 provides visual representation of how most of the ground cover and all of the canopy cover was removed by the burn versus only the removal of the most of the canopy cover by trimming.

Figure 21. Ground cover and canopy cover removed after the fire (left) versus only the removal of most of the canopy cover after the trim (right) on the burned plots.

Though the trimmed and park-forest treatments were also trimmed, erosion rates did not increase as much as they did when the burned treatment plots were trimmed. These treatments may have had less of a net increase in erosion because they were less dependent upon the canopy cover to protect the bare soil. The vegetation on the burned treatment plots included several tall grasses that formed dense canopies while the trimmed treatment plots had more sod forming grasses and leaf litter for the park-forest plots. Once the canopy cover was removed there was little ground cover left to protect the bare soil. As depicted in Figure 22, after the trimmed plots were trimmed there was still a dense sod under the grass clippings, which provided more ground cover then the grass did on the burned plots. In addition, most of the ground cover remained intact on the park-forest plots.

Figure 22. Ground cover left mostly intact after trimming the trimmed plots (left) and ground cover left mostly intact after trimming the park-forest plots (right).

Neither the trimmed nor the park-forest treatments had a significant increase in erosion resulting from trimming. The mowed treatment had the least net gain in erosion after the plots were mowed but the erosion rate did increase significantly ($p = .0114$). The only other treatment to have a significant increase in erosion after the treatment was performed was the burned treatment after the burn (Table 2). In both situations the erosion rates increased almost two-fold as compared to before treatment values. The big difference between the two treatments is that the net increase in erosion after the burn was 13.9 Mg/ha/yr versus 1.7 Mg/ha/yr after the mowing.

Special attention was paid to the vegetation on the burned treatment because it was the reason the burned treatment was burned. Several years ago, portions of Fort Harrison were hand planted with little bluestem, which is a warm season grass that proliferates with fire. In an effort to promote the establishment of this species, the National Park Service used fire as a management technique in hopes of forming a monoculture on the earthworks. In general, the little bluestem did not survive and grow as the vegetation did on the trimmed plots, which provided over 80% ground cover for the duration of the study (Figure 20). From personal observations, the burned treatment plots with the least slope elevation had the most little bluestem growing on them (Figure 23).

Figure 23. Burned earthworks with a shallow grade and dense vegetation (left) versus steeper earthworks lacking dense vegetation (right).

Though the prescribed burn did not produce the desired results at Fort Harrison, prescribed burning has been an effective tool for the Richmond National Battlefield Park under different circumstances. In recent years the National Park Service has performed a prescribed burn on forested earthworks at the Cold Harbor Unit of the Richmond National Battlefield Park in order to remove undesirable (visually) saplings. A portion of this burn actually exceeded its intended intensity, however, most of the burn removed the understory and bare soil was recovered within 1 year. The recovery of this prescribed burn was based upon major differences in site and vegetation characteristics between the sparsely vegetated grass earthworks of Fort Harrison and the densely forested earthworks of Cold Harbor. The earthworks of Fort Harrison were much larger, had steeper side slopes, and exposed bare soil prior to the burn while the earthworks of Cold Harbor were much smaller and had approximately 8.4 cm of leaf litter covering close to100% of the mineral soil (Figure 24).

Figure 24. Illustration of size and ground cover on Fort Harrison earthworks before the burn (left) and Cold Harbor earthworks (right).

In addition to comparing the differences between the active maintenance performed on the treatments, a comparison was performed between the forested treatments. The forested treatment had a significantly lower erosion rate than the park-forest treatment. Differences in erosion between these two treatments can be linked to the average amount of ground cover that both treatments had over the duration of the study (Figure 18) and the size difference between the earthworks.

The earthworks that composed the park-forest treatment were part of Fort Gilmer, which was much larger in size then the smaller breastworks that composed the forested treatment (Figure 25).

Figure 25. The large thinned earthworks of the park-forest treatment (left) versus the smaller forested earthworks of the forested treatment (right).

As illustrated in Figure 25, the larger park-forest earthworks had fewer trees on them and less ground cover than the forested treatment. At the present time the differences in the leaf litter depth and dry weight between these two treatments doesn't differ significantly (p=.4553 & p=.6933) but as more trees are thinned from the park-forest overstory and the understory is annually trimmed, there will be less and less litter inputs and more bare soil exposed.

One additional factor accelerating the erosion rate on the park-forest treatment is the removal of the ground cover during maintenance. As maintenance personnel trim the earthworks they slide down the slope on the slick leaves leaving behind patches of bare soil (Figure 26). Also, the intent of the park-forest treatment is to increase visibility and the increased visibility undoubtedly leads to some increase in traffic by visitors.

Figure 26. Illustration of ground cover being moved down slope during a trimming on the park-forest treatment.

4.3 Comparison of the Treatments Using the Erosion Pins

Soil loss values from around the erosion pins also indicated the burned treatment had significantly more soil erosion then the other four treatments (Z-value > 1.6449). The erosion pins on the burned treatment plots lost an average of 0.85 cm/yr of soil or an average of 125.6 Mg/ha/yr while the forested treatment only averaged 0.19 cm/yr or 27.6 Mg/ha/yr (Table 3).

Table 3. Estimated average annual soil loss from around the erosion pins for the 5 treatments for the period between March 13 and October 12, 2000.

Treatments	Erosion Rate cm/yr (in)/yr	Erosion Rate Mg/ha/yr (tons/ac/yr)
Burned	.85 (.34) a*	125.6 (56.1) a
Park-forest	.43 (.17) b	63.6 (28.4) b
Mowed	.21 (.08) c	40.0 (13.8) c
Trimmed	.21 (.08) c	29.0 (13.0) c
Forested	.19 (.07) c	27.6 (12.3) c
Mean	.40 (.16)	59.6 (26.6)

* Different lowercase letters, within a row, indicate a significant difference at the 0.01 level.

