Footpath degradation of the Malvern Hills

1.1 Introduction

Britain's upland environment is scenic but fragile. Over the last 200 years the natural environment of the Malvern Hills has been dramatically modified by human activities. The combined effects of climate change, agricultural intensification, quarrying, air pollution, and over grazing coupled with increased visitor pressure have exposed the Malverns to degradation in the form of weathering and erosion.

1.2 Literature review

In the field of path erosion, there is limited academic study, allowing scope for further work. Despite the Malvern Hills being a popular tourist attraction, drawing thousands of visitors a year and experiencing high degrees of people pressure along its paths and route ways, there have been no previous studies on the state, or causal factors of path erosion in this region. I feel that there is need therefore, for this study of path degradation on the Malvern Hills.

1.2.1 Erosion on the macro-scale

Firstly I will review Harden's 1992 paper; incorporating roads and footpaths in watershed-scale hydrologic and soil erosion models. Harden (1992) examines strategies for modelling rainfall, runoff, and soil erosion at the watershed scale, and controls of soil erosion effects on extensive networks of unimproved roads and footpaths.

His main findings are that path initiated erosion depends on the distribution of paths in conjunction with topography and other types of land use. Harden (1992) discovered that paths occupy a very small portion of the surface area but can play a disproportional, important erosion role. Path density is a significant factor, and was estimated using 1:100 000 topographic maps. This was not an effective method , so field observations, photos, and air photos were used. Through this second method it was concluded that actual path density was nine times than what was originally estimated. Harden's 1992 work clearly shows a continuing need to identify actual processes and their controls over path erosion, and to establish their importance at various scales of watershed analysis.

Grieve *et al.* (1995) nature and extent and severity of soil erosion in upland Scotland, examines erosion via the use of aerial photographs. The main conclusion from this paper regarding footpath erosion is that the broad technique of using aerial photographs is not appropriate. This is because Grieve *et al.* (1995) found that footpaths were difficult to identify and quantify, especially at lower altitudes. Conclusion drawn from the studies of Harden (1992) and Grieve *et al.* (1995) is that studies of path erosion must be carried out by way of first hand field studies.

1.2.2 Controls over recreational pressures

The aims of Zinng's (1940) experiments were to produce an equation quantifying the effect of land slope and length has on soil loss, with the respect to one variable, runoff. This equation is primarily for use in agricultural studies and does not take into account recreational pressures that are experienced along footpath slopes.

The main findings of Zingg (1940) are that 1) doubling the degree of slope increased the total soil loss in runoff 2.80 times. 2) Doubling the horizontal lope length increases the total soil loss in runoff 3.03 times. 3) increasing the degree of sloe increased the total runoff. 4) Increasing the length of slope decreased the total runoff. From these findings and other statistical methods Zing (1940) developed this equation for soil loss in runoff:

Figure 1: $E=CS^{1.4} L^{1.6}$ Where: E = Total soil loss from a land slope of unit width

C = a constant = 0.065

S = Degree of land slope

L = Horizontal length of land slope

This equation has restrictions as it simplifies the problem of erosion by only taking into account runoff, also that the plot of land affected is of constant width, slope, material and land cover. However, it is a useful tool in quantifying soil loss, even if the results may give an under estimation.

Deluca *et al.* (1998) looks at the influence of llamas, horses and hikers on soil erosion from established recreation trails in western Montana, USA. The primary objective of this research was to assess the relative impact of horses, llamas and hikers on paths. A secondary objective was to better understand how recreational pressure leads to path erosion. Erosion potential was expected to increase with a rise in traffic. Deluca *et al.* (1998) found this to be true, as traffic rose, so too did the detachment and compaction of soil particles, and the concentration of flow into channels.

The recreational paths used were two 300m segments of parallel paths that were closed to the public after the 1995 snow melt. The paths were then subject to intensities of 250 and 1000 passes, along with no traffic for control. This was assessed by sediment yield and runoff. Deluca *et al.* (1998) recorded soil moisture, slope and rainfall intensity as independent variables to keep the experiment as constant as possible.

The main finding of this paper is that horse traffic consistently made more sediment available for erosion from paths than llamas and hikers, when analysed across wet and dry plots with high and low intensities of traffic (Deluca *et al.* 1998). When trail traffic was increased by a factor of 4, from 250 passes to 1000 passes, sediment yield rose by only a factor of 1.4 (Deluca *et al* 1998). This suggests that initial trail traffic is much more damaging than subsequent traffic.

The study by Deluca *et al.* (1998) is useful in grading the erosive power of recreational traffic on footpaths, and is useful information when considering this in my own study, although llamas are not commonly found on the Malvern Hills. However mountain bikes produce similar rates of erosion to that of llamas, and so may be used instead.

Vogler *et al.* (1996) looks at footpath erosion on a University campus at a small scale. Studying path erosion in an urban environment is a different approach to one at a rural upland environment level, such as the Malvern Hills. However, similar measurements were taken of length, depth, and width, though in less detail. Vogler *et al.* (1996) generally does not focus on environmental variables in detail, such as slope angle, rainfall, and vegetation cover, although does explore the causal factors for high erosion levels of certain paths. They deduce that high levels of erosion are due to people pressure at two sites, and high slope angle at another two. Overall Vogler *et al.* (1996) work is a useful addition to the study of path erosion fro a unique urban perspective.

1.2.3 Path degradation studies

The main objectives of the paper Leung *et al.* (1996) trail degradation as influenced by environmental factors: a state-of-knowledge review, are threefold. Firstly to clarify terms used in trail condition research. Secondly to asses the development of trail degradation research, and finally, to review and summarise the influence of environmental factors affecting trail degradation.

Leung *et al.* (1996) have developed a classification system for trail research. (See Table 1). They split research into four classes, path impact, path deterioration, path degradation and path erosion. Path impact is the most general term, and is concerned with all physical, ecological , and aesthetic factors. Path deterioration studies are distinguished by their inclusion of path proliferation and vegetation assessments, and general focus of a landscape scale. These form of studies are extreme in the fact that they consider the very existence of paths as a form of impact on the natural landscape. Path degradation studies focus on the effects of path use on the surface after they are formed. This type of research accepts the necessity of paths in natural areas as a means of protection. Finally, path erosion, which is the most restrictive term, relates specifically to assessments of processes and consequences of soil erosion on the path. My own work falls into the category of trail degradation.

Table 1.- Classification of path research

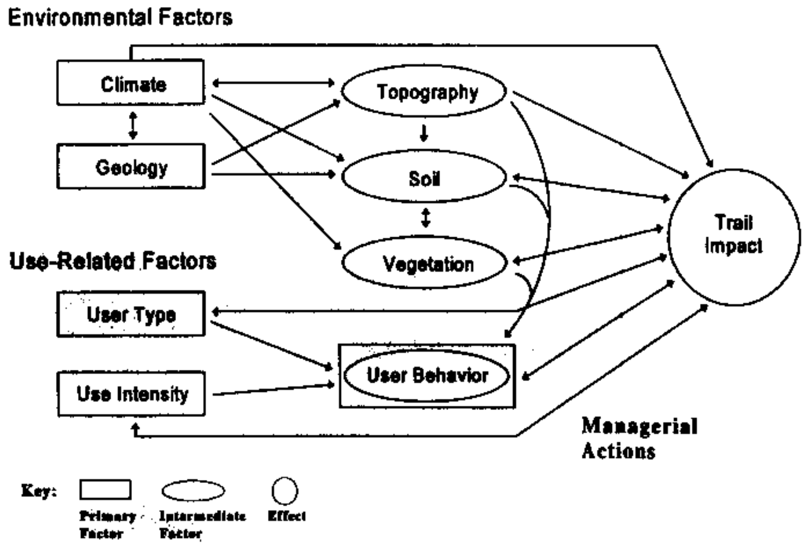
	Path condition term			
Problem	Path impact	Path deterioration	Path degradation	Path erosion
Social impacts	*			
Path proliferation	*	*		
Vegetation loss	*	*		
Soil compaction	*	*	*	
Path widening	*	*	*	
Soil loss	*	*	*	*

Source: Leung et al. 1996 p130.

Leung *et al.* (1996) goes on to look at path degradation research in more detail. They state that path degradation can be classified into four topical concentrations with descending order of the volume of literature. Firstly, descriptive studies of the type and magnitude of degradation, analytical studies of the recreational use-degradation relationship, analytical studies of the environment-degradation relationship, and evaluative studies of the effectiveness of path management actions. My own study spans the first three topics of research.

The most common path degradation variables studied are, path width, incision depth, path erosion as cross-sectional area, presence of braiding, and soil compaction. However, comparison between studies is a problem due to the lack of standardisation for both the variables studied, and the method used.

Figure 2. – Interrelationships between environmental, use-related, and managerial factors affecting path degradation



Source: Leung et al. 1996 p131

A model of the principal groups of environmental and use-related factors is presented in figure 2. Primary environmental factors include, climate and geology, which act on each other as well as the intermediate elements of topography, soil and vegetation (Leung *et al.*1996). Primary use-related factors include, user type, intensity and behaviour. User behaviour also plays an intermediate role because it is affected by user type and intensity, as well as the three intermediate environmental factors. Also, all user influences are affected by trail impact.

All environmental factors affect path degradation at different degrees of severity. Climate and geology influence degradation indirectly by acting on other factors, such as, vegetation, topography, and soil. Vegetation with high density and resilience to trampling restrict path widening, although are not important at preventing soil loss. Dense path-side vegetation cover prevents the braiding of paths. However, the influence of these attributes diminishes with increasing use and a relatively unimportant at high levels of use.

Topography on the other hand is possibly the most important variable. Various studies have documented a strong positive correlation between path slope and soil loss. Also the orientation of the path to the prevailing slope, termed the path angle, is an important factor often overlooked. Paths that more directly ascend the fall line, have a low path angle, they are parallel to the slope. Paths with a low path-to-slope angle are susceptible to degradation because their flatter side slopes offer little resistance to path widening, or to hinder the drainage of water from incised path treads. Paths which follow the contour of the slope have high path-to-slope and are perpendicular to the slope. Their steeper side slopes prevent lateral spread, and aids tread drainage. The importance of the path angle increases in significance as path slope increases.

Paths on soils with fine homogenous textures have been found to have greater tread incision (Leung *et al.* 1996). However, paths on soils with high contents of rock and gravel are more durable. Also, poorly drained paths cause path widening and braiding, as user seek to find better routes.

The paper by Coleman (1981) footpath erosion in the English Lake District arises from a research project carried out between 1975 and 1978. The paper summarises the results of a broad survey, representing a wide scope of environmental and recreational conditions, enabling factors affecting footpath development to be assessed. Coleman (1981) produced a general model to summarise the factors acting on footpath morphology. This is highly simplified model, which Coleman (1981) goes on to explain further.

Figure 3: Pm = Fr + Fg + R Where Pm = path morphology

Fr = recreational forces

Fg = geomorphological forces

R = resistance

Coleman (1981) summarised recreational pressure forces as, 1) the number of people using the path, 2) the slope of the ground which modifies the effect of 1) i.e. the maximum force exerted by walkers on the ground increases with slope. 3) The distribution of walkers across the path, which dictates the intensity of force per unit area of path.

Coleman (1981) also investigated into vegetation resistance, he found that plants producing buds and shoots at ground level are less vulnerable to trampling. Plants that reproduce well are better equipped to regenerate after trampling. Vegetation production depends on the climate and the environment. The variables that affect the relationship of soil and regolith resistance to footpath erosion are, particle size, stoniness, and sheer strength. I intend to study this through the method of dry sieving of soil samples.

Coleman (1981) looked at 25 paths in two areas of the Lake District. The paths varied from infrequently used routes to major routes. This cross-section of paths is mirrored in my own study. Estimates of recreational use of the paths were made by a self-recording method. Walkers were asked to record their trips on strategically placed notice boards. This method worked well for Coleman, and gave accurate measurements. However, this technique is not suitable for use on the Malverns due to a lack of resources available to myself, so a less accurate people count method was employed. The distribution of walkers across the path affects the intensity of use at any one point. Direct measurements were not possible, so intensity was based on two controlling factors. Firstly, the slope across the path, the greater the slope the lower the lateral spread of walkers. Secondly, the degree of restriction imposed on lateral development by physical features such as, streams, rock faces, and boulder fields.

Environmental variables looked at included, vegetation type, soil type, slope angle, altitude, aspect, general surface characteristic, and position on hillside, either main hillside or top of a ridge. Coleman (1981) used altitude and aspect to approximate climatic variations. Problems were encountered when attempts were made to estimate the volume of water running down paths. This was due to the water collecting properties of incised paths, and the pattern of subsurface drainage on mountain slopes.

