Rates and Controls of Footpath Erosion in Giant's Castle Game Reserve, KwaZulu / Natal Drakensberg

by

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Preface

The research described in this dissertation was carried out in the Department of Geography, University of Natal, Pietermaritzburg and in Giant's Castle Game Reserve, KwaZulu/Natal Drakensberg, from January 1993 to December 1994, under the supervision of Mr H. Beckedahl.

These studies represent original work by the author and have not otherwise been submitted in any form for any degree or diploma to any other University. Where use has been made of the work of other authors it has been duly acknowledged in the text.

"As a young man, my fondest dream was to become a geographer. However while working in the customs office I thought deeply about the matter and concluded it was far too difficult a subject. With some reluctance I turned to physics as a substitute."

(Albert Einstein, Unpublished Letters)

Abstract

The Drakensberg is an important ecological and recreational resource area within southern Africa, yet little knowledge exists concerning the factors controlling soil erosion in the region. The two most important anthropogenic modifiers of natural erosion processes in the areas beyond the Drakensberg Park main camps and access roads are vegetation burning and the erosion associated with footpaths. This dissertation investigates the rates and controls of footpath erosion in Giant's Castle Game Reserve in the KwaZulu/Natal Drakensberg.

Two measurement techniques are employed. Sediment yield and runoff were monitored from six runoff plots installed on different gradients on a high user-intensity footpath. Runoff is found to increase linearly with increasing footpath gradient. Sediment yield increases gradually with increasing footpath gradient to a threshold path gradient of 13.36°, after which sediment yield increases rapidly. Soil eroded from the runoff plots has a finer particle size distribution than the footpath tread surfaces within the plots. Rates of sediment generated from the runoff plots is dependant on the rainfall intensity index (I_{60}), as opposed to rainfall kinetic energy or total rainfall related indices, while runoff is dependant on the EI_{60} index.

A 100m point-based survey of footpath attributes, totalling a distance of 21km along four paths in the Reserve was undertaken. Where footpath gradients are low and user-intensity is high, path morphometry is dependant on orientation to the slope. Morphology of footpaths with both higher gradients and user-intensities show a dependence on path gradient. The degree of compaction of the footpath tread decreases away from the main camp and is positively related to user-intensity. Multiple path development is associated with the path width to maximum depth ratios and a threshold ratio range of 4.01 to 4.50 is established for the initiation of secondary path routes. A comparison of the survey data with a survey conducted in 1989 indicate erosion rates between 3.24 and 13.0 tons/km/a over a four year period.

Erosion rates for the runoff plots and for the surveys indicate that the values obtained for the two techniques of measurement utilised in the study approximate each other. Path erosion rates, while still presenting a problem, are not uncharacteristically high in Giant's Castle Game Reserve in comparison to the scarce data available on rates of path erosion within and beyond southern Africa.

Acknowledgements

I would like to thank the following people and organisations who have been of assistance to me during the course of compiling this dissertation. The Natal Parks Board staff at head office for providing access to path survey data, and particularly Peter Thomson for his encouragement and motivation from the outset of the project. Natal Parks Board staff at Giant's Castle Game Reserve for their cooperation with the tedious task of emptying the sediment traps. Don Yunie and Tim Dale for their encouragement of the project, support in obtaining the pedestrian counters, and for providing accommodation in the Reserve. Financial assistance was provided by the Foundation for Research and Development, the Natal Parks Board and a Graduate Assistant Scholarship from the University of Natal.

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Lastly, a special word of thanks to my family for their support and encouragement during these long years at University.

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1. Introduction

1.1 Geomorphology as a science

Geomorphology is not a unique science. It is concerned with the Earth and its form and must by its very nature draw on the disciplines of Geology, Agronomy, Chemistry, Physics, Hydrology, Botany and Mathematics amongst others (Vitek and Giardino, 1993). This interdisciplinary relationship enables geomorphologists to actively engage in numerous fields beyond that of geomorphology, particularly in the applied components of the discipline. In turn, however, weaknesses in defining the discipline are created, where aspects of geomorphology are reflected or practiced in other fields of science.

As geomorphology is a science, it is permeated by theory. The most useful view of geomorphology as a science is one in which theory and observation are viewed symbiotically. Theory provides the generative force, whereas observation provides a vital policing role (Rhoads and Thorn, 1993). Theory is an integral component of science, yet theoretical considerations in geomorphology must be based on a firm understanding of the processes and responses driving the natural systems. Fortunately, there are still many avenues of research in theoretical and in applied aspects of the discipline open to the student of geomorphology, and many questions to be both asked and answered in many sub disciplines.

> "The acquisition of geomorphic knowledge is an explosion in response to the effort and technology applied to a seemingly endless number of questions."
> (Vitek and Giardino, 1993, ix)

Looking at the present and into the past perhaps provides some insights into future directions for the discipline. Any collection of geomorphologists, if asked to define the current state of geomorphology, would probably only agree upon a generality which permits them to disagree on the nature of the current status of the discipline (Vitek and Giardino, 1993). Historical perspectives on geomorphology have, nonetheless, emerged in the last decade and have provided insights into future directions (eg. Tinkler, 1985; Baker and Twidale, 1991; Vitek and Giardino, 1993). These perspectives provide direction to the student facing dilemmas of future prospects in a discipline that appears relatively obscure to the general public.

> "... geomorphology has a role to play at the apex of a new scientific hierarchy. Rather than passively accepting a lowly position by mundanely applying idealised, long known physical and mathematical principles to nature, geomorphology might well assert itself as an integrative expression of what it is important to know of nature."
> (Baker and Twidale, 1991, p.95)

The purpose of this study is to investigate the processes responsible for an anthropogenic-geomorphic phenomena that threatens many natural environments; the erosion associated with footpaths. An interpretation of the footpath erosion mechanisms is derived through the investigation of the rates and controls of the erosion process. From this grounding, an attempt to place the findings within a theoretical framework is undertaken, and the implications and recommendations for the management of natural environments are assessed.

1.2 Background to the study

Rates of soil erosion for Africa are not exceptionally high by world standards. On a continental scale erosion rates are far lower than that of Asia, while at the scale of major drainage basins some rivers in India have 700 times the erosion rate of the Niger river system (Stocking, 1984). General rates are, however, not particularly useful to land-use planners and managers due to localised high erosion rates. Strategies for erosion control in areas where accelerated erosion presents problems to land management can only be achieved through an understanding of the soil erosion processes, how they operate and their interaction with different conservation practices (Morgan, 1986; Beckedahl *et al.*, 1988). A need exists for detailed studies of soil erosion in southern Africa to supplement the existing knowledge of soil loss and sediment yields (Beckedahl *et al.*, 1988).

The focal region of this study, the KwaZulu/Natal Drakensberg, is an important ecological and recreational resource. Little knowledge exists of the factors causing erosion and transportation of sediment in the Drakensberg as a whole. In the areas of the KwaZulu/Natal Drakensberg erosion rates are generally low, yet soil eroded from footpaths can exceed soil loss tolerances for an area (Garland, 1987a). The absence of quantitative information restricts the prediction of erosion rates from footpaths and hampers the implementation of effective conservation measures.

Two broad approaches can be used for estimation of soil loss. The first is the measurement of sediment yields from runoff plots. This is a localised approach measuring soil losses under specific climatic and geomorphic conditions. A second approach is that of soil loss modelling which yields indices of soil loss (Schulze, 1979). Models, such as the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978) and the Soil Loss Estimation Model for Southern Africa (SLEMSA) (Elwell, 1981) may be used to estimate soil losses and provide a framework for broad land use management and planning. These models must, however, be treated with caution as they are particularly sensitive to local soil erosivity and rainfall energy (Schulze, 1979; Smithen and Schulze, 1982; Albaladejo-Montoro and Stocking, 1989).

The incidence of gully erosion is greatly increased along footpaths and cattle tracks since these are devoid of vegetation and thus are natural sites for the concentration of sheetwash, with consequent increases in flow velocities (McQuaid-Cook, 1978; Holy, 1980; Toy and Hadley, 1987; Beckedahl *et al.*, 1988; Shakesby and Whitlow, 1991). There has, however, been limited research related to the erosion of footpaths in comparison to the extensive literature available on erosion associated with agriculture and forestry. Over the past three decades there have been several studies on the mechanisms and controls of footpath erosion (eg. Bayfield, 1973; Bryan, 1977; Weaver and Dale, 1978; Bratton *et al.*, 1979; Quinn *et al.*, 1980; Coleman, 1981; Garland *et al.*, 1985; Tinsley and Fish, 1985; Jubenville and O'Sullivan, 1987; Auerswald and Sinowski, 1989). Although rates of footpath erosion have long been attributed to runoff amount and velocity and the character of the footpath itself (Bryan, 1977), few studies have focused on determining actual rates of soil erosion or footpath morphological changes through time (Tinsley and Fish, 1985; Garland, 1987a; 1988; Lance *et al.*, 1989). Similarly little is known of the overall effect of footpaths on the soil properties (Ward and Berg, 1973; Starodubova, 1985) although some extrapolations may be made from campsite studies in which vegetation disruption and compaction have been measured (eg. Dotzenco *et al.*, 1967; Monti and Mackintosh, 1979; Cole and Marion, 1988).