The analysis also revealed that the park-forest treatment had significantly more soil loss than the mowed, forested, or trimmed treatments (Z-value > 1.6449) (Table 3). Other studies have found high erosion rates to be common for disturbed-construction type-sites. Ursic and Douglass (1979) found erosion rates one year after the construction of logging roads exceeding 336 Mg/ha/yr. In another study on arid rangelands, Fanning (1994) found erosion rates of 259 Mg/ha/yr on rilled surfaces, 73.8 Mg/ha/yr on flat surfaces, and 38 Mg/ha/yr on vegetated surfaces over a 10-year period using erosion pins.

During the duration of the study the erosion pins revealed a general decrease in soil loss around the erosion pins for all of the treatments. The exact cause of why the erosion pins had decreasing erosion rates over the duration of the study was not obvious. Regression analyses revealed no strong correlations between the erosion rates and the site factors. However, after reviewing the rainfall data and the data from the erosion pins there does appear to be a clear trend in the soil loss. Soil loss rates in the spring were higher for all of the treatments while during the summer the rates diminished drastically (Figure 27).

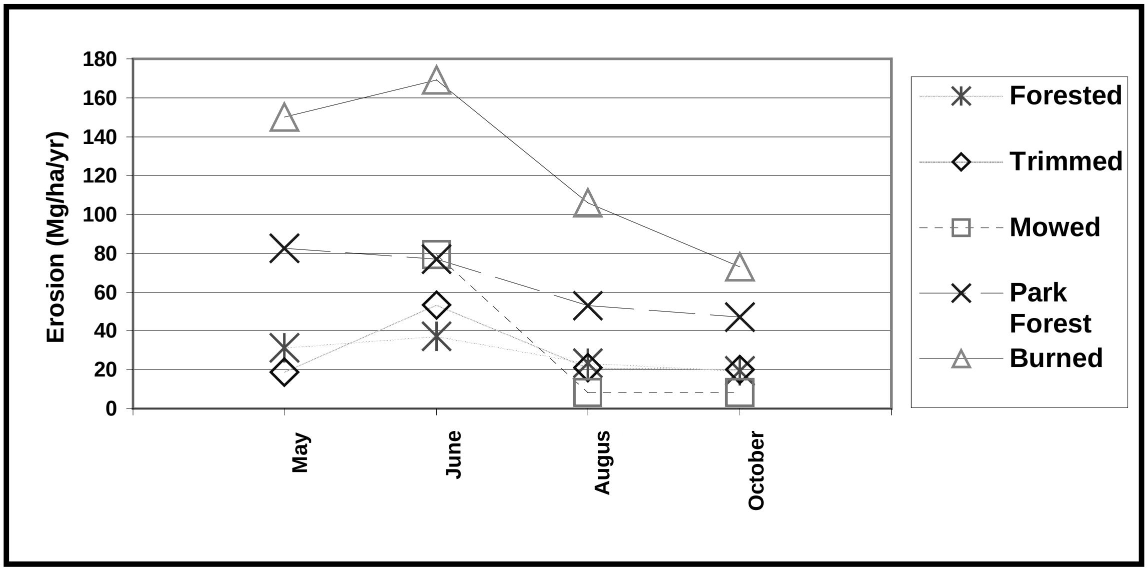


Figure 27. Decrease in soil loss from the erosion pins for all treatments.

The rainfall for the duration of the study was slightly above the average but there were far fewer storms during the spring that produced rains exceeding 2.5 cm in 24 hours (Table 4). Total precipitation data collected over the 8-month period was higher than the 30-year average for both Richmond and Yorktown (Table 4). The precipitation in Richmond was approximately 5% higher than the average while it was approximately 13% higher than "normal" in Yorktown.

Table 4. Precipitation Data for Richmond and Williamsburg VA.

Richmond precipitation data 2000 taken from the Richmond International Airport. 30 yr average taken from the Henrico Co. Soil Survey 1975.				Williamsburg precipitation data 2000 taken from the Williamsburg WTP. 30 yr average taken from the James City, York Co., and Williamsburg Soil Survey 1985.			
Month	**30 yr Average Total cm**	**Year 2000 Totals cm**	**(+ or -)**	**Month**	**30 yr Average Total cm**	**Year 2000 Totals cm**	**(+ or -)**
March	8.6	9.4	0.8	**March**	10.4	12.4	2.0
April*	8.1	**12.2**	4.1	**April**	7.4	10.2	2.8
May	9.4	7.7	-1.7	**May**	10.9	7.9	-3.0
June	9.7	15.5	5.8	**June**	11.2	7.4	-3.8
July	14.2	10.4	-3.8	**July**	13.5	19.6	6.1
August	14.0	21.1	7.1	**August**	11.7	23.1	11.4
September	9.1	9.1	0.0	**September**	11.4	17.5	6.1
October	7.6	0.03	-7.57	**October**	9.1	0.08	-9.02
Total	80.7	85.4	4.7	**Total**	85.6	98.0	12.4

*April was the month immediately after the burn treatment when the most bare soil was exposed.

During the summer and early fall there were as many as 9 storms exceeding 2.5 cm and one recorded in Williamsburg that exceeded 8 cm in 24 hours. From personal observations it was hypothesized that the surface runoff of the smaller storms in the spring only had sufficient power to transport the soil partially down the slope, which meant that erosion pins located down slope were also losing soil and inflating the erosion rates. The larger storms during the summer were able to transport soil further down slope, and actually bury the lower erosion pins "balancing" the average erosion rates.

An exception to the larger storms occurring during the summer and fall was during the month of April. The month of April had three storms that produced 1.25 cm or more of rainfall in 24 hours and one that produced 4.24 cm as was recorded at the Richmond International Airport. Only two weeks prior to the beginning of these rain events the burned treatment was burned, which exposed the greatest amount of bare soil during the duration of the study. These intense rain events may have caused the initial soil loss rates recorded by the erosion pins to be highly inflated as shown in Figure 27.