When considering footpath morphology, three factors were considered. They were, overall path width, width of bare ground, at the depth to which the path is gullied. The area of cross-section was considered, but proved difficult to interpret, possibly because path width is determined by recreational factors, and path depth more by geomorphological factors. In addition, each site was categorised as being actively eroding or not. This was done in the basis of the following observations, earth, stones, spilled onto adjacent vegetated areas, recent water gullying, skid marks and other boot scars on turf, collapsed turf masses, recent bank collapse, absence of lichen or moss cover at the path sides, and frost heave mounds at the sides of the paths.

Coleman (1981) results found that, morphological measures depend on the square root of the recreation pressure variable and the square root of the path slope. He also concluded that the maximum path depth represents incisions much as by water erosion as by feet, and that soil type appears to play a small role. Incision is high on paths running across steep slopes collecting large amounts of runoff and through flow water, which is channelled along the path. With respect to slope angle Coleman (1981) found that erosion is limited on low angle slopes, but increases rapidly on slopes above 15 degrees, a threshold slope of 7-18 degrees appears to distinguish the active from the stable paths.

Coleman (1981) has produced a good study of path erosion, not only quantifying the phenomenon but also contributing to the understanding of causal factors, and threshold limits of path erosion, only if they appear applicable to the local region studied.

The paper by Garland *et al.* (1985) an approach to the study of path erosion in the Natal Drakensberg, a mountain wilderness area, attempts to investigate fundamental relationships and to provide basic data on paths in Giant Castle Reserve. Garland *et al.* (1985) bases the factors affecting path erosion on the previous conceptual model developed by Coleman (1981). (See Figure 3). Garland agrees with Coleman that user intensity and path slope are critical variables affecting path erosion positively. Garland also suggests that site factors imparting resistance to erosion include both, vegetation, and soil type.

Garland (1985) selected only 3 paths for the work, and was chosen for convenience, although they are popular with walkers and traverse typical Drakensberg terrain. By focusing on only 3 paths in close proximity to one another, I feel that results obtained by Garland (1985) will be compromised. It was not possible to include recreational variables in the study, so Garland *et al.* (1985) made the assumption that the use of walkers along the path was uniform. Measurements were taken every 100m; Variables measured were classed as either indicating the amount of soil removed from the path, or those that have influenced erosion rates. The former group comprises of, path depth and width, which give cross-sectional area, and surface stoniness. Stoniness was included as a higher degree of stoniness means a higher degree of erosion. Also Garland (1985) concluded that the larger the stones present, the closer the path surface would be to the bottom of the soil profile, therefore more highly eroded. Although this is a logical conclusion from previous work on cast size in soil profiles, I feel that it is too general an assumption to be of value. Also size of surface stones not only come from the soil but also can be deposited from eroding rock faces and other sources.

As Coleman (1981) did, Garland *et al.* (1985) looked at path slope and aspect as an erosion influencing variable, but he also studied the hill slope gradient, unbroken path slope length, and path alignment with respect to hill slope. Garland *et al.* (1985) objectives of the analysis were three fold. Firstly simple statistical descriptions of each path, secondly, to see whether any of them bore simple relationships with each other, and finally to discover if combinations of erosion-influencing variables could adequately explain variation in observations. Pearson’s product moment correlation coefficient, and spearman’s rank correlation were used by Garland *et al.* (1985) to evaluate relationship between variables. Relationships between path width and depth, as well as between cross-sectional areas and path slope confirm results obtained by Coleman (1981). However, low coefficients of determination show that explanatory powers of the links are poor, and that other variables must play an important role. (Garland *et al.*1985). Garland *et al.* (1985) found that upslope path length was unrelated to any of the erosion inducing variables. This led to the conclusion that slope length only minimally effects erosion. This finding is in direct contrast to other erosion situations where long slopes are more susceptible to erosion. (Morgan 1995, and Zingg 1940)

Garland *et al.* (1985) suggests that for better results a number of variables should be studied, including user intensity, number of tramplers, rainfall intensity, aspect, and soil characteristics. These factors are included in Garland's later work in the Drakensberg region in 1990, where he suggests a technique for assessing erosion risk from mountain footpaths. Garland (1990) describes the unsuitability of soil loss equations, such as the universal soil loss equation and empirical models, when considering path erosion as they have their origins in agriculture. Garland (1990) considers a suitable technique to be using a simple parametric scoring system. The approach does not provide a quantative estimates, but allows comparison. The practice developed by Garland (1990) is a good tool in planning the location of new footpaths, and the rating system be adapted so that it can be used on existing paths to aid in management decisions.

The book Davies (1996) repairing upland path erosion: a best practice guide is aimed at countryside managers and environmental agencies considering implementing footpath management schemes. Davies (1996) outlines the guiding principles and stages that need to be taken to successfully plan, implement and manage footpath erosion.

The first stage is to identify path erosion and then next to measure it in a uniform way (Davies 1996). The main problem is that the assessment of the level of footpath erosion is a qualatative approach, and very subjective. Davies (1996) attempts to quantify the problem by measuring the width of scarring, depth of scarring, and width of worn vegetation. This then gives the actual figures that can be classified to give a ranked value for a footpath, a similar approach to that employed by Gartland (1990). To help standardise the approach further Davies (1996) suggests subdividing the path into 100m sections. The need is stressed to take average values of individual features such as depth of scarring.

It is also suggested that features such as braiding, pigeon holing, and gullying should be noted as present or not. Braiding is the evidence of multiple paths; pigeon holes are flattened toe holes, and are good indicators of vegetation loss and soil degradation. Gullying is a major indicator of serious erosion. Davies (1996) also suggests that the amount of loose debris covering adjacent vegetation should be noted. This is then subdivided into four categories of, absent, <10m^2, 10-40 m^2, and >40 m^2. The loose debris coverage suggests how currently actively eroding the footpath is, or not as the case may be. The results are then graded for each 100m section from 1-3. Grade 1 is a high level of erosion 2 medium, and 3 low. These grades are then colour coded and drawn onto an OS map of a scale of 1:10 000.Davies (1996) also suggests further descriptive work to be carried out.

Throughout the literature there is a general agreement that the main causal factors affecting path degradation are both human and physical, and can be sub-divided into recreational and environmental pressures. Recreational pressures include user intensity, and user type, where as environmental pressures are more broad and include such variables as, slope angle, path angle, soil composition, vegetation type, and rainfall intensity.

The suggestions of how a study of footpath erosion should be conducted by Davies (1996) are very applicable to my own study. However, not enough attention is give to causal factors of footpath erosion, only to quantifying and recording current erosion levels. This sort of work is extremely useful to build up a database of path erosion and stability, and the technique outlined would be useful to a study of footpath degradation on the Malvern Hills.

1.3 Soil erosion

Soil erosion can be subdivided into processes and mechanisms of 1) water erosion, 2) wind erosion, and 3) Recreational erosion. Soil erosion is a two-phase process involving the detachment of individual particles from the soil mass, and transportation by water and wind. Deposition occurs when there is insufficient energy available for transport. Detachment can be through agents such as, rain impact, weathering be it mechanical or biochemical, trampling by people, horses or bikes and by the action of running water and wind. (Morgan 1995)

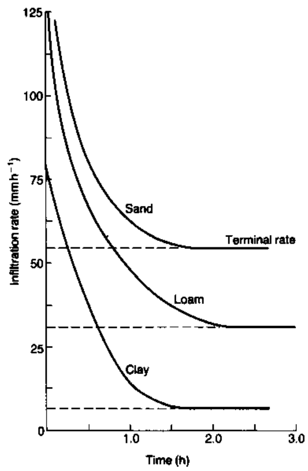
1.3.1 Water erosion

Transporting agents act either across an area, removing a uniform thickness of soil, or via channel action. Areal processes include, rain impact, surface runoff which forms a shallow flow of infinite width termed as sheet flow, and wind (Harden 1993). Rills and gullies constitute channel action; rills are small features where as gullies are much larger (Hudson 1971). Mass movements of soil also occur in the form of soil flows, slides, and creep. These processes are the result of water weakening the soils internal strength. (Morgan 1995)

Processes of water erosion are closely related to routes taken by water through vegetation cover and movement over the ground surface. Their base lies in the hydrological cycle, as described by Morgan (1995). During a rainstorm rain falls directly on the ground and moves as throughflow, or is intercepted by vegetation cover. The water is then subject to evapo-transpiration or continues to ground level via leaf drainage and stem flow. This process gives rise to rain impact erosion. When the water is at ground level it infiltrates into the ground water store and soil moisture storage. Once the soil is saturated the excess moves laterally down slope within the soil as subsurface flow, or contributes to runoff. Resulting in erosion by overland flow, or as rills and gullies. (Morgan 1995)

The rate at which water passes into the soil is known as the infiltration rate and is a major control over the generation of surface runoff and therefore controls erosion. The infiltration rate of soil decreases as a storm continues and is dependent upon soil characteristics. (Hudson 1971). Generally, coarse textured soils such as sands and sandy loams have higher infiltration rates than clay soils. This is due to larger spaces between soil particles. There can be local variability in infiltration rates due to structure, compaction, initial moisture content, and the soil profile. (Withers *et al.* 1974)

Fig 4. Typical infiltration rates for soils



Source: Morgan 1995 p8.

Rain impact is an important process of soil erosion. The transfer of momentum from the raindrop to the soil has a consolidating force that compacts the soil, and a destructive force that promotes transport (Morgan 1995). The consolidation effect causes the formation of a surface crust. The crust is only a few millimetres thick, clogging pores and promoting surface runoff, and so in turn promoting erosion. A surface crust forms only after a few storms. (Hudson 1971)

The response of soil to rainfall depends on moisture content, and therefore the structural state of the soil, and the rain intensity (Sharma *et al.* 1989). This gives rise to three possible responses. Firstly, if the soil is dry or the rainfall intensity is high there will be a rapid breakdown of the soil aggregates by shalking, and so the infiltration capacity of the soil is reduced rapidly leading to rapid runoff after a few minutes of rain (Le Bissonnais 1990). Secondly, if the aggregates are partially wetted or the rain intensity is low, then micro cracking occurs, which causes the aggregates to breakdown into smaller aggregates (Le Bissonnais 1990). The surface roughness decreases, but infiltration remains high due to large pore spaces between the micro-aggregates. Finally if the aggregates are initially saturated, then large quantities of rain is required to seal the surface. If the rain intensity is high then soils with less than 15% clay content are vulnerable to sealing (Le Bissonnais 1990).

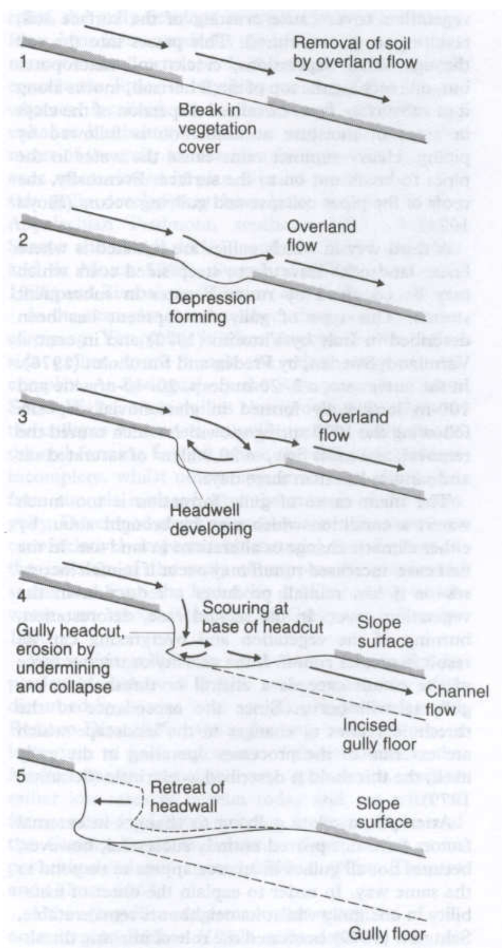
Overland flow occurs during a rainstorm when surface depression storage, soil moisture storage, and the infiltration capacity of the soil are exceeded. During peak discharge overland flow covers up to two thirds of a hillside, and is rarely as sheet of water with uniform depth, but as of braided watercourses (Horton 1945). At the top of the slope there is a zone without flow due to high infiltration, this forms a belt of no erosion. At a critical distance from the crest enough water accumulates for flow to begin (Horton 1945). Flow is broken up by stones and cobbles, and by vegetation cover, often swirling around tufts of grass and small shrubs as turbulent flow focusing erosion in these areas. At a further critical distance, the flow becomes concentrated into fewer deeper flow paths, which occupy a progressively smaller proportion of the hillside. (Parsons *et al.* 1990)

The result of the channelled flow is rill formation. Rills are small channels formed by converging flows that scour out a trench. The change from overland flow to rills occurs in four stages. Firstly from a non-concentrated channel flow, to overland flow with concentrated flow paths, next as micro channels without headcuts, and finally as micro channels with headcuts. The greatest differences in flow exist between the first and second stages (Merritt 1984). In the second stage, small vortices appear in the flow. In the third stage they develop into localised spots of turbulent flow, characterised by roll waves and eddies (Rauws 1987). At the point of rill initiation, the flow conditions change from subcritical to supercritical. At this time knick points or headcuts may form.