Coleman's (1981) model shown in Figure 1.1 provides a broad framework for investigating the various forces and environmental influences that determine the morphology of a footpath. Footpath morphology is a general term which includes the width, depth and cross-sectional profile. The morphology is determined by the interaction of the forces acting on the footpath (geomorphic and recreational) and the resistance of the materials of which the footpath is made (Coleman, 1981; Garland *et al.*, 1985). As the footpath develops the footpath itself may modify the effect of the forces by changing the underfoot characteristics and altering infiltration and runoff rates (Fig. 1.1).

The model suggested by Coleman (1981) is applied in further discussions. The interactions of the factors are broadly classified under geomorphological and recreational forces and the forces of resistance.

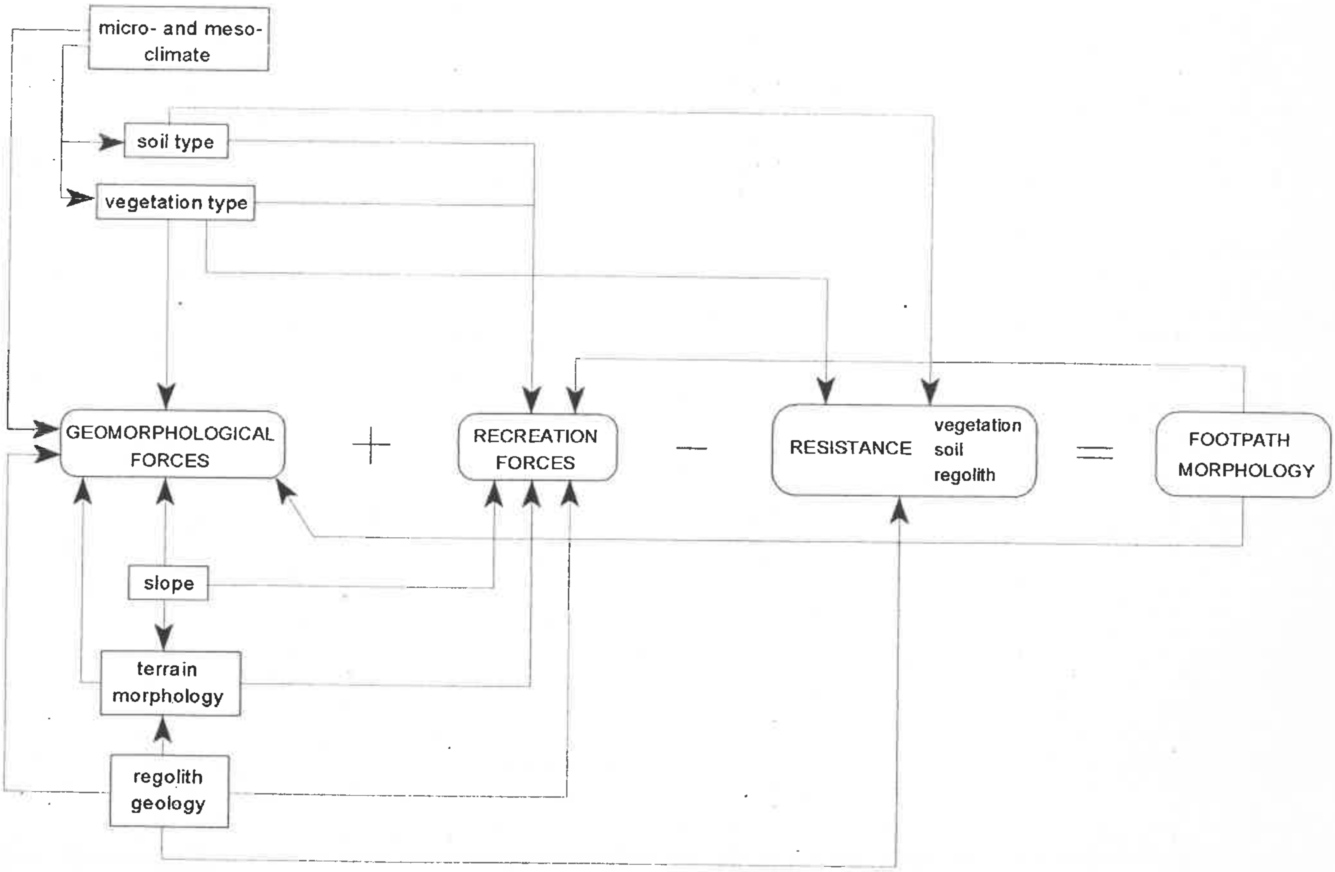


Figure 1.1 The interaction of forces in footpath erosion and the influence of environmental site conditions (modified after Coleman, 1981).

1.2.1 Geomorphological forces

The rate of soil erosion depends on a complex interaction between erosivity forces of rainfall and runoff and the susceptibility of soil to detachment by these forces (Ulsaker and Onstad, 1984; Beckedahl *et al.*, 1988). Many erosivity indices have been developed to correlate erosivity forces with quantities of soil loss. The simplest of indices is the total rainfall amount (A) which is related to the two major erosive agents, raindrop impact and surface runoff (Ulsaker and Onstad, 1984). Another simple index is the rainfall total kinetic energy (E) proposed by Wischmeier and Smith (1978). This has, however, considerable unexplained variation and is generally not considered a good indication of erosivity (Ulsaker and Onstad, 1984). Maximum rainfall intensity (I_x) over specified durations (x) of 15 and 30 minutes have been evaluated (Wischmeier and Smith, 1978) while Foster and Meyer (1975) found that interrill sources of erosion were related to the square of the rainfall intensities.

Some compound parameters have been developed. The EI_{30} index (Wischmeier, 1959; Wischmeier and Smith, 1978) which is the product of the rainfall total kinetic energy and the maximum 30-minute intensity, is widely used in the USLE. Hudson (1965; 1971) found the KE > 25 (the rainfall total kinetic energy falling at intensities greater than 25mm/hr) to be the most appropriate index in Zimbabwe. In the development of the SLEMSA, Elwell (1981) used the seasonal kinetic energy as the erosivity index to estimate mean annual soil loss from sheet erosion. In western Nigeria, Lal (1976a, b) found correlations of soil loss with the AI_{30} index (product of rainfall amount and maximum 30-minute intensity). More recent research in southern Nigeria showed the EI_m index (kinetic energy and maximum intensity for a 6-minute duration) to be a better erosivity index than the AI_m or the EI_{30} (Salako *et al.*, 1991).

Indexes such as those listed above require testing for two main reasons. Firstly, the results obtained from one region are not necessarily transferable to a second region due to different local geomorphic characteristics. The results for Nigeria, cited above, highlight this problem. Further, a general tendency for results from other regions to be utilised in studies in southern Africa without regard to local variables or consideration of local geomorphic characteristics of erosion, has previously been criticised (Beckedahl *et al.*, 1988). Secondly, the effect of drainage modification by footpaths on different gradients, with the added influence of soil compaction and aggregate disintegration by walking action, on erosivity index application still requires testing.

The susceptibility of soil to detachment has been extensively used in both theoretical and practical approaches to soil erosion (Bryan *et al.*, 1989). Spacial and temporal changes in soil moisture content as well as the physical and chemical dynamism of the soil surface change the precise processes of detachment. Soil erodibility cannot, therefore, be defined by a few properties alone and only rankings established for the same processes, measured under similar conditions can be compared (Kirby and Mehuys, 1987; Bryan *et al.*, 1989).

Knowledge of the relationship between flow velocity, depth and discharge is important in applications of deterministic hydrology and erosion models (Govers, 1992). Although issues of flow velocities and depth are not a component of this research, quantities of runoff in relation to sediment yields from footpaths are investigated. Knowledge of variations in discharge are necessary for the calculation of variations in the hydraulic parameters governing sediment detachment and discharge (Abrahams *et al.*, 1989; Govers, 1992). Such relationships are virtually unknown for the hydraulics of footpaths.