Personal observations lead me to believe that rainfall intensity and duration were the driving force behind the high erosion predicted by the pin rates. Unfortunately weather stations were not installed at the research sites, so exact precipitation and rainfall intensity data was not available to make more definitive conclusions on this hypothesis.

4.4 Conclusions

Over the duration of the study, the burned treatment had the highest erosion rate value while the forested treatment had the lowest value. Even though the mowed, trimmed, and park-forest treatments were on drastically different earthworks, their erosion rates were not significantly different.

In general, the earthworks will be preserved the longest when maintenance is performed in a way that impacts the ground cover the very least. Trimming, mowing, and leaving earthworks in forested cover are all acceptable methods for maintaining the earthworks, but care should be given in choosing and implementing the practice. The prescribed burning of earthworks should be avoided unless mitigating circumstances exist (such as maintenance of fire ecology species) while the park-forest treatment should also be used cautiously.

Mowing should be used when it is possible to use the "boom arm mower" in a manner so that the tractor does not actually drive on the earthworks. The blade height should also be set at a height that will prevent it from touching the earthworks. The benefits of mowing are that it is fast, safer for the staff than trimming, and impacts the earthworks the least because no walking is required on the earthworks. The use of the mower is constrained by its inaccessibility and cost of owning and training staff to use it properly.

Trimming is also an acceptable method for maintaining the earthworks. It is most beneficial for smaller earthworks where walking on the earthworks is not required. However, it is also advantageous on earthworks that are inaccessible by a "boom arm mower" and trimming requires less training than the operation of the mower. The greatest problem with trimming is that there can be negative impacts to the earthworks from staff walking up and down the steep side slopes.

Leaving the earthworks in full forest cover is the best choice for earthworks that are not being managed for viewing. In this situation, you typically have the least soil erosion and very little time or resources are required to preserve them. One exception is erosion caused by windthrow of large old trees.

Creating an earthwork environment that combines views of the earthworks in a forested setting is a management technique that should be used cautiously. Throughout the Richmond National Battlefield Park there are many miles of earthworks in this "park-forest" setting. As the research has indicated, the earthworks at Fort Gilmer have started to develop accelerated erosion due to the removal of selected overstory trees, understory vegetation, and the removal of ground cover by walking on the steep side slopes during maintenance activities. Portions of Fort Gilmer represent the worst-case scenario where most of the organic matter has been removed from the top of the slope. In addition, the side slopes are spotted with patchy areas of bare soil that were formed from people walking on them. Without the annual additions of leaf litter from the overstory trees and understory vegetation these areas of bare soil will only increase as will the erosion (Figure 28).

Figure 28. Illustration of soil washed away from an erosion pin at the top of a slope on a park-forest plot.

Areas that have already developed bare soil at the top of the earthworks need to have a ground cover established soon. However, these areas are usually shaded by the remaining large trees, which make it hard to establish grass as a ground cover. An option may be to plant shade tolerant trees in these areas to establish a new source of ground cover from the leaf litter.

In order to minimize the removal of the existing ground cover from the side slopes, the trimming of the understory vegetation should be reconsidered. An alternative might be using an herbicide to kill the vegetation, which would require less walking on the side slopes.

Burning the earthworks at Fort Harrison was problematic because of the lack of ground cover combined with the steep side slopes. The burning exposed even more bare mineral soil as the ground cover was burned, which accelerated the erosion rate to levels that were significantly higher than any of the other treatments. Though the intent of the fire was to promote native grass species and control the remaining vegetation, this was not the best management practice for this particular area because the earthworks were already lacking ground cover. Prescribed may be used on the earthworks at the Richmond National Battlefield Park, but care should be taken in deciding which earthworks to burn.

5. Differences Between Erosion Calculation Methods

5.1 Introduction

The second goal of this project was to determine if the empirical formulas and the field estimate provided comparable trends in estimated soil erosion between management activities on earthworks. This goal was achieved by comparing the general erosion trends from both types of methods over the duration of the study.

5.2 Differences in Trends Between the Empirical Formulas and the Field Estimate

In general, both the Dissmeyer and Foster and erosion pin estimates revealed the same trend in soil erosion between the management regimes. The burned treatment had the most soil erosion while the forested treatment had the least. However, only the general trends could be used for a comparison between the erosion pins versus the Dissmeyer and Foster and RUSLE methods because the erosion pins were estimating soil loss from around the erosion pins and not total soil loss from the earthwork slopes, while the Dissmeyer and Foster and RUSLE methods estimated soil erosion from the whole earthwork slope.

There was a discrepancy in the trend, however, between the erosion pin estimates and the Dissmeyer and Foster method over the forested areas. In the case of the park-forest treatment, the erosion pin values were significantly higher then all of the other treatments except for the burned treatment (Z-value > 1.6449) while the Dissmeyer and Foster method revealed that the park-forest treatment was not significantly different than the mowed or trimmed treatments (Z-value < 1.6449).

In addition, the Dissmeyer and Foster method revealed that the forested treatment had significantly less soil erosion than all of the treatments (Z-value > 1.6449) while the erosion pin data revealed that the forested treatment was similar to the mowed and trimmed treatments (Z-value < 1.6449).

5.3 Explanation of Why the Methods Differed

The discrepancies between the Dissmeyer and Foster method and the erosion pins could be attributed to the sensitivity of the erosion pins to minor movements of soil. As was stated before, the erosion pins were measuring the soil loss from a specific site, around the erosion pins, while the Dissmeyer and Foster method was estimating soil loss from the whole slope. From personal observations, most of the forested earthworks had the deepest ground cover towards the bottom of the slopes, leaving areas of bare soil above. Erosion pins located in these areas of bare soil may have measured large amounts of soil moving away from the erosion pins but the soil that was removed did not necessarily make it to the toe of the slope. In contrast to the erosion pins, the Dissmeyer and Foster method estimated soil loss from the whole slope, which is why the erosion estimates calculated using this method revealed less of a soil loss problem then did the erosion pins.