Subsurface flow or interflow is characterised by the lateral movement of water downslope through the soil in tunnels and subsurface pipes. The result of concentrated flow in tunnels and subsurface pipes is tunnel collapse and gully formation (Morgan 1995). Gullies are relatively permanent steep sided watercourses. They are characterised by a headcut and various knick points along their course. Gullies are associated with accelerated erosion and therefore with landscape instability (Morgan 1995).

The sequence of stages that initiate gully erosion is described by Leopold *et al.* (1964). The first stage in gully initiation is the formation of small depressions on the hillside as a result of the localised weakening of the vegetation. Water concentrates in these depressions and enlarges, until several depressions join, and a channel is formed. Erosion is concentrated at the heads of the depressions where near vertical scarps develops over which supercritical flow occurs. Most erosion is associated with scouring at the base of the scarp that results in deepening of the channel and the undermining of the headwall, leading to collapse and retreat of the scarp upslope. Sediment is also produced further down the gully by bank erosion. (Leopold *et al.* 1964)

<u>Figure 5. Stages in the surface development of gullies on a hillside</u>



Source: Morgan 1995 p19.

1.3.2 Wind erosion

The main factor controlling wind erosion is the velocity of moving air. Wind speeds are lowest nearest the ground due to friction and resistance supplied by stones, vegetation, and soil (Hudson 1971). Compared to water, the shear stress needed to move a soil particle by wind is much greater. The larger force means that the movement is more violent, this violence is rapidly transmitted to surrounding particles, and so acts as a chain reaction of motion (Morgan 1995). The most erodible particles are 0.10 to 0.15mm in size (>3phi) this restricts the erosive power of wind (Morgan 1995). Overall the affect of wind erosion on soils is small compared to water erosion, but under specific conditions of advanced soil degradation and high winds, it can have a great detrimental affect, e.g. the great American dust bowl.

1.3.3 Factors controlling erosion

Erodibility defines the resistance of the soil to both detachment and transport. Erodibility varies with soil texture, aggregate stability, shear strength, infiltration capacity and chemical content. The least resistant particles are silts and fine sands. Soils with restricted clay content of between 9 and 30% or 40 to 60 % fine sands are most susceptible to erosion (Morgan 1995). Clay particles combine with organic matter to form soil aggregates, and it is the stability of these that determines the resistance of the soil. Soils with a high content of base minerals are more stable as they contribute to chemical bonding of the aggregates. (Morgan 1995)

An important part of footpath degradation is people pressure. As upland areas increase in popularity as areas for recreation, the pressure on footpaths increases. Davies (1996) defines path erosion as, *"where the vegetation and soil structure has been lost or substantially altered due to concentrated people pressure."* The most erosive form of human activity is horse riding, followed by mountain bikes, and finally walkers.

Erosion increases with the increase in slope angle, and slope length. This is due to the increase in velocity and volume of surface runoff, and the erosive power of walkers is greater going up hill. Also on a slope rainsplash is greater in the downslope direction than upslope, and so increases transportation of particles (Morgan 1995). The relationship between erosion and slope can be expressed by the equation (see Figure 1.) by Zingg (1940).

Vegetation acts as a protective layer between the atmosphere and the soil. Above ground components, such as leaves and stems, absorb some energy of falling raindrops. Below ground components, comprising root systems contribute to the mechanical strength of the soil (Sharma *et al.* 1989). Plant cover provides resistance from recreational pressure and dissipates the energy of running water and so reduces the erosive power of overland flow. However this is only true for dense uniform vegetation cover. Clumps of vegetation are less effective and may lead to concentrations of flow with localised high velocities. (Morgan 1995)

1.4 Weathering

Weathering as well as erosion contributes to the degradation of upland regions. Weathering occurs over a longer period of time than erosion, and the effects may not be noticed for hundreds of years, however the weathering of rocks causes them to become awkward to walk upon, and so contributes to the problem of footpath divergence and widening.

"Weathering is the breakdown and alteration of materials near the earth's surface to products that are more in equilibrium with newly imposed physio-chemical conditions." Ollier (1984)

Physical weathering is the breakdown of material by entirely mechanical methods brought about by a variety of causes. The main processes at work are frost weathering, salt weathering, insulation, moisture swelling, slaking, and abrasion. Frost weathering is the most prevalent agent at work. When water freezes it expands and this has a disruptive effect (Ollier 1984). The process of freeze-thaw action is more destructive than just freezing alone. The growth of salt crystals in some cases can cause the desegregation of rocks, and acts in a similar way to frost weathering. Mineral and rocks may be worn away by simple mechanical abrasion by impact or due to friction as rocks slide over each other (Ollier 1984). Insulation and moisture swelling is insignificant in the UK as there is not the climate extremes needed to set up high enough temperature gradients for insulation weathering, or high enough levels of humidity for moisture swelling of rocks.

1.5 Aims and objectives

The aims and objectives of this study are to produce a classification map of footpath quality in the Malvern Hills region, and to device the causal factors and their threshold limits of footpath erosion. Specific attention was paid to vegetation cover, slope angle, the angle of the footpath to the slope, the soil structure, and surface protection of existing footpaths.

The most erosive form of human activity is horse riding, followed by mountain bikes, and finally walkers. The purpose of this project was not to encourage the restriction of public access to the Malvern Hills, but to help in the understanding of the processes of path erosion. So that erosion can be combated and controlled, allowing the continued public recreational use of the Malvern Hills.

2. Study area

The Malvern Hills spread across the borders of Worcestershire and Herefordshire County. They are ten miles in length and have been split into management zones by the Malvern Hills Conservators. My study is concerned with the three ‘hill’ zones, North, Central, and South. The north zone is concerned with areas north of the Wyche cutting, which include, Worcestershire Beacon, North Hill, and End Hill. The central zone is located between the Wyche cutting and Black Hill. The southern section is concerned with the less prominent hills south of Black Hill including, Herefordshire Beacon, Broad down, Swinyard hill, and Hangman's hill. 11 footpaths were studied in total. (See table 2 for grid ref). To achieve an overview of footpath quality across the entire Malvern Hills, 5 footpaths were studied in the northern zone, 2 from the central zone and 3 from the southern zone. (See fig 6). Suitable paths were chosen based on factors of length, popularity, accessibility, degree of erosion and position.

Figure 6. Study site – The Malvern Hills

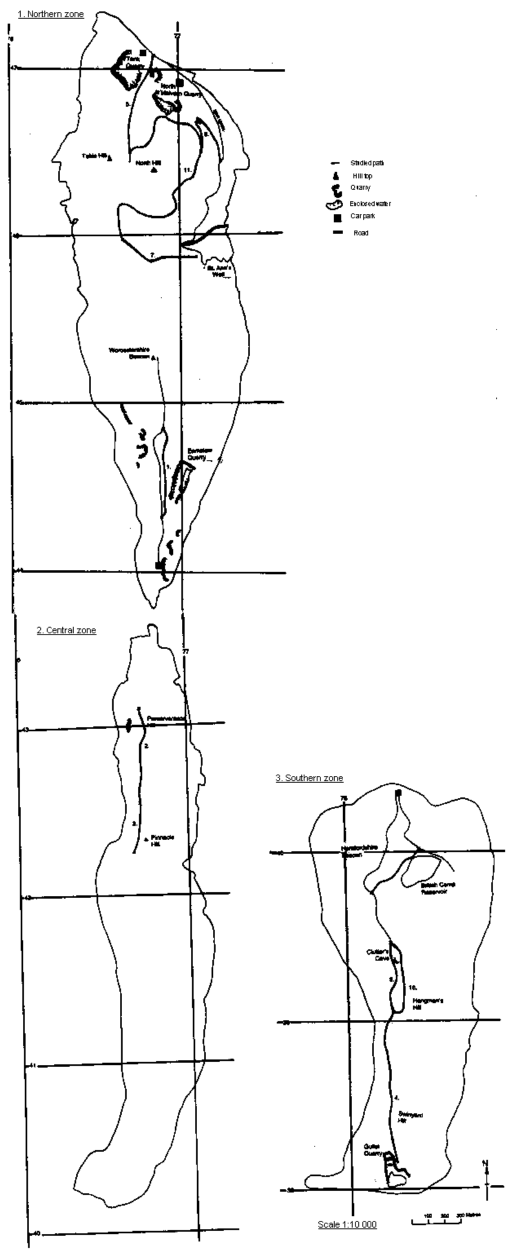


Table 2 Location of studied footpaths.

Path No.	Location	Grid ref: Start point	Grid ref: Finish point
1	Worcestershire Beacon	769443	769448
2	Perseverance Hill	769433	769427
3	Pinnacle Hill	769427	768424
4	Swinyard Hill	762382	762390
5	End Hill	769470	768464
6	North Hill	773464	772465
7	St Ann's knoll	771458	767450
8	British camp reservoir	764400	761398
9	Clutters cave	762395	762390
10	Hangman's Hill	762391	762395
11	Lady Howard de Walden drive	768465	767460

3. Materials and Methods

3.1 Classification of path quality

Each footpath was firstly walked along and general observations noted, such as, the type of recreational use, erosional features, and types of vegetation cover. The paths were numbered for reference, location including the OS grid reference starts and finish point were noted, and the path length measured using a *trundle wheel*. The path was then subdivided into 100metre sections. Measurements of the width of worn vegetation, width of scarring and depth of scarring are then made using a *30metre tape measure* at 20metre intervals along the section. The presence of braiding, gulleying or pigeon holing was also recorded.

For each 100metre section the average result for each variable was calculated and then graded 1, 2 or 3. 1 represents a high level of erosion, 2 medium and 3 a low level.

Taking into account the 3 grades of the variables and general observations, the 100metre subsection is then rated and noted onto an OS map of scale 1:10 000 using coloured lines, red for 1, amber 2 and green for 3. Footpaths with a grade of 1 and 2 should be revisited every year, as they are highly reactive, grade 3 footpaths can be revisited on a four yearly basis.

3.2 Recreational variable

A major factor affecting footpath erosion is how popular and frequently used the paths are. Horses are the most erosive, followed by mountain bikes, and finally walkers. Due to a public access act passed in 1848, fencing or fines cannot restrict the movement of people on the Malvern Hills. Also some routes are classed as bridle-ways, which gives the right of way to horse riders and cyclists as well as walkers. This means that mountain bikes cannot be banned from the Hills. To measure footpath popularity a simple frequency table was used. Basically observe who uses the footpath in 1hour and record the count of walkers, mountain bikers, and horse riders in that period.

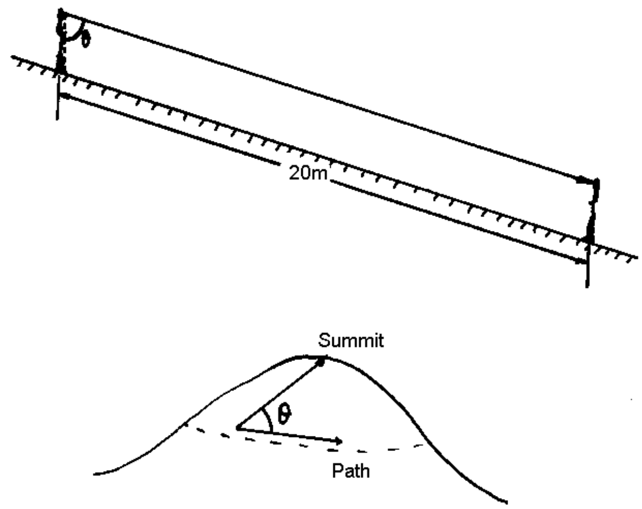
3.3 Environmental variables

To complete the second objective of devising causal effects and thresholds of footpath erosion, 5 footpaths were studied in more detail. At which slope angle, path angle (angle of path alignment to slope), and soil structure were studied. The footpaths chosen are located at Worcestershire beacon, End hill, St Ann’s knoll, British camp reservoir and Lady Howard De Walden’s drive.