Rainsplash impact has been found to have little effect on runoff velocities but does increase the transport capacity and wash sediment concentrations (Savat, 1979; Kirkby, 1980; Bryan, 1987). Rainsplash is therefore an important factor affecting particle entrainment (Bryan, 1987), with the detachability of the soil linked primarily to soil shear strength (Nearing and Bradford, 1985; Brunori *et al.*, 1989). Further, soil surface slope has a positive effect on the raindrop force of detachment of soil particles. Slope effect acts through the addition of a gravity component to the drop detachment force rather than modifying the raindrop force (Torri and Poesen, 1992). This should theoretically contribute to higher sediment yields from higher gradient slopes or footpaths, however, little empirical data on footpath gradient and soil loss are available to substantiate this.

It is widely accepted among geomorphologists that sediment removal by overland flow is particle size selective, yet the geomorphological literature contains few studies in which the size selectivity has been examined and upon which this view may be based (Poesen and Savat, 1980; Parsons *et al*, 1991; Durnford and King, 1993). Young and Onstad (1978) found interrill sediments in a runoff plot to have higher sand contents and lower clay contents than the matrix soil and rill sediments. Meyer *et al.* (1980), however, found no difference in particle size distributions between eroded and matrix soil. Generally, no broad relationship has been found between eroded and matrix soil (Parsons *et al.*, 1991). A similar situation exists for the understanding of particle size selectivity of sediment generated from footpaths, where no general relationship has been established. This is due to the almost complete absence of data on soil and sediment particle size distributions, and is exacerbated by the difficulty of projecting findings for natural surfaces or those under agriculture to the compacted and disaggregated conditions of a footpath.

Footpaths act as conduits for water, diverting and confining overland flow and sediment that would otherwise drain directly downslope, along a new drainage channel. In principle this is similar to the significance of rills as drainage systems on hillslopes, clearly recognised by Horton (1945) and later identified as temporary or permanent channels (Schumm, 1956). A major difference between rills and footpaths is that the drainage created by footpaths is not natural, and the pedestrian influence on the soil surface results in soil and vegetation characteristics which differ considerably from natural or agricultural environments. A further dissimilarity from rills is that the vegetation cover has been shown to be a major control on rill erosion rate, with other significant factors being soil texture and aggregate stability (Govers, 1991). With a footpath, in the almost complete absence of vegetation on the footpath tread surfaces, the interaction between geomorphological and recreational forces appears more significant, while vegetation may play a role in stabilising the tread peripheries. Rills also have the ability to readily adapt their geometry in response to changes in discharge and slope (Govers, 1992). Rill flow velocities may therefore be expected to be equal to or close to equilibrium values, a situation not necessarily applicable to footpaths where recreational pressures can have a major impact on footpath morphology.

The smaller scale, yet no less significant, processes alluded to above must be considered within the broader geomorphological influences on footpath erosion, and *vice versa*. The broader geomorphological influences include the cross-slope (hillslope), path gradient, aspect and orientation, all of which have been found to influence footpath morphology. In the English Lake District Coleman (1981) showed that the extent of path erosion was found to increase with the square root of the path gradient. Trail width has been found to increase linearly with increasing path gradient in Scotland (Bayfield, 1973) while in the North Rocky Mountains Weaver and Dale (1978) found trail depths tended to be greater on slopes than on level sites. Auerswald and Sinowski (1989) found that path depth increased linearly with path steepness in the Bavarian Alps. Garland *et al.* (1985) found, however, that path cross-sectional area could not be satisfactorily predicted by hillslope, path gradient and unbroken path-length in the Drakensberg but found a weak yet significant relationship between depth and path gradient, depth and hill-slope gradient, and depth and width.

In Sweden, Bryan (1977) observed that topography was significantly related to footpath orientation and that where paths follow the fall-line severe water erosion hazard exists, regardless of slope angle. When paths run parallel to the contours little damage is caused unless the incision is deep enough to divert the runoff. The footpath orientation is calculated as the difference between the path aspect and the cross-slope aspect and ranges between 0° and 90° (Bratton *et al.*, 1979; Tinsley and Fish, 1985). Bratton *et al.* (1979) found a significant negative correlation between orientation and erosion, thus confirming Bryan's (1977) findings.

1.2.2 Recreational forces

Initially, footpaths may either be constructed or demarcated and 'walked-in' by users. Previous construction techniques employed in the Drakensberg were to cut-and-fill where footpaths traversed hillslopes. On shallower gradient slopes the A horizon (rooting zone) was removed to a depth of 80mm to define the footpath (Garland, 1988). This technique results in immediate compaction of the soil surface by pedestrians and almost precludes any form of stabilisation by vegetation. A more recent approach is to demarcate a new footpath by cutting the grass and allowing the pedestrians to walk the footpath in (Day *et al.*, 1994). The trampling by visitors damages vegetation and initiates the erosion process (Willard and Marr, 1971) and heavy recreational use generally leads to changes in the physical and chemical properties of the soil (Monti and Mackintosh, 1979; Starodubova, 1985; Jusoff, 1989). Bryan (1977) showed that vegetation is completely broken down by an intensity-of-use approaching 800 - 1000 users (no time period specified) while Day *et al.* (1994) found vegetation to have completely disappeared after 600 users over a period of four months at Royal Natal National Park, northern Drakensberg. Although previous findings show that soil loss generally does not commence until at least 30% of the ground surface is bare (Elwell and Stocking, 1976), breakdown of the soil by trampling has been shown to occur while wear of the vegetation is still in progress. By the stage where declining plant cover is evident, the critical period in which erosion is initiated has already past (Quinn *et al.*, 1980). The damage caused to vegetation is cumulative if the intensity-of-use is sufficient to prevent regeneration during the growing period. This is generally the situation for footpaths in the Drakensberg, where intensity-of-use restricts regeneration of vegetation and most paths are thus devoid of vegetation and have compacted tread surfaces.

Associated with vegetation damage by pedestrians is the compaction of the soil. Path depth depends on both the degree of compaction and on the extent of erosion (Weaver and Dale, 1978), however, scarce data are available on the relative degrees of compaction and soil truncation (cf. Bryan, 1977). The degree of compaction varies with the type of soil, soil moisture content, user-intensity and the distribution of the force exerted by the feet of the path users (McQuaid-Cook, 1978; Toy and Hadley, 1987). The extent of erosion is generally controlled by the geomorphic factors discussed above in combination with the shearing and disaggregating effects of the feet of pedestrians as soil particles are trampled, pushed and rolled along the footpath (Coleman, 1981). Compressive forces decrease with increasing gradient, but the shearing effect on the tread increases (Quinn *et al.*, 1980). Although the compressive forces decrease with increasing footpath gradients, the pace length of pedestrians also tends to decrease (Bayfield, 1973). This may explain the greater degree of compaction, and a corresponding trend of increasing footpath tread shear strength on steeper gradient sections of footpaths found by Day *et al.* (1994).

Some further relationships between footpath intensity-of-use and erosion have been established. Coleman (1981) found erosion to increase with the square of the user-intensity while findings by Dale and Weaver (1974) and Weaver and Dale (1978) show trail width to increase with the logarithm of users. Auerswald and Sinowski (1989) found trends for user-intensity influencing both footpath width and depth. In southwest Texas, Tinsley and Fish (1985) found that trail width and visitor-use were directly related to increased amounts of soil movement, but did not necessarily result in greater net erosion. Although relationships have been suggested concerning the geomorphic control of footpath erosion in the Drakensberg (eg. Garland *et al.*, 1985; Garland, 1988) the effects of user-intensity have not been investigated to any meaningful degree.

Pedestrian behaviour is also an important component of footpath erosion. Compaction generally decreases outwards from the centre of the footpath and the overall width of trampled vegetation adjacent to the bare central areas depends on the lateral spread of pedestrians (Bayfield, 1973; 1987; Ward and Berg, 1973; Starodubova, 1985). The lateral spread is governed both by individuals 'searching for footing', particularly on sloping sections, (Weaver and Dale, 1978) and by the desire for pedestrians in a group to walk abreast. Similarly, social behaviour at footpath intersections where pedestrians typically stop to rest and discuss the hiking experience, often causes trampled zones in the immediate vicinity of the intersection.

Pedestrians generally are more damaging to vegetation when going downhill (Weaver and Dale, 1978), ostensibly due to greater shearing forces exerted by the feet on the soil surface. Bayfield's (1973) research indicates a greater tendency for pedestrians to leave the footpath when walking downhill, with an overall proportion of 30% of pedestrians walking off the footpath (bare tread) on the adjacent trampled zone..Such trampled zones are not common in the Drakensberg, however, secondary (or multiple) footpaths are frequently found (eg. Garland *et al.*, 1985). No known research into the initiation of these secondary paths has been undertaken in southern Africa. In Scotland, Lance *et al.* (1989) observed the tendency for secondary paths to form where paths pass through wet hollows and, less frequently, where paths were narrower and firmer underfoot. Auerswald and Sinowski (1989) observed that an increasing number of pedestrians resulted in a distinct tendency toward extensive branching of paths, however, this tendency was not quantified. Generally the recreational control on the initiation of secondary paths is poorly understood.