5.4 Differences Between the Dissmeyer and Foster and RUSLE Methods

The Dissmeyer and Foster and RUSLE methods were not significantly different from one another over the duration of the study for the 5 treatments (Z-value > 1.6449). In trying to determine which empirical formula provided the most correct erosion estimate several facts had to be reviewed about the design and use of each method. The Dissmeyer and Foster method was designed to predict soil erosion from forested land while the RUSLE was suited to predict soil erosion from cropland and constructions sites. The Dissmeyer and Foster seemed fairly flexible for estimating soil erosion on pasture-type land because the C factor and subfactors could be interpreted to use the ground vegetation. However, the RUSLE requires knowledge of plant species and root mass in order to determine a C factor. This knowledge made adapting the RUSLE very difficult and a chart from the NRCS that had approximate C factors for pastureland was used.

The largest difference between the Dissmeyer and Foster and RUSLE methods was that the RUSLE consistently found there to be less soil erosion after a treatment while the Dissmeyer and Foster found increases for the burned, mowed, and trimmed treatments (Figures 29, 30, & 31).

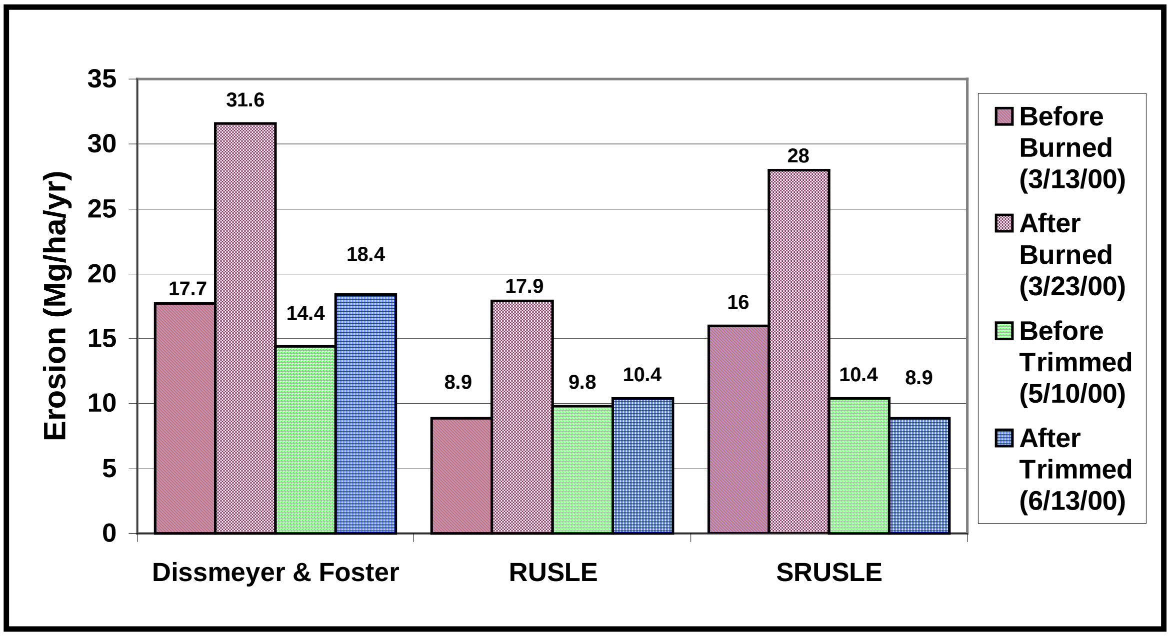


Figure 29. Erosion rates before and after burned treatment was burned and trimmed using the Dissmeyer and Foster, RUSLE, and SRUSLE.

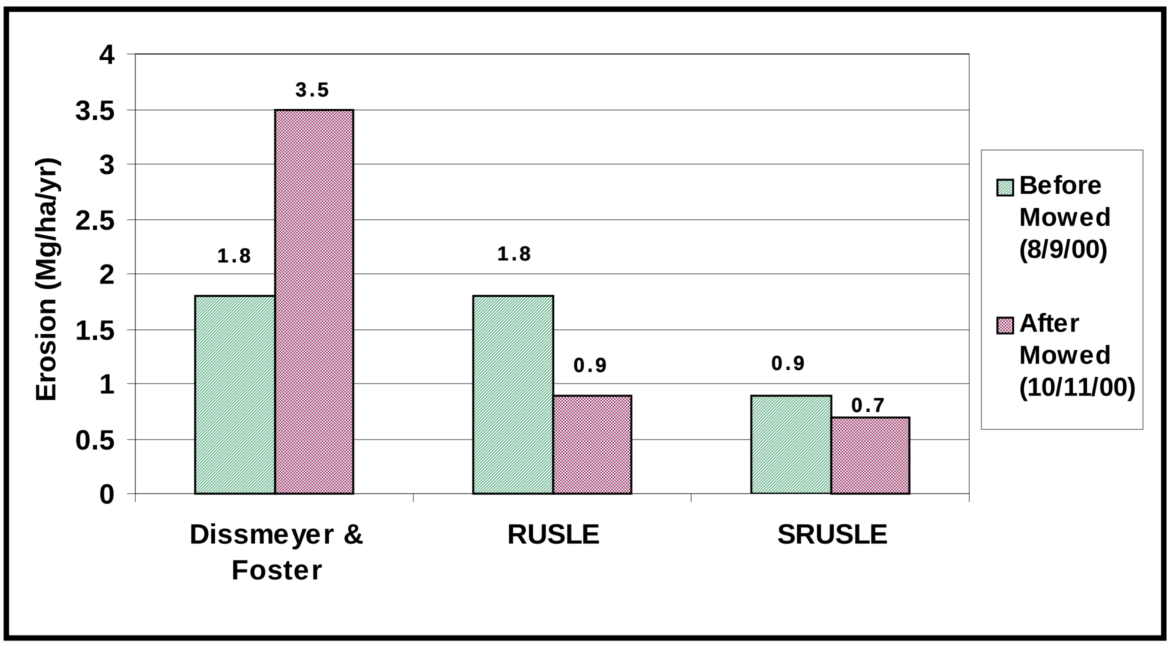


Figure 30. Mowed erosion rates before and after the mowed treatment using the Dissmeyer and Foster, RUSLE, and SRUSLE.