The Worcestershire beacon footpath was chosen because it is popular with walkers and mountain bikers, showing evidence of gullying and braiding. The path angle remains relatively constant, and therefore shows the effect that the change in slope angle and recreational pressure has on erosion. The footpath at End hill is situated in a valley and is rarely used by walkers. During rainfall the path becomes a watercourse. There is little change in the path angle, so this will enable observations of how the change in slope and presence of water effects footpath erosion. There is also evidence of the early stages of gully formation and pigeonholing on the upper slope. This is a popular footpath running from Sugarloaf hill to St Ann’s knoll. Existing gravel based footpath protection has already been laid down. Storm drains are present, giving evidence of watercourses flowing across the path. Therefore it would be interesting to see how this protection stands up to erosion. The footpath located at the British camp reservoir is not well used and there is no erosion protection in place. The path angle goes through 3 distinct changes throughout the slope. Pigeonholing occurs on the steeper upper part of the slope. This should provide good insight into the effect of changes to the path angle has on erosion, and how slope angle effects the occurrence of pigeonholing. Lady Howard De Walden’s drive is a long, well protected, popular, relatively flat contour path with little to no change in the slope angle, and path angle. These constants make it a good control sample, which can show effects of recreational pressure on erosion.

The angle of slope was measured at 20metre intervals along the path using a *compass-clinometer* by setting it to an east-west orientation and sighting over the 20metres to another person at the same eye line, then reading the result where the small red arrow is pointing. (See figure 7) The path angle is measured at points along the path where there are distinct changes. Again this is done using the *compass-clinometer,* set to a north south orientation and used as a bearing. With the compass flat in hand sight to the top of the hill, twisting the dial so that the small red arrow sits in the large red north arrow, record the bearing. Next, sight along the path and record the bearing. (See figure 7) To calculate the path angle, subtract the results from each other. Samples of the path sub-strata were taken every 100metres using a *trowel* and placed into *sample bags*, to be taken back to the laboratory to be dry sieved.

Figure 7. Techniques to measure slope angle and path angle



3.4 Method of dry sieving

Wet soil samples are transferred from the sample bags into pre-weighed containers and dried in the open air. Due to the drying processes the soil particles cement together and must be broken down into individual particles, this process is completed using a pestle and mortar. Prior to sieving the sample is weighed using a top ban balance accurate to 1/100th of a gram, and the weight of the container subtracted to give the total weight of the sample. The sample is then sieved mechanically for ten minutes in a set of sieves ranging from –3phi to >4phi. The material from each phi size is then placed into a pre-weighted container and weighed, and the weight of the container subtracted to give the actual weight of the sample. The % of total weight for each phi size is then calculated using the following equation:

$$\%\ \text{Weight} = \frac{\text{Weight of phi sample}}{\text{Total sample weight}}$$

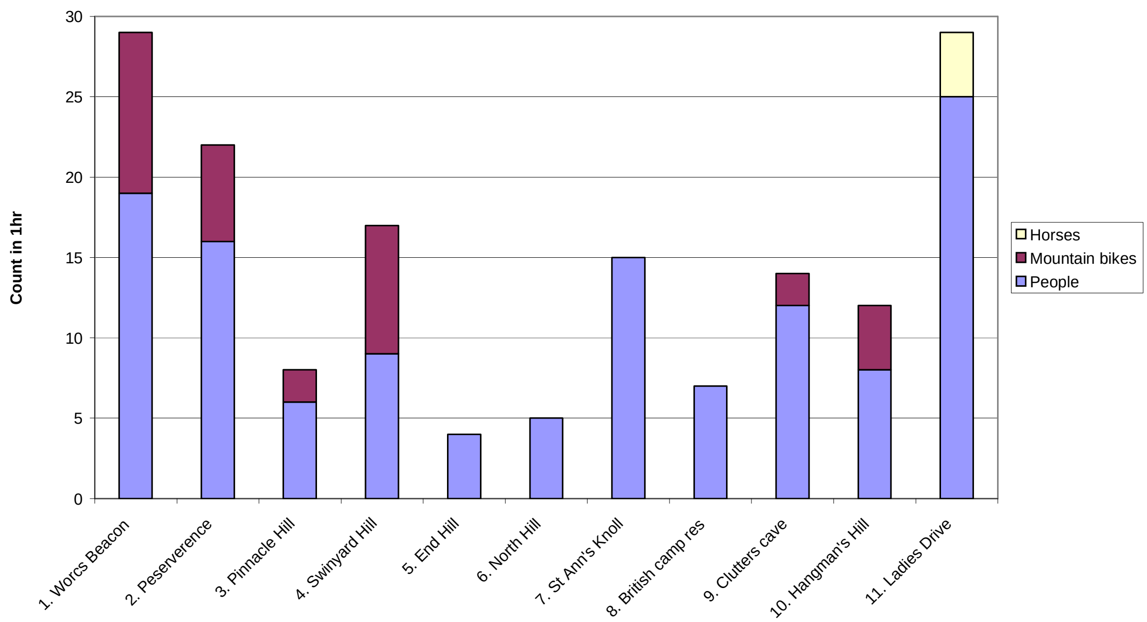
Cumulative % is found by simply adding up the % weight of each phi size, from small (>4phi) to large (-3phi). The % weight is then plotted against phi size to give a particle size distribution curve, which shows the degree to which the soil is made up of clay, silt, sand, and gravel.

4. Results

4.1 Footpath classification – see fig 8 p35

4.2 Recreational variable

Figure 9. - Footpath popularity



4.3 Environmental variables

4.3.1 Soil structure

Table 3. – Soil composition

Path Number	% coarse / medium gravel	% medium / fine gravel	% fine gravel / coarse sand	% Medium sand	% fine sand	% silt/clay
1	54.89	8.48	11.29	12.77	8.57	3.86
5	42.4	6.07	13.94	18.28	12.23	6.69
7	47.25	15.67	19.16	11.39	5.34	1.86
8	10.55	7.99	20.17	29.51	15.27	13.54