1.2.3 Resistance to erosion

Resistance to erosion is governed by vegetation and soil characteristics, and to a lesser extent by lithology. The resistance of vegetation to trampling is well documented (eg. Burden and Randerson, 1972; Bayfield, 1973; Liddle, 1975). Various factors, including climatic and soil conditions, influence the vigour and productivity of vegetation and thus its susceptibility to trampling (Coleman, 1981). Vegetation reduces raindrop impact, increases soil infiltration capacity and decreases runoff. Vegetated footpaths should therefore experience less erosion than bare tread surfaces (Garland *et al.*, 1985). Further, organic matter within the soil generally increases aggregate stability (Mbagwu and Piccolo, 1989; Nwadialo and Mbagwu; 1991), thus reducing the erodibility of the soil and decreasing the degree of compaction (Dotzenco *et al.*, 1967; Day *et al.*, 1994) and assisting in the regeneration of vegetation.

The resistance of soil is an important variable in soil erosion, the relevant factors being particle size, shear strength and stoniness (Coleman, 1981). Stoniness generally influences overland flow hydraulics and sediment yield (Bunte and Poesen, 1994) while the influence of particle size and shear strength have been incorporated into the above discussion of the geomorphological forces.

Lithology plays an important role in determining soil characteristics and ultimately vegetation cover. In an assessment of erosion risk of footpaths in the Drakensberg, Garland (1990) used lithology as a substitute for soil erodibility due to the differences in infiltration rates and lower potentials for runoff from different lithologies as recorded by Schulze (1979). Considerations of resistance to erosion from footpaths, therefore, need to take cognisance of lithological changes and the related soil and vegetation characteristics.

Investigation into the forces determining footpath morphology requires a holistic approach which focuses both on the localised processes such as rainfall erosivity and runoff, and on the broader influences of user-intensity, path orientation, gradient, orientation and cross-slope gradients. Some interaction between the two categories is obvious. For example, the influence of path gradient applies broadly to modification of hillslope drainage but it also influences rainsplash detachment and local runoff rates. The objectives of the study and the methodology adopted to achieve this are outlined in following sections.

1.3 Objectives of the study

Research indicates that footpaths in mountain environments are generally more susceptible to erosion (Ketchledge and Leonard, 1970, Bratton *et al.*, 1979). This is due mainly to the harsher climates, steeper slopes, thinner soils and poorer vegetation cover often found in mountainous environments. Research on erosion associated with footpaths in southern Africa has been limited to a few studies in the KwaZulu/Natal Drakensberg (Garland *et al.*, 1985; Garland, 1987a; b; 1988; 1990; Day *et al.*, 1994) and one general report on the planning of hiking trails which includes minor reference to footpath design (Little *et al.*, 1977).

The Drakensberg region is both an important recreational and ecological resource. Unfortunately recreational use can result in a deterioration of this fragile resource. In the remote areas of the Drakensberg the two main anthropogenic influences are the burning programme and the existence of footpaths. Thus the management of footpaths and the planning and design of new footpaths should rate highly in management objectives.

In order to conserve existing footpaths and to plan for new footpaths, a detailed knowledge of the controls of the erosion process and the anticipated rates of erosion under different environmental conditions is required. Due to the generally poor understanding of the phenomena of footpath erosion, the research conducted for the purposes of this study aims to achieve the following objectives:

- a greater understanding of the geomorphological and recreational factors controlling the erosion process and the associated rate of erosion,
- a greater understanding of the erosive forces of rainfall and runoff as a control on soil erosion rates,
- improve the understanding of the influence of soil and vegetation on resisting footpath erosion rates,
- determine the rates of erosion on footpaths under different environmental conditions, and
- compare erosion rates with other available data so as to assess the severity of footpath erosion for the area.

Fulfilling these objectives will enable recommendations to be made for both the management of existing footpaths and for the designing of new footpaths such that the associated soil erosion can be minimised.

1.4 The study area

Giant's Castle Game Reserve was selected as a research site due to its extensive footpath network and anticipated increases in visitor numbers over the next few years, accessibility from Pietermaritzburg and the availability of accommodation. The Reserve is located on the border between KwaZulu/Natal (South Africa) and Lesotho (Fig. 1.2). It was established in 1903, is 34 638 ha in extent and forms a large portion of the Drakensberg Park currently administered by the Natal Parks Board. Giants Castle Game Reserve is situated in what is traditionally known as the Central Drakensberg. It is bounded in the north by the Natal Parks Board Monk's Cowl area, in the east by KwaZulu/Natal (previously referred to as a KwaZulu Homeland area) and in the south by the Natal Parks Board Highmoor and Mkhomazi areas. The western boundary is the watershed of the Main Escarpment which also serves as the KwaZulu/Natal and Lesotho international boundary (Fig. 1.2). Access to the Reserve is via the town of Mooiriver on a secondary road. The Reserve is a well known area of the Drakensberg and attracts both chalet and cottage dwellers to the Main Camp, and hikers who frequently use the mountain huts (Fig. 1.3).

The Main Camp has a chalet and cottage facility comprising a total of 70 beds. No campsite is available as yet, however an extension to the Main Camp is planned which will include a campsite facility (Dale, *pers. commun.*). This will increase visitation numbers and thus place increasing pressure on the footpath network. Occupants of the main Camp frequently use the footpaths for day hikes and high intensity-use footpaths have been surfaced with concrete in the vicinity of the camp. The Reserve is also open to overnight hikers who make use of the mountain huts and, less frequently, the passes up the Escarpment which access the Lesotho Highlands (Fig. 1.3).

The footpath network is extensive with footpaths generally starting in the vicinity of the Main Camp and linking up with the contour path (Fig. 1.3). The contour path extends below the Escarpment between 2200 and 2300m, passing two mountain huts, namely Giant's Hut and Bannerman Hut. A third mountain hut, Centenary Hut, was opened approximately 7km north of Bannerman Hut along the contour path during the course of the research. A fourth hut, Meander Hut, is located approximately 4km east of the Main Camp. All huts accommodate up to eight persons.

Detailed descriptions of the environmental setting of Giant's Castle Game Reserve and the related anthropogenic influences are provided in Chapter 2.