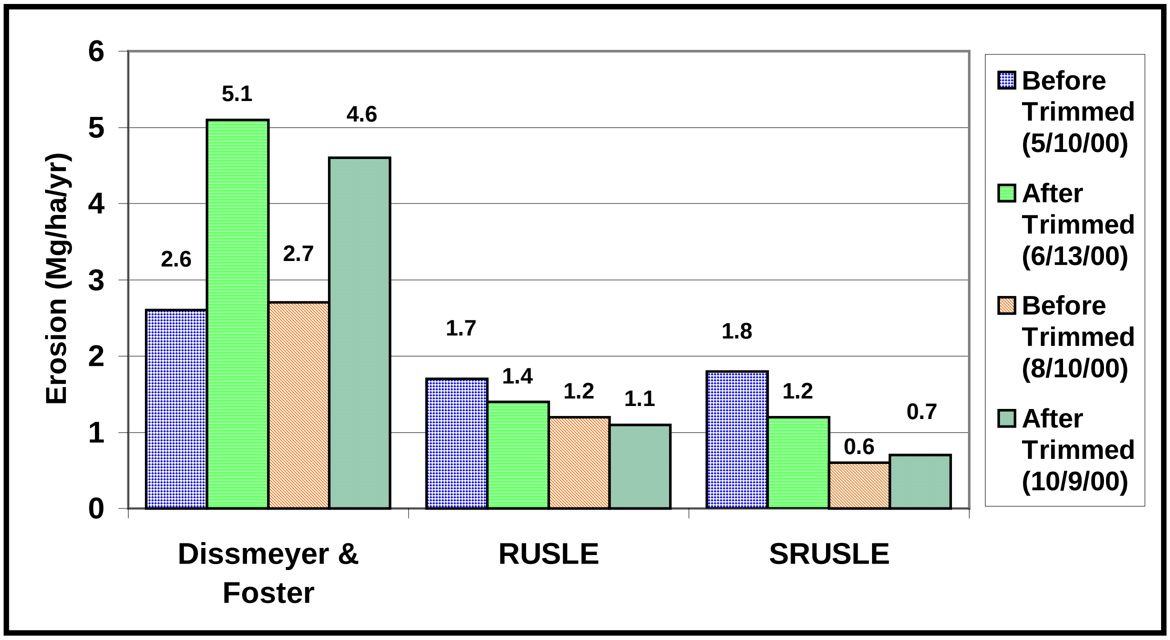


Figure 31. Erosion rates from before and after the trimmed treatment was trimmed using the Dissmeyer and Foster, RUSLE, and SRUSLE.

The decrease in the erosion rate after the treatment activity by the RUSLE was hypothesized to be related to the increase in vegetative ground cover as the growing season progressed (Figure 20). Though there was less canopy cover after the treatment activity, the RUSLE weighted the percent ground cover more heavily, which resulted in a lower erosion rate.

In general, the Dissmeyer and Foster method places more emphasis on the canopy cover then the RUSLE because it was developed to estimate soil erosion on forested areas. In contrast, the RUSLE was developed to estimate soil erosion on agricultural land and construction sites and it placed more emphasis on the amount of ground cover on those sites. From this data, however, it is impossible to say whether the Dissmeyer and Foster method was more accurate in estimating increases in erosion after maintenance activities or the RUSLE.

5.5 Conclusions

Both the empirical formulas and the erosion pins have established the same general trends in the ranking of the 5 treatments. The burned treatment caused the most soil erosion while the forested the least. It is hard to say, however, whether the erosion pins or the Dissmeyer and Foster method were correct in their erosion rankings for the park-forest and forested treatments. In general, the Dissmeyer and Foster data indicated that both of these treatments either had similar or significantly less soil erosion than the mowed or trimmed treatments while the erosion pins indicated that the park-forest treatment had lost significantly more soil than the mowed, trimmed, or forested treatments and the forested treatment was similar in soil erosion to the mowed and trimmed treatments. The higher soil loss estimation by the erosion pins may indicate a potential soil erosion problem in the future.

The Dissmeyer and Foster and RUSLE methods had statistically similar results but the Dissmeyer and Foster method would be the preferred method for estimating soil erosion on the earthworks. Because these two methods were so similar in their results, this judgment is based upon the relative simplicity and flexibility of the Dissmeyer and Foster method.

6. The Soil Genesis of Earthworks

6.1 Introduction

Battlefield earthworks provide a unique opportunity for studying the development of disturbed soils. During the American Civil War, 1861-1865, earthworks served as primary defensive structures. Also known as field fortifications, entrenchments, and field works, earthworks made of soil and timbers, were initially engineered for relatively short-term duration during battles. The basic earthwork is made up of the parapet and ditch. A parapet is the earthen mound that was engineered to protect the soldier from the enemy's missiles and enable them to use their weapons effectively. The ditch was the second component of the earthwork (Figure 1).

The soil that was piled up to form the parapet usually came from the ditch located directly in front of it. As the height of the parapet increased so did the depth of the ditch. After completion of an earthwork, the soils finally located on the top originated from the subsoils many feet below the soil surface and did not resemble surface soils.

Today, many of the earthworks are forested and the soils have a developed A horizon. By examining these factors through taxonomic investigations we can help determine the rate at which soils form on earthworks. These findings will be useful to the National Park Service interpreters as well as for predicting recovery on similarly disturbed areas such as road right of ways, construction sites, dams, levees, and urban soils.

The objective of this study was to gather information regarding the soil development which has occurred during the 135 + years since the earthworks were constructed.