Figure 10. - Path 1. Worcestershire Beacon - Cumulative %

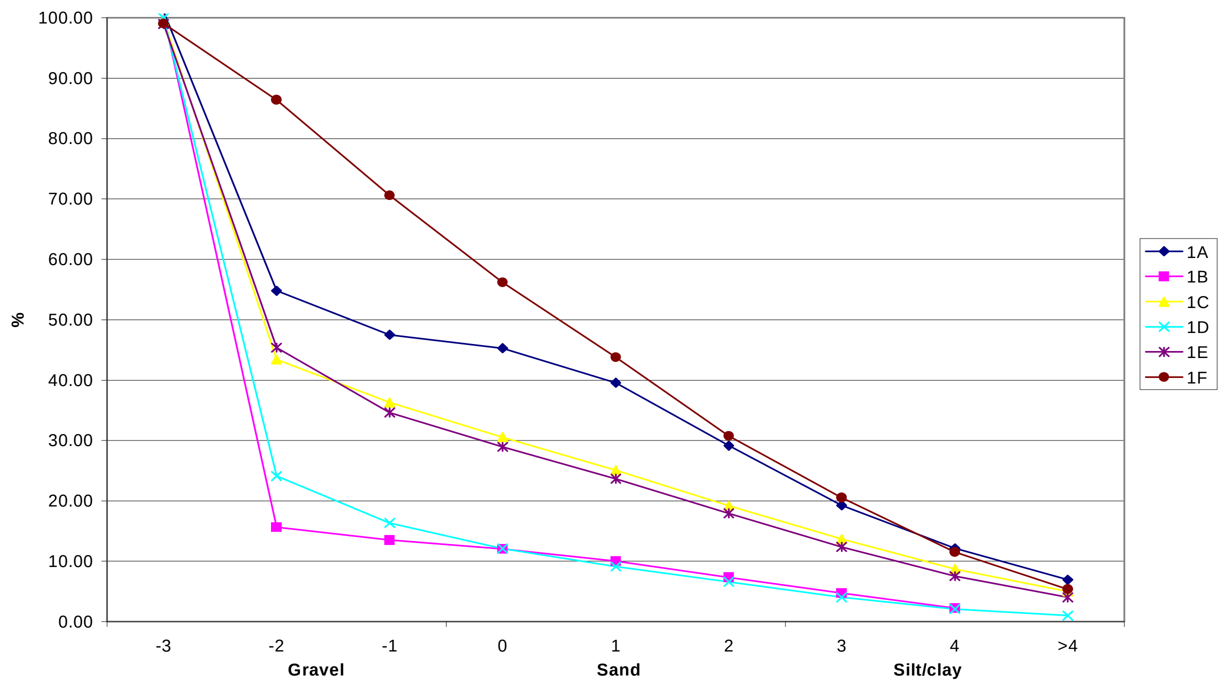


Figure 11. - Path 5. End Hill - Cumulative %

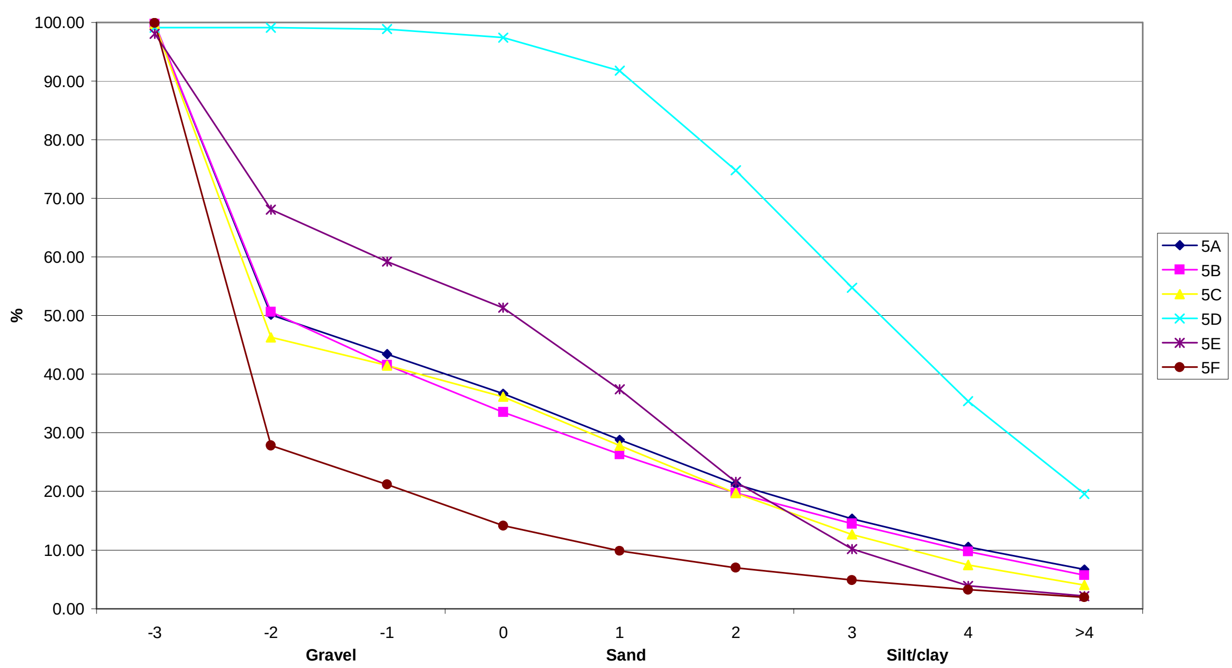


Figure 12. - Path 7. St. Ann's Knoll - Cumulative %

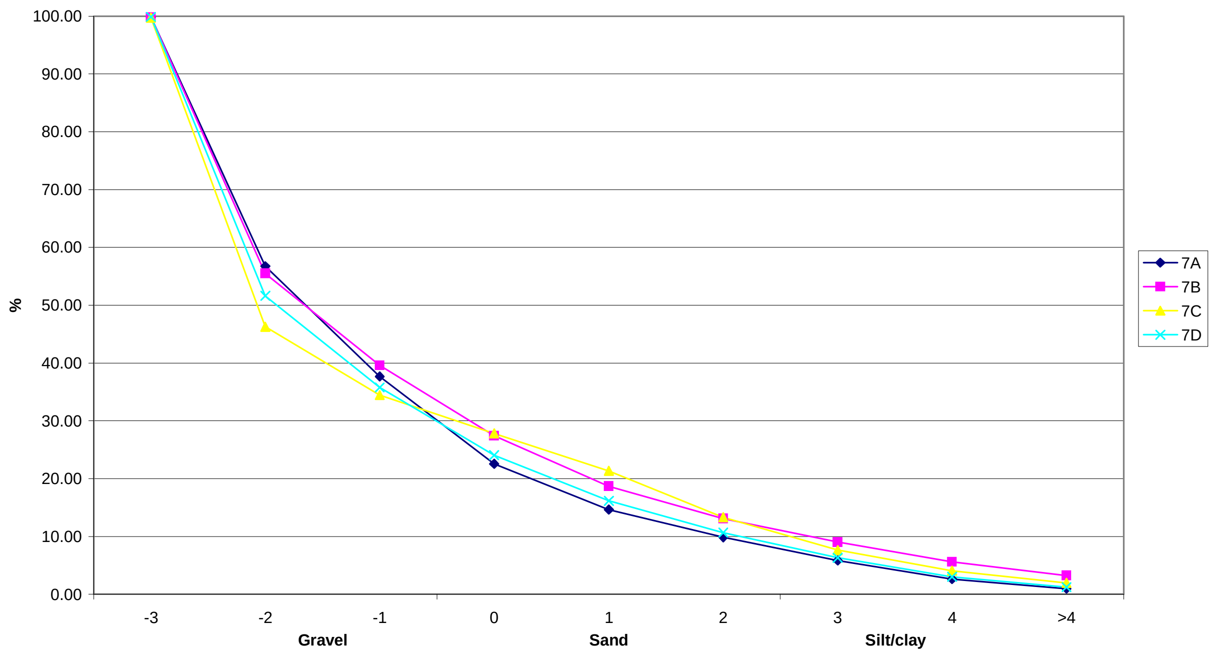
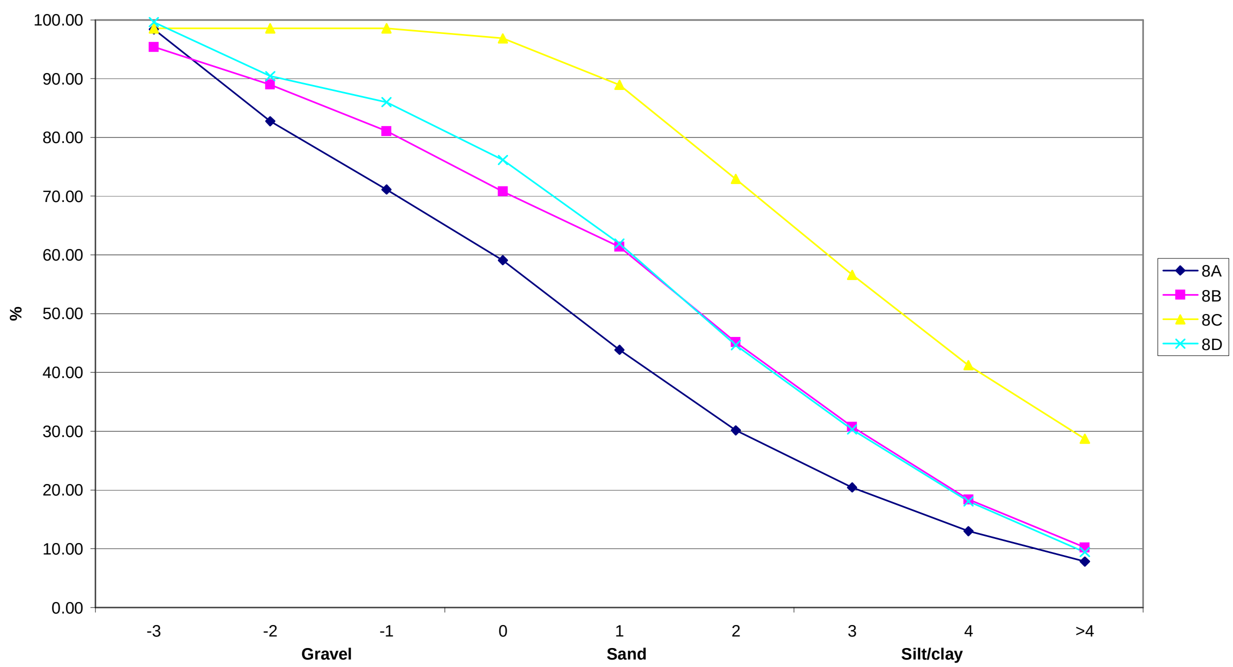


Figure 13. - Path 8. British Camp res - Cumulative %



4.3.2 Slope angle and path angle

Figure 14. - Effects of slope angle on erosional processes

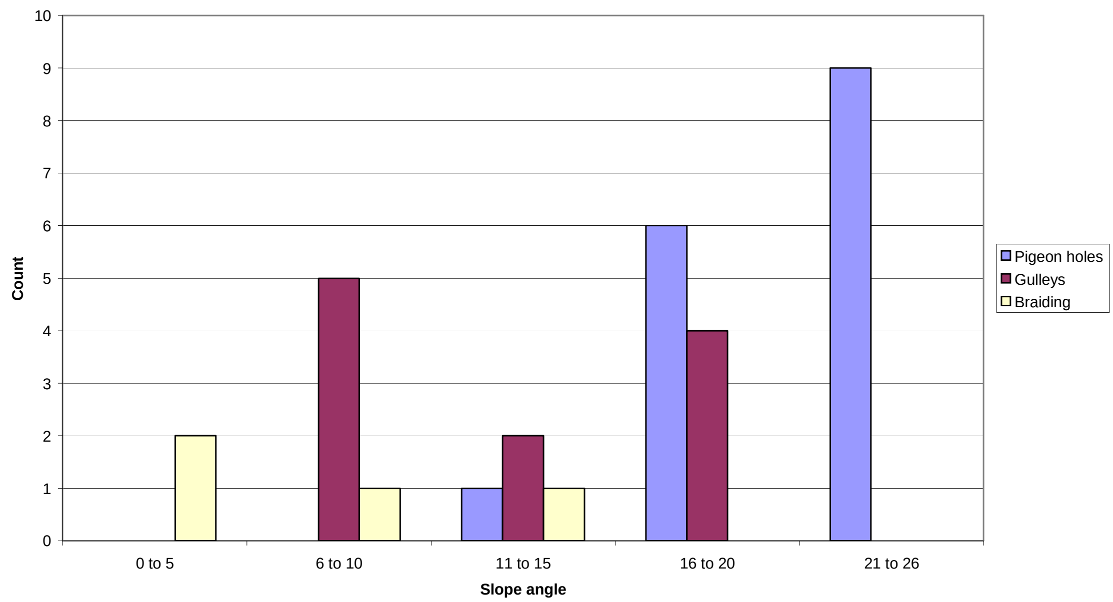


Figure 15. - Effect of path angle on erosional processes

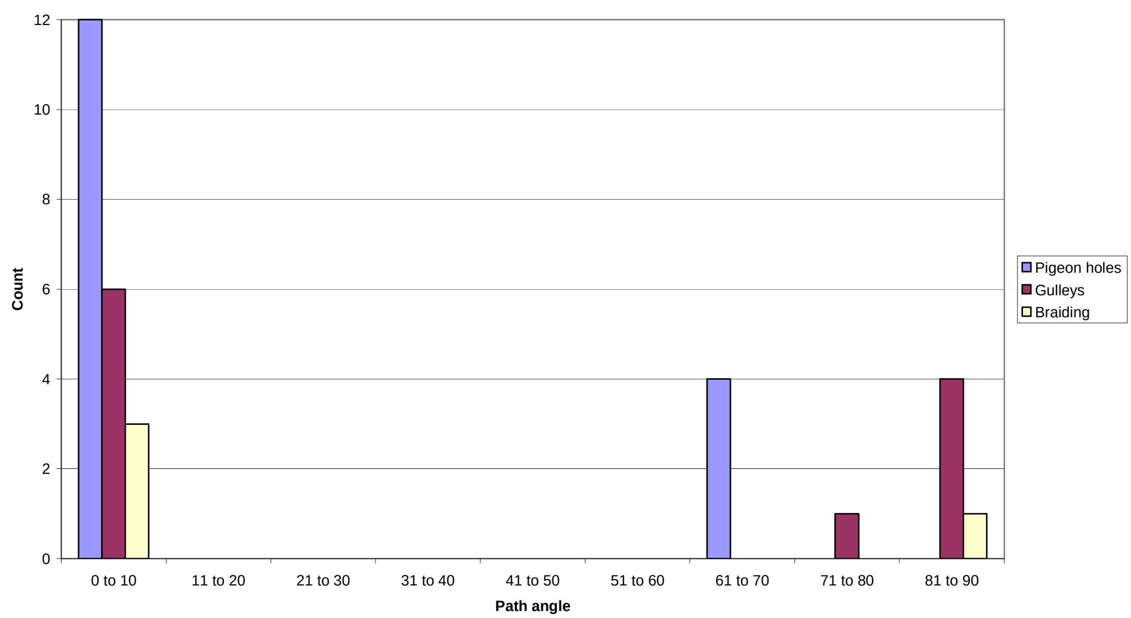


Figure 16. - Path 1. - Worcestershire Beacon

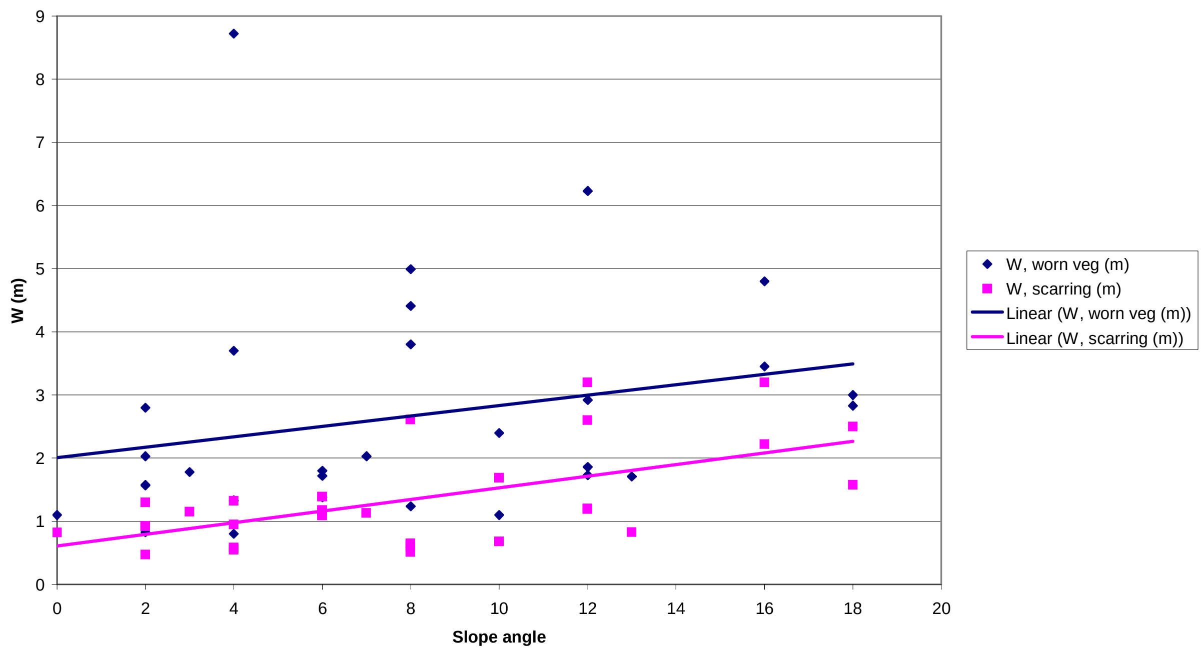
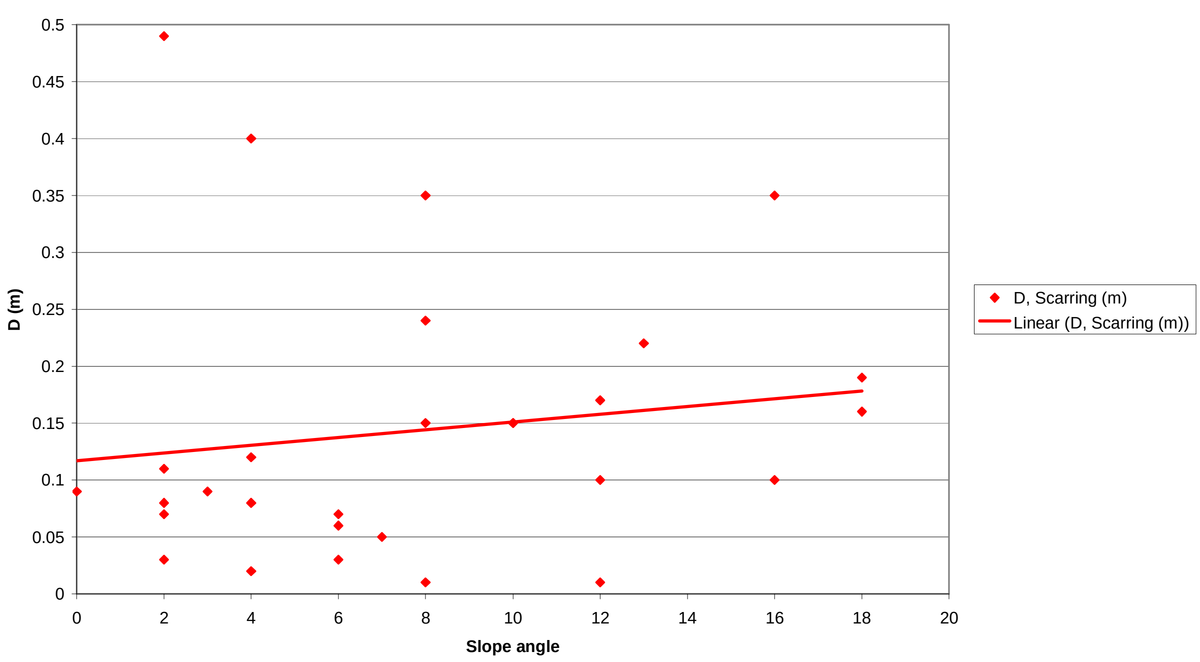