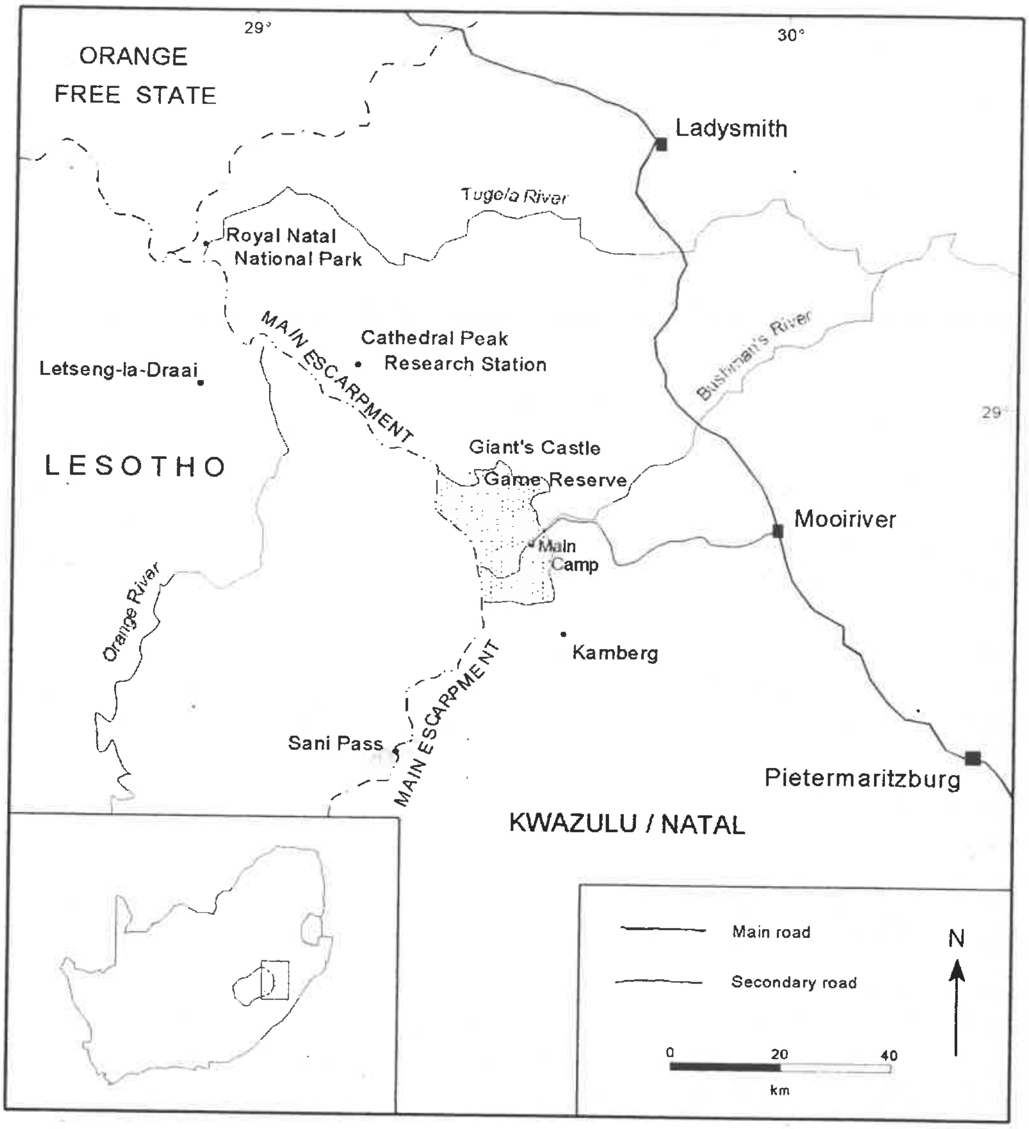


Figure 1.2 Location of Giant's Castle Game Reserve in KwaZulu/Natal

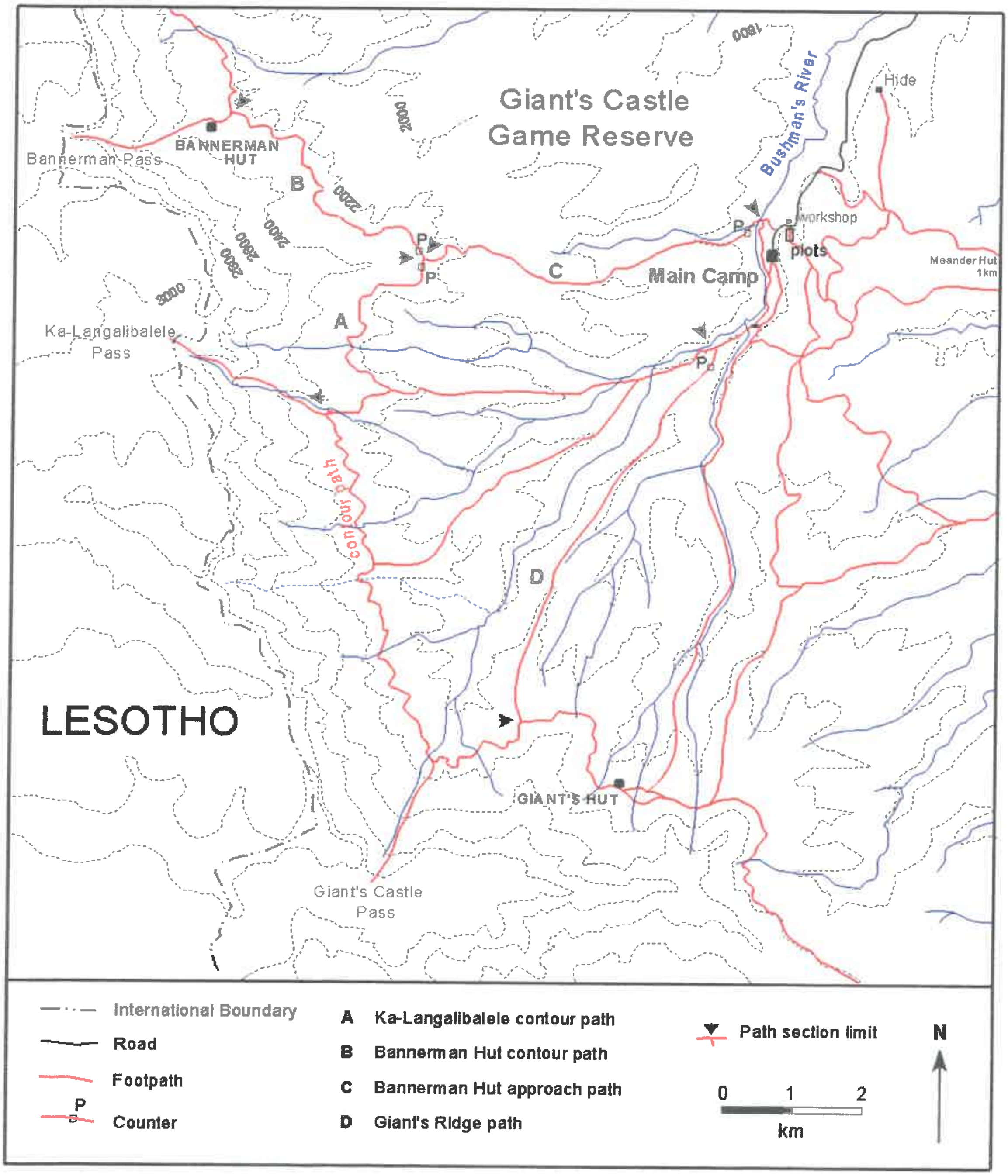


Figure 1.3 Study area in Giant's Castle Game Reserve

2. Environmental Setting of Giant's Castle Game Reserve

2.1 Topography and drainage

The KwaZulu/Natal Drakensberg is a part of the Main Escarpment which extends from the Eastern Cape through KwaZulu/Natal and into the Orange Free State (Fig. 1.2). The Main Escarpment separates the coastal lowlands from the interior plateau of southern Africa and forms an enormous horseshoe-shaped step at distances ranging from 50km to 500km inland from the coast (King, 1982). The topography of the Reserve can be divided into three zones: the Little Berg, Escarpment and Lesotho Plateau (Fig. 2.1). Peaks on the escarpment reach up to above 3400m and the valley floors in the Little Berg extend down to 1500m. The study area is part of the upper region of the Bushman's River catchment which drains to the northeast and finally into the Tugela River (Fig. 1.2).

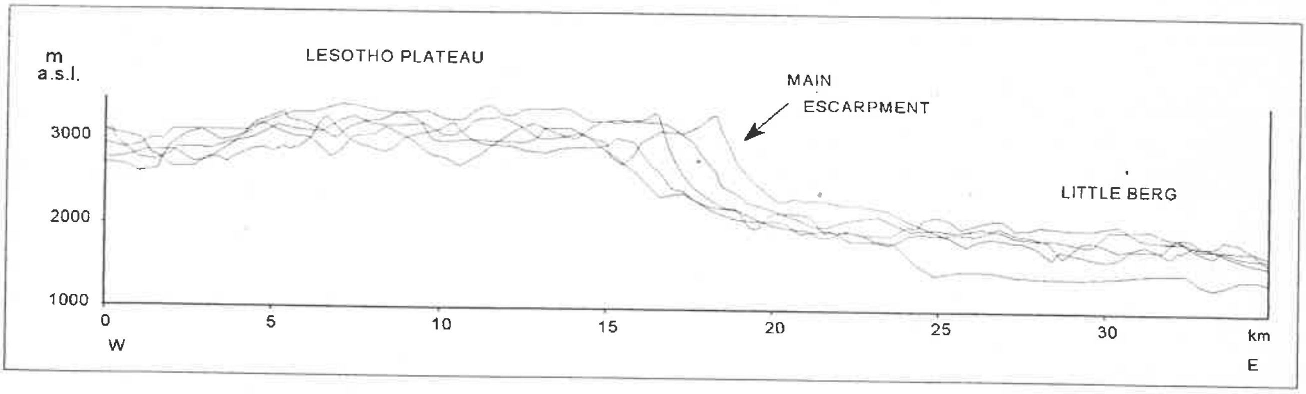


Figure 2.1 Superimposed transects at Giant's Castle Game Reserve (modified after Boelhouwers, 1992).

2.2 Geology

The stratigraphy of the Drakensberg is characterised by a concordant sequence of sedimentary strata which are overlain by basalts and intruded by a lattice of dolerite sills and dykes (Table 2.1).

The Upper Beaufort Subgroup, exposed at between 1500m and 1590m in the Bushman's River valley floor, is the lowermost member of the Karoo Supergroup to outcrop in Giant's Castle Game Reserve (Boelhouwers, 1988). It consists of fine-grained to medium-grained yellowish feldspathic sandstones, alternating with thicker members of red or maroon coloured mudstones and blue-green shales. The Beaufort-Molteno stratigraphic contact is readily distinguished whereas the Molteno-Elliot and Elliot-Clarens contacts are gradational and therefore exact stratigraphic boundaries of the formations are difficult to define (Du Toit, 1954; Haughton, 1969; Eriksson, 1983).