6.2 Methods and Materials

6.2.1 Site Description

The study site was located on the earthworks that lie adjacent and perpendicular to the north side of Picnic Road in the Fort Harrison area of the Richmond National

Battlefield Park. Fort Harrison is located near State Highway 5, approximately 8 miles southeast of Richmond, in Henrico County, Virginia and is situated in the Coastal Plain physiographic province (Figure 2). The average temperatures range from 12.8^0 to 15.6^0 C with a maximum temperature of 32.2^0 C and a minimum temperature of 0^0 C. The county annually receives 1.1 meters of precipitation. Based on air temperatures, the average growing season for the county lasts from March 11 until November 23 (U.S. Dept. of Agriculture 1975).

Undisturbed soils located at Fort Harrison consist of Turbeville fine sandy loam (Clayey, mixed, thermic Typic Paleudults) 2 to 6 percent slopes and Turbeville fine sandy loam 0 to 2 percent slopes. The soils are deep, well drained, and found on somewhat broad, slightly convex ridges formed in alluvial material. Small areas of well-drained Kempsville soils (Fine-loamy, siliceous, thermic Typic Hapludults) and areas of gravelly soils can be found associated with Turbeville soils. The typical profile consists of a surface layer that has a brown fine sandy loam texture 18 cm thick. The subsoil is 190 cm thick consisting of a yellowish-red sandy clay loam in the upper 13 cm and dark-red clay to 190 cm. Soils found between 208 to 277 cm + are red, brownish-yellow, and light-gray clay. These soils have a medium water holding capacity and a moderate permeability in the subsoil. The runoff potential is medium with a moderate erosion hazard if the soil is disturbed and left without plant cover.

The earthwork soils also included the Ruston soils (Fine-loamy, siliceous, thermic Typic Paleudults), fine sandy loam 2 to 6 percent slopes. These soils are deep, well drained, and found on weakly convex ridges formed in coastal plain sediments. These soils also include small areas of well drained Faceville (Clayey, kaolinitic, thermic Typic Paleudults) and Norfolk soils (Fine-loamy, siliceous, thermic Typic Paleudults). A typical profile of these soils consists of a surface layer that has a grayish brown to yellowish-brown fine sandy loam in the upper 28 cm. The subsoil is 226 cm thick with a strong-brown sandy clay loam in the upper 18 cm, a yellowish-red-brown clay loam in the next 135 cm, and a red and reddish-yellow light clay loam in the lower 76 cm. The substratum begins at 254 cm and continues to a depth of 361 cm +. It consists of a mottled red, gray, and olive-yellow clay loam. The Ruston soils have a high available water holding capacity and medium permeability. These soils also have a medium runoff potential with a moderate erosion hazard (U.S. Dept. of Agriculture 1975).

6.2.2 Field Description

The purpose of the study was to determine the speed at which the pedogenic process takes place on earthwork soils. On June 6 and 7, 2000, soil profiles were described. Twenty-one of the soil profiles were described on earthworks that lie adjacent and perpendicular to the north side of Picnic Road and an additional ten soil profiles were performed in less disturbed forested, areas around the earthworks. The area was forested with a mixture of loblolly pine (*Pinus taeda)* and red maple *(Acer rubrum)*. Most of the earthworks had little or no loose organic matter on the surface but the flat-forested areas had an average of 4.7 cm of L material.

Each soil profile was dug to a depth of 183 cm with a 7.6 cm diameter hand auger. The soils were laid out in a soil tray the order in which they came out of the ground for viewing and descriptions. The soil descriptions followed the guidelines of the USDA Soil Survey Manual. After the descriptions were recorded, the soil was placed back into the hole in the order in which it came out.

6.2.3 Statistical Analysis

After the taxonomic data were compiled a two sample t-test was used to determine if the depths of the A horizons, from the earthwork soils and the adjacent flat-forested soils, were significantly different. Additionally, classifications of the soils were performed which included the Family and Subgroup.

6.3 Results and Discussion

6.3.1 Soil Descriptions

A typical earthwork profile was made up of two separate levels (Table 5). The first level was the soil material used to construct the earthworks. It consisted of a very dark grayish brown A horizon from 0 to 2.5 cm with a sandy loam texture. The second horizon was a yellowish brown loam Bw from 2.5 to 48 cm with light brownish gray mottles (Figure 32). In several profile descriptions the Bw horizon was comprised of a

Bw1 and a Bw2. Soils whose matrix color was not completely variegated usually had mottles with similar colors. These variegations in soil color can be attributed to the mixing of soil during earthwork construction. The lighter colors were probably attributed to the A and E horizons toward the soil surface while the darker colors were from the underlying B material.

Figure 32. Example of an earthwork soil profile.

Table 5. Typical soil profile taken from an earthwork.

Horizon	Depth cm	Matrix Color	Texture	Redox Features	Structure	Consistence	Roots
A	0 - 2.5	10YR 3/2	Sandy Loam		Weak Fine Granular	Very Friable	Common Fine
Bw	2.5 - 48	10YR 5/4	Loam	10YR 6/2	Weak Fine Subangular blocky	Friable	Few Fine
2Eb	48 - 142	2.5Y 6/3	Sandy Loam		Weak Fine Subangular blocky	Friable	Few Fine
2Btb	142 - 183	10YR 5/6	Clay Loam		Moderate Medium Subangular blocky	Firm	Few Very Fine

The second level of the earthwork was the original soil surface. This level started at the base of the Bw horizon and was categorized as a buried E horizon. The buried E horizon was a pale brown sandy loam from 48 to 142 cm. The last horizon in the profile was typically a buried Bt from a depth of approximately 142 to 183 cm. It typically had a yellowish brown matrix color and ranged in texture from sandy clay loam to clay loam.

The buried E horizon was typically the deepest horizon because it was the first horizon dug up and thrown on top of the existing E horizon.