Figure 17. - Path 1. - Worcestershire Beacon



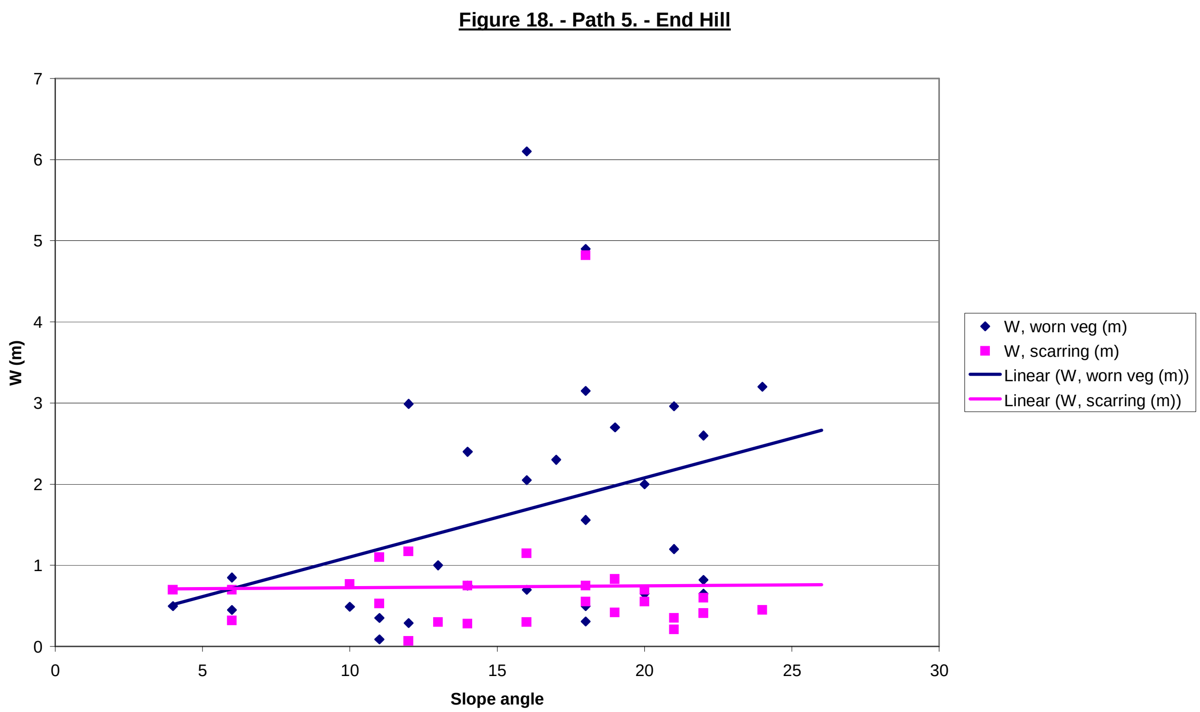


Figure 18. - Path 5. - End Hill
W (m)
Slope angle
W, worn veg (m)
W, scarring (m)
Linear (W, worn veg (m))
Linear (W, scarring (m))

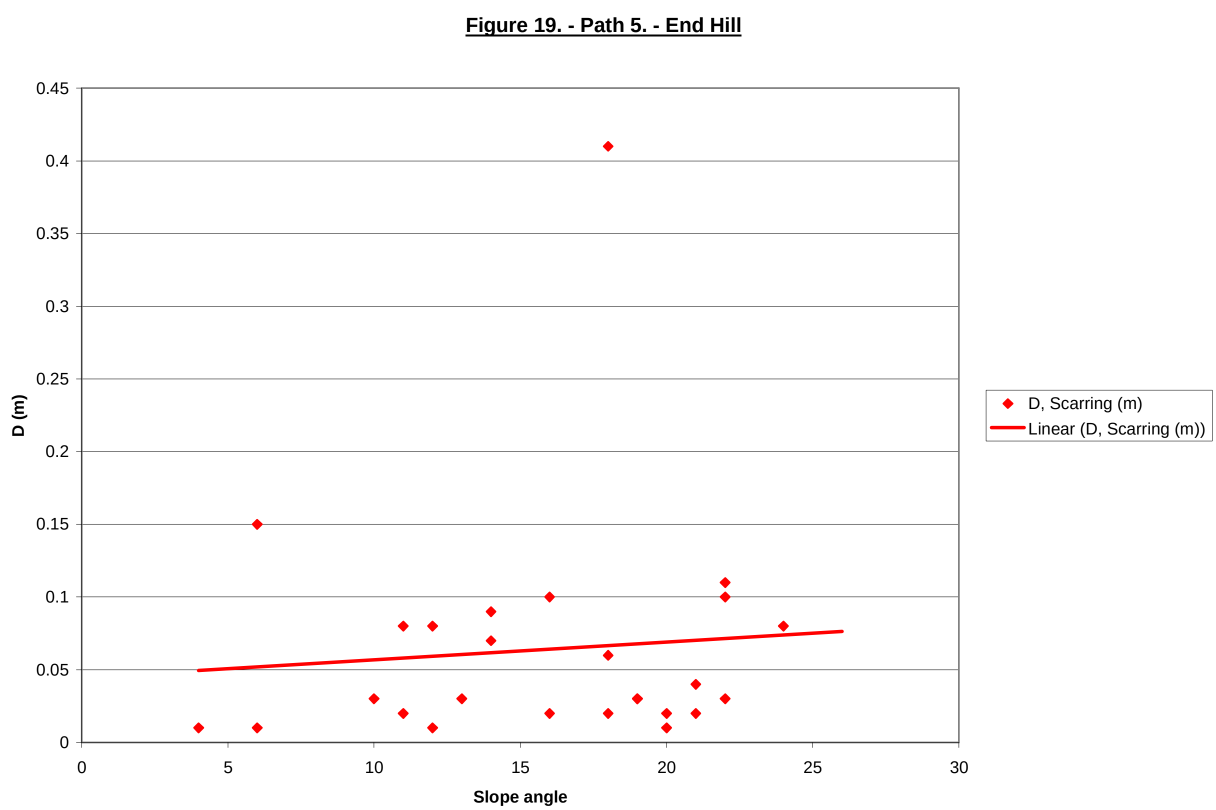


Figure 19. - Path 5. - End Hill
D (m)
Slope angle
D, Scarring (m)
Linear (D, Scarring (m))