SUPERGROUP	GROUP	SUBGROUP / FORMATION	AGE
Karoo Supergroup	Drakensberg Group (volcanics)		Upper Triassic - Lower Jurassic
	(No group name)	Clarens Formation	Upper Triassic
		Elliot Formation	Upper Triassic
		Molteno Formation	Middle Triassic
	Beaufort Group	Upper Beaufort Subgroup	Lower Triassic
		Middle Beaufort Subgroup	Lower Triassic
		Lower Beaufort Subgroup	Upper Permian

Table 2.1. Stratigraphy and ages of the upper part of the Karoo Supergroup (modified after Eriksson, 1983).

The Molteno Formation is characterised by light-coloured, fine to course-grained sandstones which display argillaceous beds and lenses. These grade upwards into deposits of the Elliot Formation which display subordinate sandstone lenses set in massive red siltstones and mudstones. The Clarens Formation (previously known as the Cave Sandstone) overlies the Elliot Formation and consists of pale, fine sandstones with subordinate argillite layers and lenses (Du Toit, 1954; Eriksson, 1983). By comparison the contact of the Clarens Formation with the Drakensberg Basalts is quite distinct. Small lenses of volcanics are occasionally found within the Clarens Formation sandstones and low grade contact metamorphism has often affected the upper few metres of sandstone (Eriksson, 1983). The basalts consist of numerous individual lava flows, generally attaining a total thickness of over 1350m (King, 1982) and up to 1800m at Sani Pass (Dunlevey *et al.*, 1993) (Fig. 2.1). Secondary minerals of calcite, chalcedony, zeolite and analcime are common in amygdales (Brink, 1983) with a distinct zonal distribution (Dunlevey *et al.*, 1993). A summary of the lithologies of the upper stratigraphic sequences of the Karoo Supergroup is shown in Table 2.2.

GROUP	FORMATION	LITHOLOGY	THICKNESS	ALTITUDE
Drakensberg	-	basalt	1350m	>1880m
No group name	Clarens	sandstone	120m	1720 - 1880m
	Elliot	red siltstone and mudstones/ sandstone lenses	50 - 80m	1630 - 1720m
	Molteno	sandstones/mudstones/ shales	7 - 20m	1600m

Table 2.2 Characteristics of the upper stratigraphic sequences of the Karoo Supergroup found in Giant's Castle Game Reserve (modified after Boelhouwers, 1992).

2.3 Geomorphological evolution

The earliest interpretation of the Main Escarpment (the dominant feature of the Drakensberg) was that of a huge fault (Suess, 1904). Such interpretation was refuted by Penck (1908) who suggested it to be the product of scarp retreat. This theory was extended by Dixey's (1942) proposal of four erosion surfaces and the later recognition by Fair and King (1954) of three surfaces caused by cycles of erosion initiated by intermittent uplift since the Triassic, with parallel retreat of slopes. King (1976) later concluded that five datable surfaces exist. Five stages of uplift were identified, the late Pliocene stage of uplift hypothesised as giving rise to a rejuvenation of streams in the Little Berg (King, 1982). Not all researchers agreed with these earlier interpretations. King was criticised for a lack of empiricism and objectivity (Young, 1972; Le Roux, 1991). Problems emerged with the dating and correlating of surfaces over extensive areas (De Swart and Bennet, 1974; Summerfield, 1985) and Birkenhauer (1985) proposed structural control as the cause of the distinctly stepped topography. Simultaneously, a number of general problems associated with the application of denudation chronology in landscape interpretation emerged (Chorley *et al.*, 1984; Selby, 1985). Ollier and Marker (1985) alternatively suggest that the Escarpment was initiated by erosion on the downwarped continental margins to the base level of the newly emerging coastline. In response to the confusion of geomorphological interpretation there has been a re-evaluation of the geomorphological history of the subcontinent by Partridge and Maud (1987).

Partridge and Maud (1987) interpreted the mountainous regions above the Great Escarpment as being unrelated to particular phases of erosion, in contrast to King's reference to a Gondwana surface, although generally discrete phases of erosion can be identified. The oldest surface identified by Partridge and Maud (1987), the African surface, coincides generally with the African surface described by King (1967). Two surfaces of the post-African age were identified, and are referred to as the Post-African I and the more recent Post-African II surface. The relationship between surfaces and stages is hypothesised as being indicative of landform development by progressive backwearing and downwearing, where existing surfaces continue to develop at the expense of higher lying areas.

Notwithstanding the work of King (*interalia* 1982) and Partridge and Maud (1987) few broadly based studies of geomorphic evolution of the sub-continent have appeared in the last two decades. The recent focus within the geomorphology of the sub-continent has been on landscape development at the regional to local scale and on landscape processes that are active under present-day conditions. The presence of periglacial activity on the Lesotho Plateau supports the contention that periglacial processes have played, and continue to play, a role in modifying the morphology of the high Drakensberg (Lewis, 1988; Boelhouwers, 1991; 1994; Hanvey and Marker, 1992; Meiklejohn, 1992; 1994; Grab, 1994). The cryogenic influence may have extended down the Main Escarpment in the last glacial in the form of niche glaciers (Hall, 1994) with some evidence of cryogenic processes at lower altitudes (Lewis, 1988).

By analysing the scarps of the Main Escarpment basalts near Royal Natal National Park, Moon and Selby (1983) contested the idea of strictly parallel retreat, citing evidence for the occurrence of strength equilibrium slopes. Findings by Munro-Perry (1990) on the Clarens Formation Sandstone show that slope retreat will occur only under the specific condition of a resistant caprock. In the absence of a caprock the slope will decline. Moon (1990) showed that the parallel retreat model is not a general model and will occur only where there is sufficient difference in resistance in the capping and the underlying strata. Although some research has been directed to mass movement and erosion (eg. Beckedahl, 1977; Boelhouwers, 1988, 1992; Sumner, 1993) the contribution of mass movement and erosion process to the landforming processes of the Drakensberg is as yet little understood.

2.4 Climate

The position of southern Africa, in relation to the pressure and wind systems of the Southern Hemisphere, strongly influences the climate of the subcontinent. South of 20°S the climate of Africa is dominated by two subtropical anticyclones. The South Atlantic anticyclone feeds south westerly on-shore winds onto the west coast. The South Indian anticyclone fluctuates in position off the east coast; the cell withdraws in summer and advances in winter. This anticyclone controls the general airflow over Natal (Tyson, 1969; Schulze, 1972; Preston-Whyte and Tyson, 1988). South of the anticyclones is the zone of westerlies in which mid-latitude frontal depressions form and travel eastward. Over the subcontinent an anticyclonic circulation is the predominant feature. This weakens in summer and moves south through a few degrees of latitude. The essential features of circulation in summer and winter are similar, yet the seasonal variations of climate with respect to rainfall and temperature are marked (Jackson and Tyson, 1971).

In winter the high pressure systems move northwards bringing the Westerlies and intermittent cold fronts. These fronts may extend far inland. The presence of the high pressure systems over the subcontinent and the occurrence of subsidence result in clear skies and calm conditions (Hurry and Van Heerden, 1981). In summer the Atlantic and Indian anticyclones move southwards causing the westerlies to blow well south of the continent. There is a weakening and southward movement of the anticyclone positioned over the subcontinent. The development of weak and shallow low pressures over the plateau of southern Africa permits the influx of humid air from the Indian Ocean which influences the eastern parts of southern Africa (Jackson and Tyson, 1971; Hurry and Van Heerden, 1981). These broad circulation patterns in turn influence the local climatic parameters affecting Giant's Castle Game Reserve and are discussed below.

There is a scarcity of climatic data for the Drakensberg area due to the small number of weather monitoring stations. All Natal Parks Board camps keep records of total rainfall. There are, however, only three automated weather stations within the Natal Parks Board Drakensberg areas. One station is at the Cathedral Peak Research Station (1870m a.s.l.) and the other two are at the Main Camp in Giant's Castle Game Reserve (1780m a.s.l.) (Fig. 1.3). The two stations in Giant's Castle Game Reserve are controlled respectively by the Natal Parks Board and the Weather Bureau. Both stations have been in operation intermittently since 1985. The most complete records come from the Cathedral Peak Research Station (some 45km northwest of Giants Castle Game Reserve Main Camp) whereas some high altitude data are available from above the Escarpment at Letseng-la-Draai (3050m) (Fig 1.2).