A typical profile for the flat-forested soils consisted of O, A, E, and Bt horizons (Table 6). The O horizon typically had a depth from 4 to 0 cm and was black. The A horizon was a very dark grayish brown to a dark gray sandy loam from 0 to 2.5 cm. A typical E horizon was light yellowish brown sandy loam from 2.5 to 41 cm. Below the E horizon was a brownish yellow sandy clay loam Bt_1 from 41 to 66 cm. The final horizon was a yellowish red sandy clay loam Bt2 from 66 to 183 cm (Figure 33).

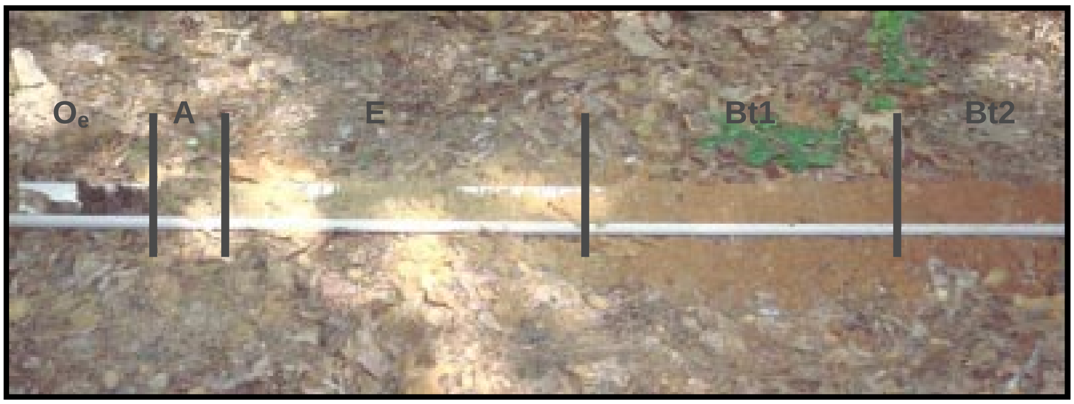


Figure 33. Example of a soil profile from a relatively undisturbed adjacent forest floor.

Table 6. Typical profile from a relatively "undisturbed" area near the earthworks.

Horizon	**Depth cm**	**Matrix Color**	**Texture**	**Redox Features**	**Structure**	**Consistence**	**Roots**
O_e	1.27 - 0	10YR 2/1	OM				
A	0 - 2.5	10YR 3/2	Sandy Loam		Weak Fine Granular	Very Friable	Common Fine
E	2.5 - 41	2.5Y 6/4	Sandy Loam		Weak Fine Granular	Friable	Few Fine
Bt_1	41 - 66	10YR 6/6	Sandy Clay Loam		Moderate Medium Subangular blocky	Firm	Few Very Fine
Bt_2	66 -183	5YR 4/6	Sandy Clay Loam	5YR 5/6	Moderate Medium Subangular blocky	Firm	

These soils resemble the Ruston soil series more than the Turbeville soil series. The only major difference was the depth of the A horizon. The flat-forested A horizon had a depth from 0 to 2.5 cm while the Ruston series had a depth from 0 to 20 cm.

6.3.2 Soil Formation Process

The formation of soils on the earthworks was broken up into surface and subsurface horizons. A two sample t-test was performed on the A horizon depths from the earthwork soils and the flat-forested soils. The mean depth of the earthworks A horizon was 2.9 cm while the depth of the flat-forested soils was 3.7 cm. Using an alpha level of 0.10 no significant difference in their depths was found (p=.2212). No statistical analysis was performed on the subsurface horizons.

The average depths found for the A horizons were an accurate assessment for the physiographic area. The Henrico County Soil Survey (1975), describes the Duplin Series (Clayey, kaolinitic, thermic Aquic Paleudults) as having an A horizon depth of 0 to 2.5 cm. Duplin soils are similar to the Ruston soils from which these earthworks were constructed. The typical Duplin soil profile was not classified from a farm field and therefore had a description of a more natural A horizon.

The rate at which surface and subsurface horizons develop varies. In a chronosequence of mine spoils, Daniels and Amos (1981) found A horizons up to 13 cm after 5 years and B horizon development after 12 to 19 years. In a similar study, Roberts et al. (1988) found A horizon thicknesses of 4 cm in mine spoils without amendments and 14 cm thick in mine spoils with sludge amendments in 2.5 years. Haering et al. (1993) looked at mine spoil genesis on similar sites over an eight-year period. They found a distinct A horizon from 5 to 8 cm after two growing seasons which coincided with the root zone. At that time no soil structure was found in the subsurface soils. After four growing seasons the A-horizon had become darker and the C-horizon had been separated into C1 and C2 with some patches of weak structure in the C1. At year eight the A horizon was well developed and ranged in depth from 5 to 11 cm. It was generally underlain by an AC horizon, which showed some granular structure and was followed by separate C1 and C2 horizons. With documented A horizon development in mine spoils of 5 years or less, it is clear that after 135 years the A horizons on the earthworks and surrounding flat-forested soils are approaching a state of equilibrium.

The subsurface horizons of the earthworks are still in the soil formation process. As was stated before, Daniels and Amos (1981) found B horizon development after 12 to 19 years in mine spoils and Haering et al. (1993) found patchy weak structure after four.

In order to consider subsurface soil a B-horizon, or Cambic Horizon, the altered soil layer must be 15 cm or more thick and show signs of physical alterations, chemical transformations, or removals or a combination of two or more of these processes (USDA Soil Survey Staff 1999). The subsurface horizons of the earthworks show signs of structure to a depth greater than 15 cm. The typical depth of the Bw horizon was 46 cm and it had a moderate medium subangular blocky structure. These characteristics allow the earthwork subsurface soils to be classified as Cambic but it is hard to say how long it took to form. Under the right circumstances it may have taken several years but may have taken much longer. Ultimately the subsurface soils will form an argillic horizon, which is what they were prior to excavation, but this normally requires thousands of years (Fanning & Fanning 1989).