Figure 20. - Path 7. - St Ann's Knoll

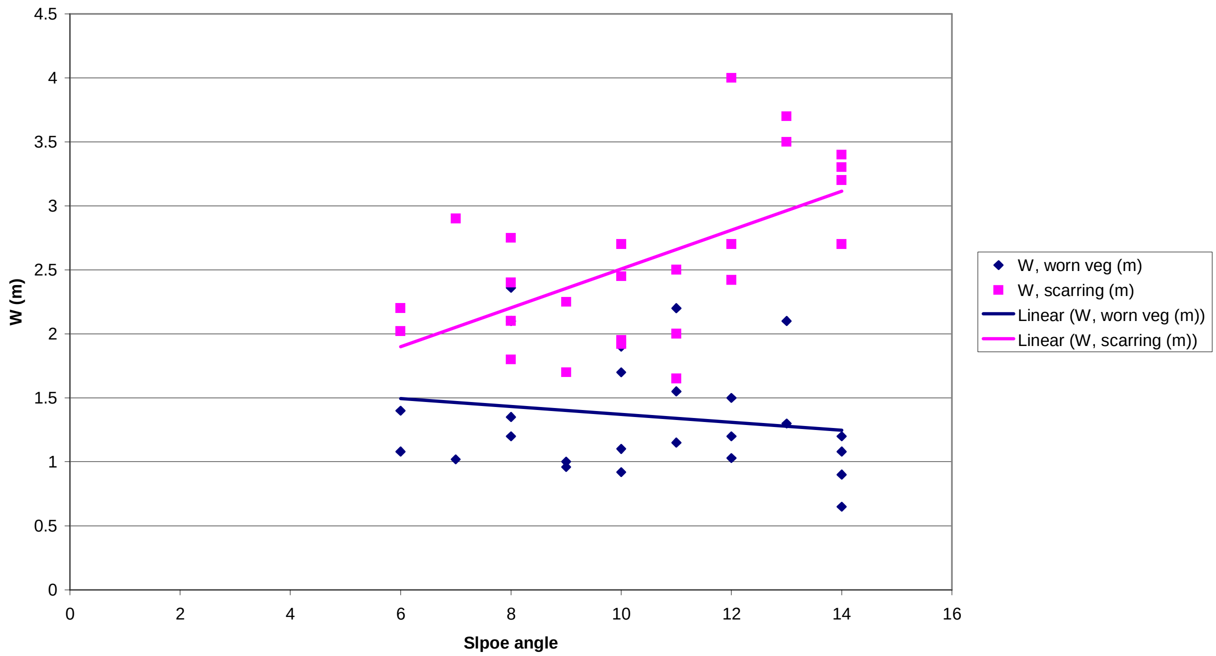


Figure 21. - Path 7. - St Ann's Knoll

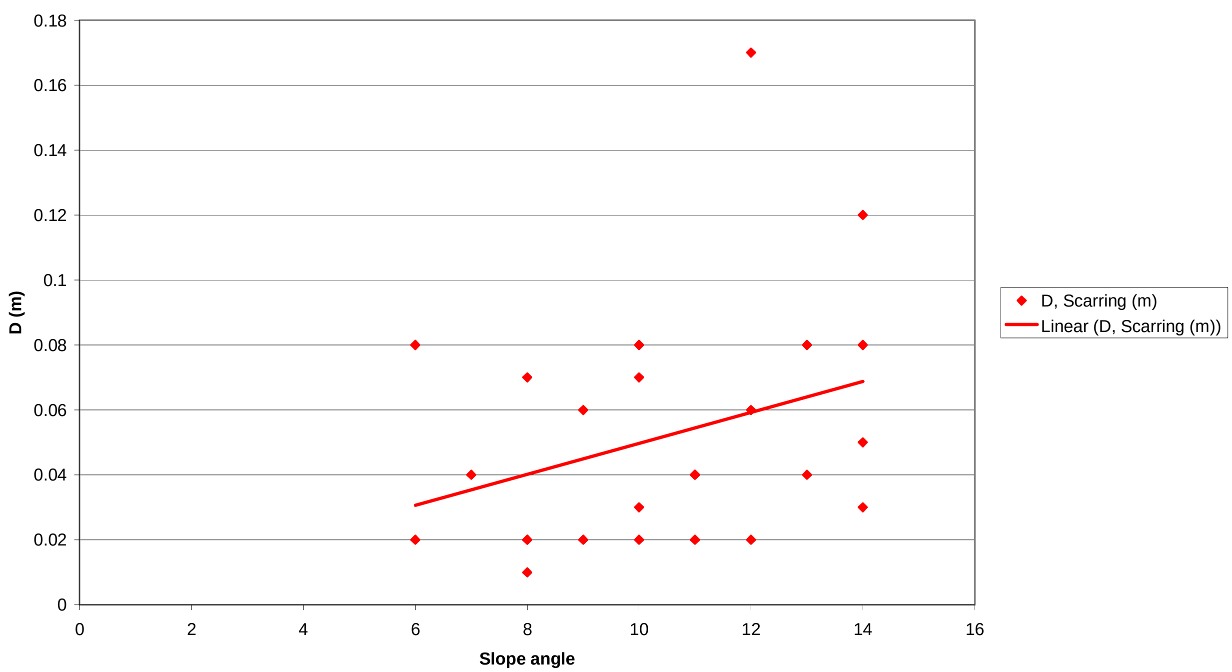


Figure 22 - Path 8. - British camp resevoir

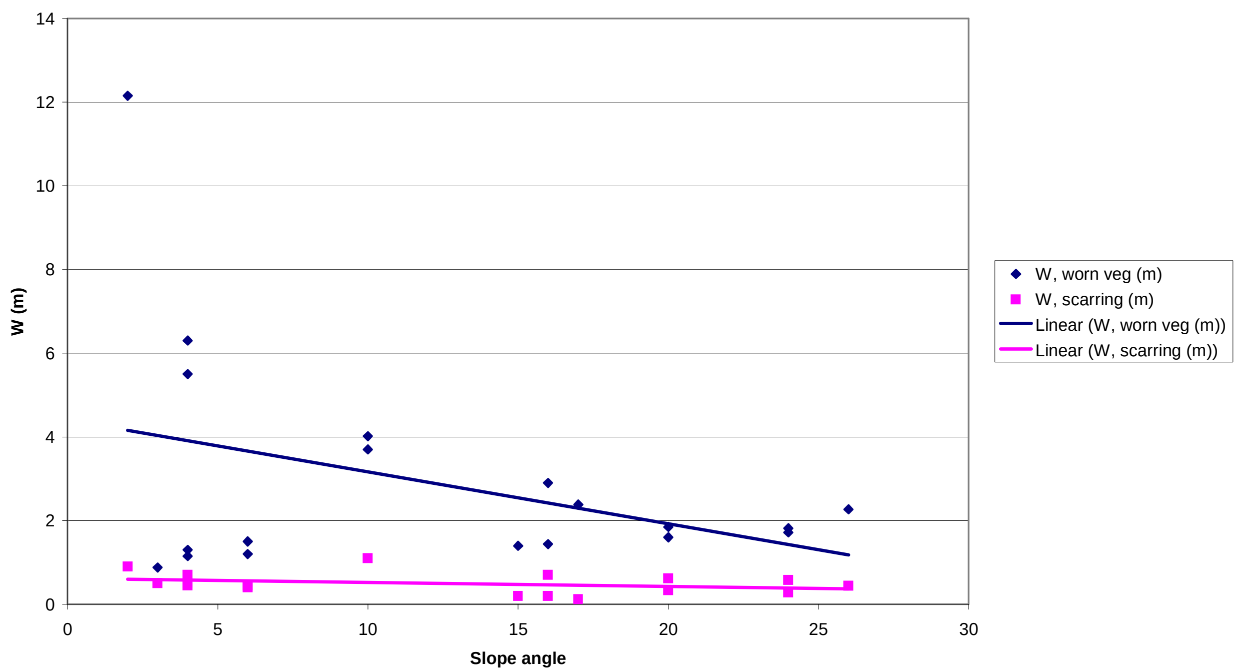


Figure 23. - Path 8. - British camp resevoir

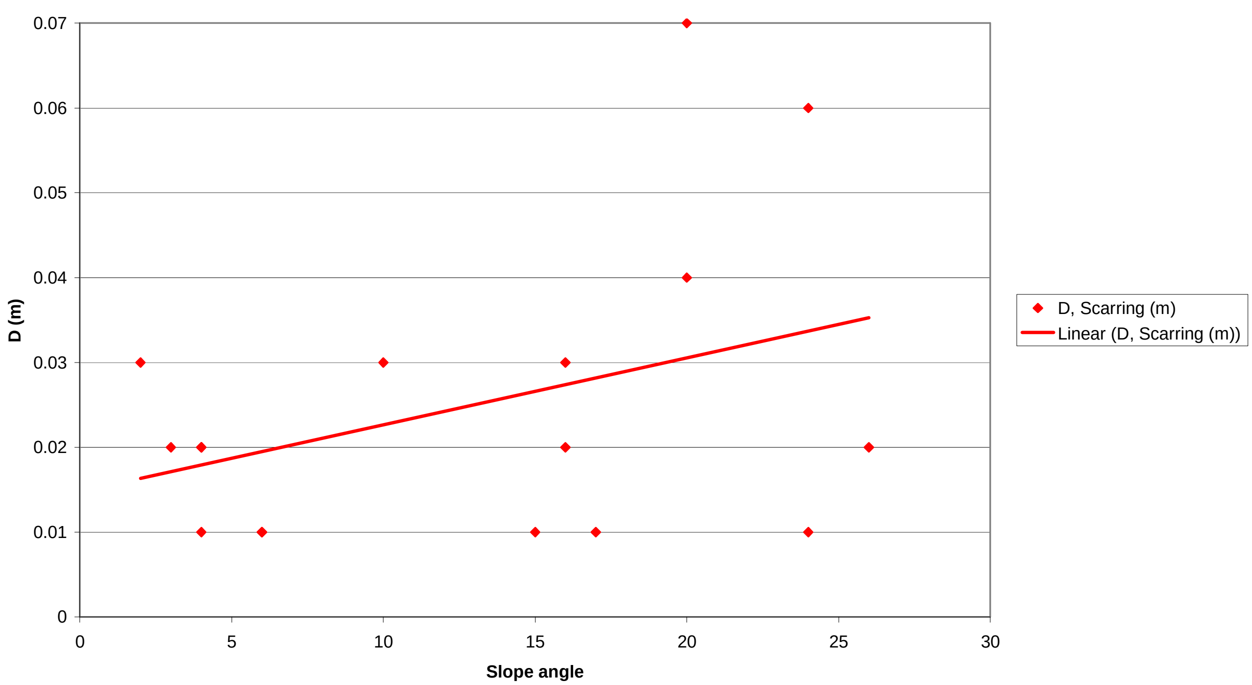


Figure 24. - Path 11. Lady Howard de Walden's Drive

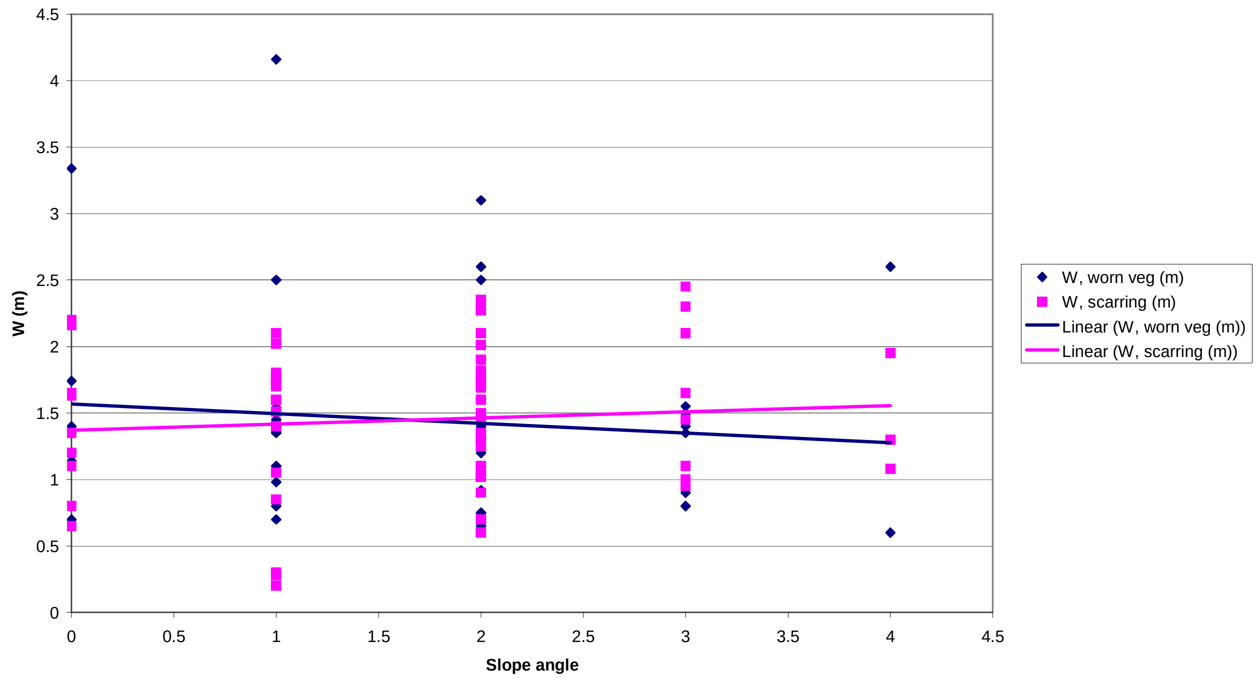


Figure 25. - Path 11. Lady Howard de Walden's Drive

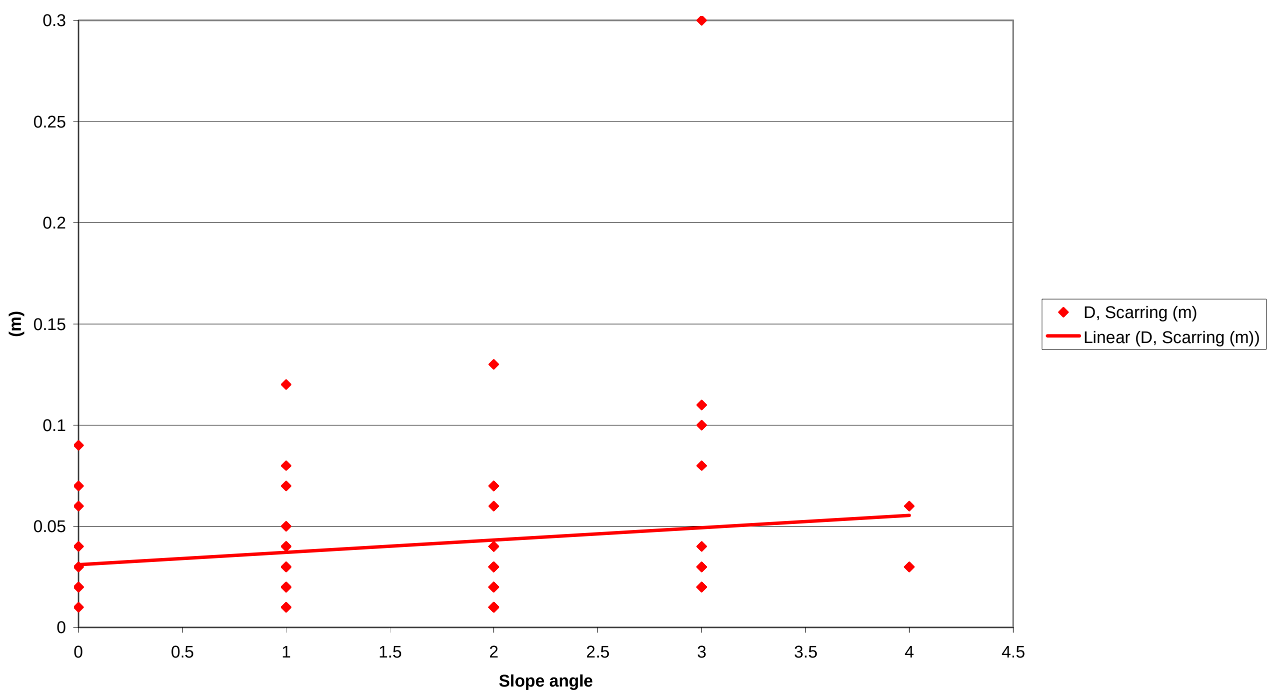


Table 4. - Pearson's correlation coefficient, r. - Slope angle and path angle against erosion indicators.

Slope angle			
Path no.	Width of worn vegetation	Width of scarring	Depth of scarring
1	0.24	***0.60***	0.15
5	***0.35***	0.08	0.08
7	0.17	*0.59*	0.32
8	0.38	0.33	***0.38***
11	0.11	0.09	0.15
Path angle			
5	***-0.43***	***-0.65***	***-0.72***
Overall	-0.14	-0.11	-0.03

4.3.3 Description of results

Figure 8 shows the degree of use of each footpath by walkers, mountain bikes, and horses. The most popular paths are 1 and 11, the least used are 5 and 6. Mountain bikes are twice as erosive as people, so values are doubled. Horses are 4x as erosive as people, so values are multiplied by 4.

Figures 10 to 13 show the cumulative % of each 100metre section of each path. Letters represent 100m e.g. 1C = 300metres along path 1. The general trend is that the majority of the path's soil is mainly composed of gravel. Path 7 has particularly uniform soil composition, where as the other path composition varies across their length. Table 3 shows the % average soil composition of each footpath. Paths 1,5 and 7 have high % of gravel; path 8 has a high % of medium sand.