2.4.1 Precipitation

Rainfall amount and the associated kinetic energy vary spatially and seasonally in the Drakensberg. Total rainfall varies between about 1000mm in the Little Berg to 1800mm at the Escarpment (Tyson *et al.*, 1976). Precipitation in the summer months between November and March accounts for 70% while the winter months (May to August) contribute only 10% to the total annual precipitation (Tyson *et al.*, 1976). Most of the rain occurs in the form of thunderstorms with more than 100 rainfall-days being recorded on an annual basis in the Escarpment region (Schulze, 1974). Mean monthly rainfall totals and the number of rainfall days for Giant's Castle Game Reserve and at the Cathedral Peak Research Station are shown in Figure 2.2. Giant's Castle Game Reserve and Cathedral Peak have a similar number of rainfall days, although Cathedral Peak has a higher total rainfall.

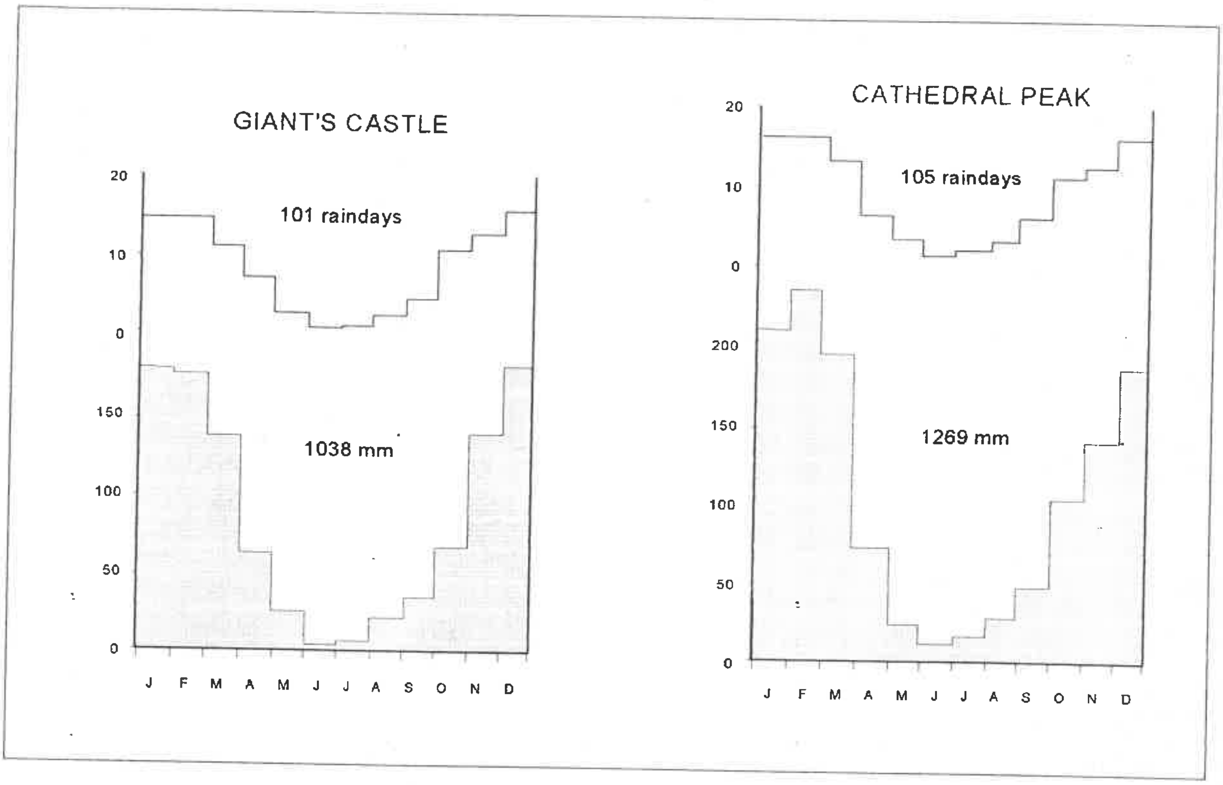


Figure 2.2 Monthly rainfall totals and number of raindays in Giant's Castle Game Reserve and at the Cathedral Peak Research Station (modified after Tyson *et al.*, 1976)

Long-term rainfall intensity data are available from the Cathedral Peak Research Station. Rainfall kinetic energy relationships for Cathedral Peak show considerable seasonal differences (Fig. 2.3) with winter months displaying much lower kinetic energies than summer months (Schulze, 1978). The frequency of occurrence of extreme rainfall events above threshold intensities for selected durations are shown in Figure 2.4. This indicates the highest frequency of occurrence for the selected parameters from October to the end of May. Peak occurrences are in the December - January period and a second peak occurs in March. The return period for maximum expected rainfall intensities at Cathedral Peak are shown in Figure 2.5. Recent short-term intensity data from Giants Castle Game Reserve for the 1993/4 summer will be discussed in Sections 4 and 5.

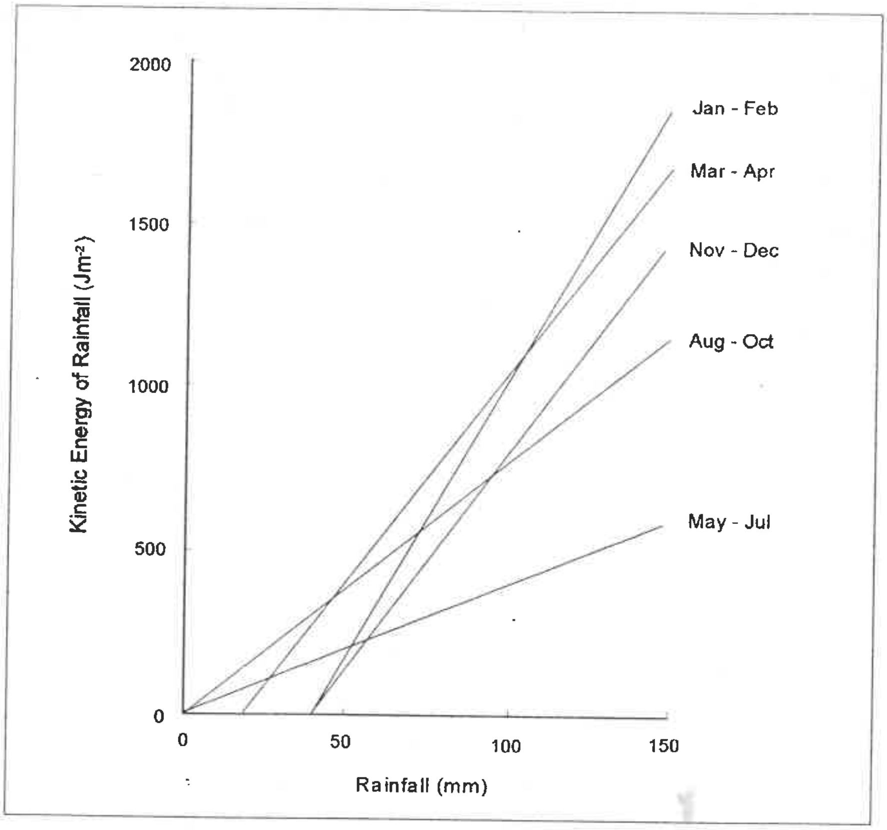


Figure 2.3 Rainfall kinetic energy relationships for Cathedral Peak (modified after Schulze, 1978)