6.3.3 Taxonomic Classification

The earthwork soils were classified as a Fine-loamy, siliceous, thermic Arentic Dystrudepts. The soil order was classified as an Inceptisol because of the Cambic Horizon. The Suborder of Udepts was chosen because the Inceptisol has a udic soil moisture regime. The Great Group was classified as Dystrudepts because these soils did not fit any of the others. The Subgroup was classified as Arentic. Though Arentic is not a Subgroup for Inceptisols, it describes these soils as soils with fragments from other diagnostic horizons mixed in the subsoil at a depth between 25 and 100cm (USDA Soil Survey Staff 1999). The Family (Fine-loamy, siliceous, thermic) was taken from the Henrico County Soil Survey (1975) for the Ruston Soil Series.

6.4 Conclusions

The exact rate at which these earthwork soils formed is not known. From the literature we can conclude that the A horizon formation begins in as little as 5 years but the formation of an A that is very similar in depth to less disturbed areas took longer. The presence of soil structure in the B-horizon indicates that the pedogenic process is working but it may take a thousand more years before the soil becomes an argillic horizon. These findings indicate that efforts used on construction and urban sites and similar areas to enhance soil formation have reasonable and beneficial outcomes in relatively short time frames.

7. Conclusions

The main purpose of this project was to evaluate soil erosion from the five most common earthwork management regimes used by the National Park Service at the Richmond National Battlefield Park and the Colonial National Historical Park. Soil erosion was estimated from 25 plots on each of the five management regimes/treatments except for the trimmed treatment, which had 16 plots. The soil erosion was estimated using an empirical formula based on the Universal Soil Loss Equation for forested land by Dissmeyer and Foster and the Revised Universal Soil Loss Equation (RUSLE). It was also estimated in the field by measuring the soil loss from 4 erosion pins per plot. An additional goal was to determine how the empirical formulas ranked the treatments based on soil erosion versus the erosion pins. As a subproject, soil profile descriptions were performed on earthworks to gather information on their soil genesis over the past 135+ years.

The overall conclusions of this study were that the burned treatment had the highest soil erosion values while the forested treatment had the lowest erosion values. Both the empirical formulas and the erosion pins supported this overall conclusion.

Estimated soil erosion by the Dissmeyer and Foster method indicated that the mowed, park-forest, and trimmed treatments were not significantly different in their overall erosion rates while the forested treatment had significantly less soil erosion then all of the treatments. The erosion pins estimated that the mowed, forested, and trimmed treatments were similar but that the park-forest treatment had lost significantly more soil around the erosion pins than all but the burned treatment. The two main differences in the rankings between the Dissmeyer and Foster method and the erosion pins were based around the park-forest and forested treatments. Recall, that the Dissmeyer and Foster method and erosion pins were developed for different time frames and purposes. The Dissmeyer and Foster method was estimating the loss of soil from the top to the bottom of the slope and the erosion pins were only measuring the soil lost around the erosion pins. Because forested earthworks generally have a larger accumulation of ground cover towards the bottom of the slope, large amounts of soil may have moved away from the erosion pins towards the top of the slope without reaching the bottom. This could cause erosion estimates calculated by the Dissmeyer and Foster method to be low because it estimates soil loss from the top to the bottom of the slope whereas the erosion pins detected larger amounts of soil movement on the slope. These results may indicate that the park-forest treatment may have future erosion problems if the ground cover towards the top of the slope continues to move down the slope without any replenishment.

In general, the earthworks will be preserved the longest when maintenance is performed in a way that impacts the ground cover the very least. Trimming, mowing, and leaving earthworks in forested cover are all acceptable methods for maintaining the earthworks, but care should be given in choosing and implementing the practice. The prescribed burning of earthworks should be avoided unless mitigating circumstances exist (such as maintenance of fire ecology species) while the park-forest treatment should also be used cautiously.

In addition to ranking the five treatments with the empirical formulas and erosion pins, erosion estimates between the Dissmeyer and Foster and RUSLE methods were compared to determine which method would be the most useful for estimating soil erosion on earthworks. The Dissmeyer and Foster and RUSLE methods had statistically similar results but the Dissmeyer and Foster method would be the preferred method for estimating soil erosion on the earthworks. Because these two methods were so similar in their results, this judgment was based upon the relative simplicity and flexibility of the Dissmeyer and Foster method.

Determining the exact rate at which the earthworks soils have formed was not known. However, from the literature we can conclude that the A horizon may have begun to form in as little as 5 years. The presence of soil structure in the B-horizon indicated that the pedogenic process was working but it may take a thousand more years before the soil becomes an argillic horizon. These findings indicated that efforts used on construction and urban sites and similar areas to enhance soil formation may have reasonable and beneficial outcomes in relatively short time frames.

From this study we can conclude that keeping the earthworks covered with grass or trees is vital for their preservation and that using the current management regimes of mowing, leaving forested, or trimming are the best ways to accomplish these goals.

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Vita

Anthony Azola was born on December 27, 1974, in Baltimore, Maryland. Anthony is the son of Lone and Martin P. Azola of Baltimore, Maryland. He has a younger brother, Matthew Azola and a younger sister, Kirsten Azola of Baltimore, Maryland. Anthony grew up in Baltimore, Maryland, until graduation from Towson High School in 1993. In the fall of 1993, he became a member of the freshman class at Virginia Polytechnic Institute and State University in Blacksburg, Virginia. He pursued a degree in environmental resource management in the Forestry Department under the advisement of Dr. James A. Burger. In December of 1997, he completed the requirements for a Bachelor of Science degree in Forestry and began working with Dr. W. Michael Aust on a Master of Science degree in the same discipline. After one semester of graduate school, Anthony left to pursue a dream of becoming a professional cyclist. At the end of that cycling season, he took a job as a wetland scientist with Exploration Research, Inc. of Ellicott City, Maryland. In August of 1999, Anthony returned to Virginia Polytechnic Institute and State University to complete his degree under Dr. W. Michael Aust. In February 2001, Anthony was hired by ESRI as a sales representative for the state of New York. Anthony graduated from Virginia Polytechnic Institute and State University with a Master of Science degree in Forestry in May 2001.