Figures 14 and 15 show the effects of variations in slope angle and path angle has on erosional processes of pigeon holing, gullying, and braiding. Braiding is found to occur on flatter slopes ranging from 0 to 15 degrees, gullys develop on mid-slopes of 6 to 20 degrees, and pigeon holes form on the steepest slopes above 11 degrees. When considering path angle, it can be seen that most erosional processes form at the lowest and highest degrees of orientation, namely 0 to 10 degrees, and 61 to 90 degrees.

Figures 16 to 25 looks at the relationship between slope angle and erosion indicators, namely, the width of worn vegetation, and the width and depth of scarring. Each graph shows a positive correlation, however there are exceptions. Paths 7, 8, and 11 show a slight negative relationship between slope angle and the width of worn vegetation. These relationships are studied further in Table 3, which looks at the Pearson's correlation coefficient of slope angle and path angle against erosion indicators. The general trends are that there is a positive relationship between slope angle and the amount of erosion, and a negative relationship between path angle and the degree of erosion. The closer the result is to +/-1 the more significant the correlation is, although results of approximately +/-0.3 may be significant if the degree of variance of points from the line of regression on a graph is low. Significant results in Table 3 are in bold Italics.

Figure 8 shows the location and rating of footpaths along the Malvern Hills. Path sections with a rating of 1 have a high amount of erosion, 2 suffer moderate path erosion, and 3 low path erosion and are stable. The Malvern Hills are broken down into three hill zones, northern, central, and southern. These separate zones are situated in a straight line running from north to south. They are arranged in an L-shape on the map for convenience of display.

5. Discussion

In this section I will be discussing causal theories, the degree of correlation between relationships and the relative importance of variables. The main theories looked at will be, i) recreational pressure acts positively on path degradation, ii) footpaths situated on soils with high contents of gravel and larger particles are more durable, iii) path slope has a positive relationship with erosion levels, and iv) path angle has a negative relationship with path degradation.

5.1 Recreational variable

From looking at the path rating, erosion indicators, and general field observations, it can be seen that there is a strong positive relationship between the amount of recreational use and the level of degradation. Nevertheless, there are exceptions to this rule, namely path 11. Despite a recorded high level of use, this path is slightly affected by erosion, and remains stable. This may be due to the fact that the path has a low slope angle and high path angle, meaning that it is a flat contour path. Work by Leung *et al.* (1996), Coleman (1981) and Garland *et al.* (1985), state that slope angle is a controlling factor over erosion and acts positively over it, and Leung *et al.* (1996), describes contour paths to be less susceptible to erosion. This goes some way to explaining this anomalous finding.

The Malvern Hills are not solely traversed by walkers and hikers, but are also used by horse riders and mountain bikers. From studying Figure 9 and the degree of erosion of the footpaths, it can be deduced that the footpaths heavily used by mountain bikes are the most eroded. From this correlation it can be deduced that mountain bikes are more erosive than walkers. My research does not allow this to be quantified, but tests such as those carried out by Deluca *et al.* (1998) on sample plots could allow this to be achieved. Satisfactory results for the erosive power of horses could not be inferred due to the lack of observed horse use on the studied footpaths.

5.2 Environmental variables

This section will deal with the effects of soil structure, slope angle, and path angle on path degradation, while considering the fore mentioned theories and the relative importance of each variable to path morphology.

5.2.1 Soil structure

There are two conflicting schools of thought when considering soil composition in relation to path degradation. Firstly, Leung *et al.* (1996) and Morgan (1995) state that paths that are found upon soils with a majority of the composition as large particles, such as gravel are more durable than soils with a particularly high content of fine sands and silt. Conversely, Garland *et al.* (1985) believes that the larger the stones present the greater eroded the path is, and so the more susceptible the path is to erosion. My own study shows mixed results.

The soil samples taken from path 1 contain a high percentage of gravel (see Table 1) and are also quite highly eroded; also path 8 has a low percentage of gravel and displays low levels of erosion. This agrees with Garland *et al.* (1985) assumption. However, path 5 has high amounts of gravel in the soil and is lowly eroded, so displays features of the assumption made by Leung *et al*. (1996) and Morgan (1985). On the other hand path 7 displays features of both contrasting assumptions. However, a more detailed study of path 1 shows that the sections with the highest amounts of erosion are a, e and f (the first 100, 500 and 600metre sections respectively), and the lowest d and e (400 and 500metres). Comparatively low percentages of gravel is to be found in the samples from a, e and f, and high percentages from d and b. This is mirrored in paths 5 and 8 to a lesser degree. Path 7 has uniform soil composition across it's length so cannot be used for detailed study. These correlations compound Leung and Morgan's theories. In conclusion, it can be stated that paths situated on soils containing high degrees of gravel and large particles are more resistant to erosion, although this is not a strong relationship due to the fact that there are exceptions to this rule. Therefore other variables must play a more commanding role in determining the resistance of paths to soil erosion.

5.2.2 Slope angle

It is generally agreed through previous work that slope angle is a major controlling factor in path morphology and is positively related to path degradation (Zingg 1940, Coleman 1981, Garland *et al.* 1985, Garland 1990, Vogler *et al.* 1996, Leung *et al.* 1996). From looking at the Pearson's correlation coefficient results in Table 4, it is in dispute whether this is true or not for my own study. There are only four results out of a possible fourteen that show a strong positive correlation between slope angle and erosion, and the best correlation are found between slope angle and width of scarring. A more in depth study of the five paths looked at may enable clearer conclusions to be drawn.

The steepest part of footpath 1 is the final two 100metre sections, e and f, these are also the most eroded sections. This finding reinforces the theory that there is a positive relationship between slope angle and erosion. The first 100metre section is also highly eroded, but is relatively flat compared to other sections. This disagrees with the theory, and therefore other factors must play a commanding role over this section. Path angle remains a constant, so the controlling variables must be a combination of recreational pressure and soil composition.

Path 5 at End Hill is not significantly affected by recreational pressure, so slope and path angle should be the overriding factors affecting path morphology. Pearson's correlation however, shows a slight positive correlation between slope angle and width of worn vegetation, but no correlation for the other two variables. The most highly eroded section is section a, and is also comparatively steep, although the upper slope also has a high slope angle but is not highly eroded. This shows that the relationship between slope angle and erosion is not exceptionally strong. The controlling variable in this situation may be path angle, or possibly the action of water erosion. This assumption is made because the path is situated within a valley base and so within a water catchment, possibly leading the path to become a water channel in times a rain. This would lead to water erosion of the path as described by Morgan *et al.* (1995).

Path 7 running down to St. Ann's Knoll is comparatively steep across all sections, and is relatively highly eroded across its entire length. This is reinforced by the Pearson's correlation value for slope angle and width of scarring of +0.59. There is little variation in path angle, therefore this path is a good example illustrating that steep slopes result in high erosion. Path 8 has reasonably constant erosion levels across its length, but there is quite a good positive Pearson's correlation between slope angle and depth of scarring. Suggesting that theory (iii) is relevant. Path 11 shows no correlation between slope angle and erosion, but this is to be expected as it is a relatively flat, contour path, and was chosen as a control path top highlight the affect recreational pressure has on footpath morphology. Some conclusions can be drawn though, as the path is not highly eroded by recreational pressures, factors such as slope angle and path angle must effect erosion. This conclusion can be drawn from the fact that low slope angle results in low erosion. This weakly compliments the theory of a positive relationship between slope angle and erosion.

Overall it can be concluded that there is a positive relationship between slope angle and path erosion, i.e. that as slope angle increases, the amount of path degradation increases. The strongest links were between slope angle and the width of scarring, and overall the relationship is moderately strong and agrees with previous studies. Slope angle is a reasonably strong controlling variable acting over footpath morphology.

5.2.3 Slope angle and erosional processes

Slope angle is a controlling variable over the distribution of erosional features of braiding, gullying, and pigeon holing (See Figure 14). Braiding does not occur on slopes above 15degrees. This may be because a significant controlling factor affecting braiding of footpaths is user behaviour. People tend to diverge from the main path because it is beneficial to walk somewhere else. From observations in the field it can be said that people tended to diverge to get a better view of the surrounding scenery and to avoid eroded paths that are uncomfortable to walk upon. On flatter slopes divergence of walkers is more prevalent because it is easier to do, resulting in a concentration of braiding on path sections with low slope angles.

Gullys are generally signs of serious erosion, and I expected to find these on the steepest slopes, although results show that gullys form generally on mid-slopes ranging from 6to 20degrees. However, Leopold *et al.* (1964) states that the main controlling factor on gully erosion is the enlargement of depressions by the action of water. This is why my initial theory based solely on slope angle is floored. The action of water flowing across the paths is not looked at in this study due to fieldwork being carried out during the summer. Gullys are found primarily on steeper mid-slopes of angles between 16 and 20degrees, suggesting that gully formation is controlled by slope angle to a certain extent. Possibly by the fact that with a rise in slope angle water action, in the form of run-off becomes greater in volume and velocity, and so more erosive.

Pigeonholes clearly form on the steepest slopes, and are not found on lopes below 11degrees. This may be due to recreational pressure. As people walk up steep slopes the erosive action of their feet increases (Deluca *et al.* 1998). This may be the cause of pigeonholes, which once form act like steps up the slope, and are repeatedly trampled on and enlarged. Pigeonholes generally form on vegetated paths, and are signs of initial vegetation breakdown, and that further problems are ahead. In conclusion, slope angle thresholds can be stated for 1) braiding 0 to 15 degrees, 2) gullying 6 to 20 degrees, and 3) pigeonholes 11 to 26 degrees. There has been no previous work on this subject for comparison, but I feel that these relationships are strongly correlated.

5.2.4 Path angle

Previous findings by Leung *et al.* (1996) shows that there is a negative correlation between path angle and erosion, suggesting that as path angle decreases erosion increases. This trend is weakly reinforced through my own study. By looking all the footpaths as a whole it was concluded through the use of Pearson's correlation that there is no relationship between path angle and erosion. However, looking specifically at path 5, End Hill, there is a strong negative relationship between path angle and the width and depth of scarring, and a good negative relationship between path angle and the width of worn vegetation (see Table 4). Path 5 is particularly suitable for the study of path angle and erosion in detail, as path angle alters distinctly from running parallel to the slope at 0 degrees, to cutting diagonally across the slope at 46 degrees, and then back to parallel at 4 degrees. Therefore this shows a good variation in path angle.

My own findings agree with that of Leung *et al.* (1996), although I believe that path angle is only a weak controlling variable over erosion. This may be because the effect of path is controlled by the slope angle of the path. Evidence for this assumption comes from comparison between paths 7 and 11. Both paths have similar path angles of around 90 degrees, and follow the contours of the hill. Both are popular paths, though the main difference between them is slope angle. Path 11 is very flat with a maximum slope of 4 degrees, path 7 conversely ranges from 6 to 14 degrees. Path 7 is greater eroded than 11 so the controlling factor must be path slope causing the path to act more like a channel so being eroded more greatly by water.

5.2.5 Path angle and erosional processes

Most processes develop on paths running parallel to the slope, and perpendicular to the slope, although the majority (68%) are found on the lowest slope angles (0 to 10 degrees). Braiding is primarily confined to paths running parallel to the slope, cutting up vertically through the contours of the hillside. This is because the path sides are generally flat, so unrestricting the spread of people across the slope allowing multiple paths to form. Gullys ad pigeonholes are also primarily found at low path angles. This is because low path angles ascend the fall line of the slope, so easily become channels for water making them susceptible to erosion (Leung *et al.* 1996). The presence of these ersoional features at low path angles corresponds with the theory that highest erosion occurs at low path angles. The presence of these features on paths that follow the contours more closely can be explained by the fact that other variables such as slope angle, soil structure, and recreational pressure affects their formation.

5.3 Conclusions and Further recommendations

Footpath degradation is affected by a combination of the discussed variables. User intensity and slope angle are the most important variables affecting path morphology, with path angle, user type and soil structure contributing to a lesser degree. In future studies variables such as vegetation type, flow patterns of water, rainfall intensity, and the user intensity across the path should be investigated to give a clearer understanding into the problems and causal factors on path degradation.

Management schemes for footpath protection on the Malvern Hills need to be revised and modified to take into account the affects the recreational and environmental variables have on path degradation, and to protect the areas of paths highlighted by Figure 8 that are highly eroded. Footpath sections with a grade of 1 must be immediately visited and remedial measures taken to protect the path, grade 2 sections should be revisited yearly, and grade 3 sections are stable so should be monitored on a four yearly basis.

6. Acknoledgements

I would like to thank Mr Ian Rowat the head of the Malvern Hills conservators for allowing this study to take place, and for suppling topograohic maps of the area. Also my supervisor Dr. Angela Lamb, for guideaince and advice throughout this project.

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