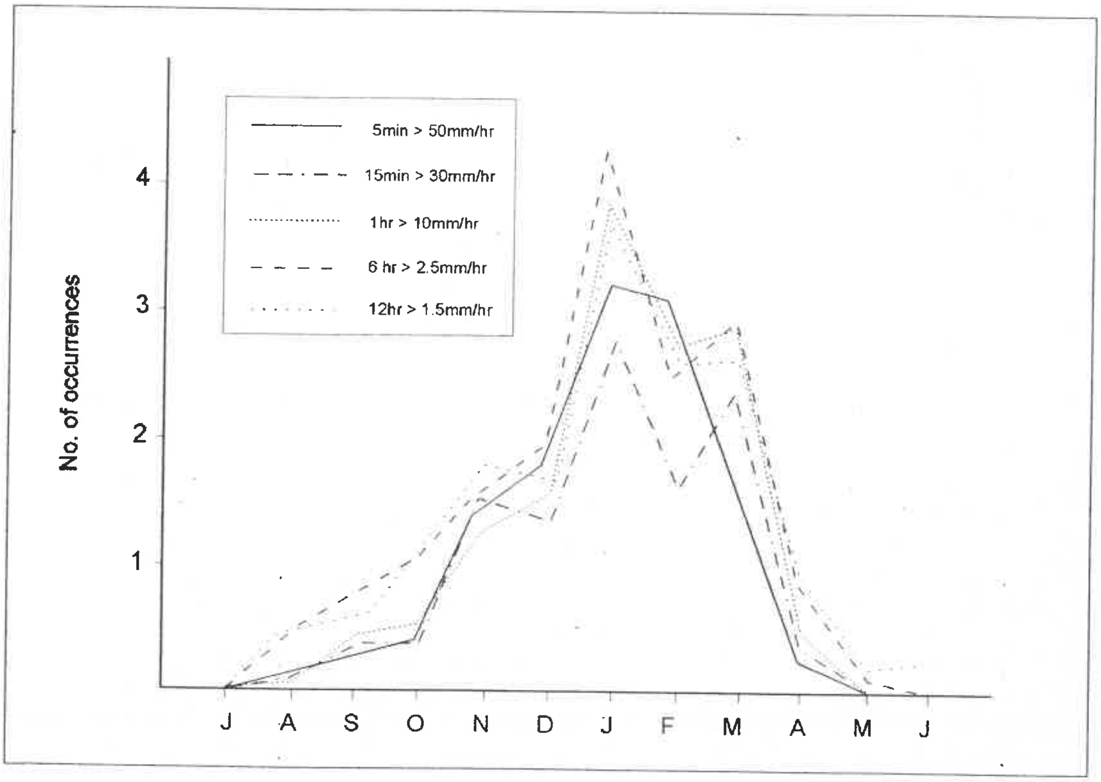


Figure 2.4 Frequency of occurrence of extreme rainfall events above threshold intensities for selected durations at Cathedral Peak (after Schulze, 1978).

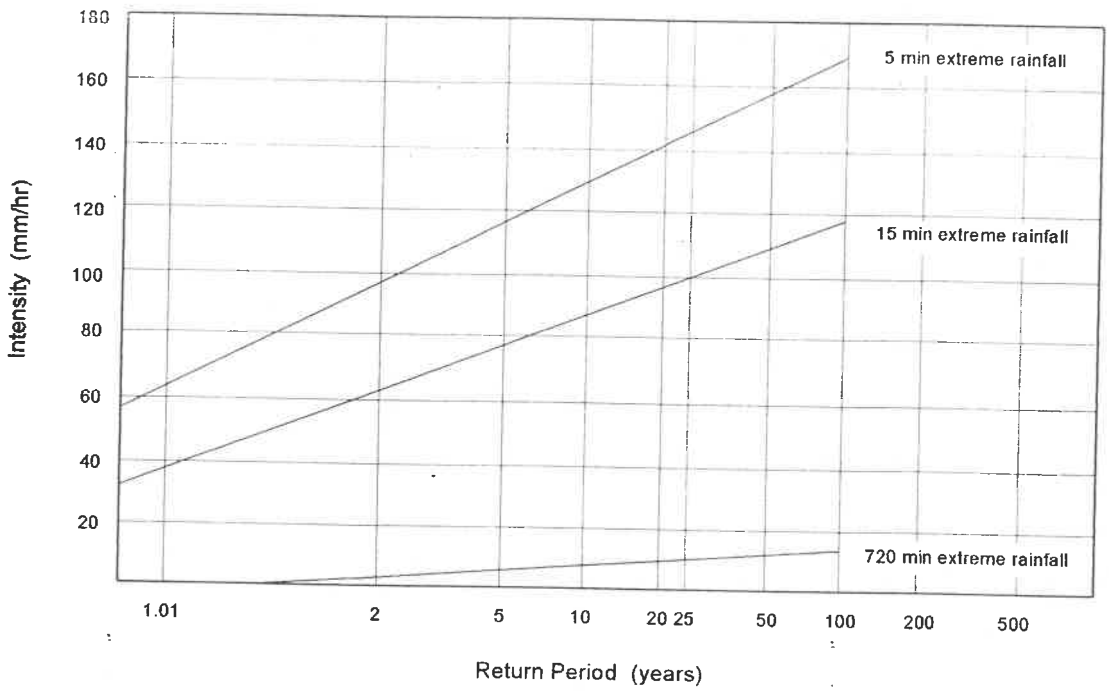


Figure 2.5 Maximum expected rainfall intensities of calculated return periods for Cathedral Peak (modified after Schulze, 1978).

2.4.2 Temperature

Mean monthly temperatures above the Main Escarpment at Letseng-la-Draai (3050m) vary between -0.5°C in July and 11.1° C in January (Grab, 1994). Temperatures are higher in the Little Berg and mean monthly temperatures for Giant's Castle (1737m) range between 2°C in July to 15°C in January (Schulze, 1981). Mean monthly temperature data for the two stations are provided in Table 2.3.

Few observations have been made of valley temperature structure in the many valleys that are a feature of the Little Berg. Lapse rates measured in the Bushman's River valley in Giant's Castle Game Reserve indicated a temperature inversion in winter (Tyson *et al.*, 1976). These valley inversions are intensified by the drainage of cool air down-valley. After sunrise, however, with the receipt of direct solar radiation, inversions dissipate rapidly. In winter, conditions of clear skies, temperature inversions, dry air and the absence of wind, favour the development of frost. In the Little Berg frost may occur from May to September with a frequency in the order of 120 days per year (Tyson *et al.*, 1976).

	J	F	M	A	M	J	J	A	S	O	N	D
L-l-D	11.1	10	9.0	4.9	2.3	-0.5	0.1	2.0	5.4	7.3	8.3	9.8
G.C.G.R.	15	12	13	7	7	2	3	4	8	10	10	12

Table 2.3. **Mean monthly temperatures for Letseng-la-Draai (L-l-D) and Giant's Castle Game Reserve (G.C.G.R.) (modified after Schulze, 1981; Grab, 1994).**

2.4.3 Wind

The airflow of the Drakensberg is strongly influenced by the presence of the Main Escarpment and the deeply dissected terrain of the Little Berg (Fig 2.1). Under clear, fine weather conditions, airflow patterns near the ground are completely dominated by topographically induced local winds (Tyson *et al.*, 1976). These are formed on a variety of scales by the solar heating of the ground during the day and radiation-cooling by night. Anabatic and katabatic winds may drain warm and cool air on slopes by day and night respectively (Tyson *et al.*, 1976).

Strong pressure gradients are usually associated with the passage of frontal systems. 'Berg Wind' conditions generally precede a cold front and wind velocities are high with and generally low humidity (Killick, 1963; Hurry and van Heerden, 1981; Preston-Whyte and Tyson, 1988). Strong winds accompanying thunderstorms are known to occur but these seldom last for long periods (Killick, 1963). The geomorphic influence of strong winds is mostly unknown as little data are available to assess the influence of wind on soil movement. Although cited by Bainbridge (1979) as being an underestimated form of soil transport, Garland (1987b) suggests that the conditions in the Drakensberg do not favour extensive wind erosion and deflation has been assumed to operate only on bare soils (Boelhouwers, 1988). The effects of burning on wind erosion have, however, not yet been fully investigated. Some tentative figures place soil loss associated with burning and high wind speeds up to peak values of 152 tons/ha near the Escarpment south of Kamberg (Sumner, 1992).

2.5 Soils

Although some small scale soil surveys of the Cathedral Peak area have been undertaken (Schulze, 1974; Granger, 1976) there has, as yet, been no comprehensive soil survey taken for the Natal Drakensberg. The Tugela Basin was mapped at a scale of 1:100 000 by Van der Eyk *et al.* (1969) but little attention was given to the soils of the Little Berg and Escarpment zones. The soils in the Little Berg have been described as ferrallitic, structureless and acid due to a high degree of leaching (Schulze, 1974; Granger, 1976; Boelhouwers, 1988). At Cathedral Peak the A horizon is rich in organic matter and is classified as orthic. The A horizon is best developed on moist, cool south-facing slopes, increasing in thickness downslope to a maximum of 25cm (Schulze, 1974; Granger, 1976). This trend has also been observed elsewhere in the Drakensberg, as exemplified by Humphrey (1983) who reported organic matter contents in the Kamberg area of 10.3% on north-facing slopes and increasing to 17.7% on south-facing slopes. The soil appears to be low in clay content in the vicinity of the Main Camp in Giant's Castle Game Reserve and samples indicate the texture class to be classified as that of loamy sand (U.S. Department of Agriculture texture classes cited in Strahler, 1975).

Five soil forms have been identified in Giant's Castle Game Reserve, namely Hutton, Griffin, Clovelly, Katspruit and Mispah Form (Van der Eyk *et al.*, 1969; Garland, 1987b; Boelhouwers, 1988). The dominant soil forms found in Giant's Castle Game Reserve and their general location are listed in Table 2.4.

FORM	DIAGNOSTIC HORIZONS	LOCATION
Hutton	orthic A / red apedal B	low gradient slopes
Griffin	orthic A / yellow-brown B / red apedal B	low gradient moist conditions on cooler slopes
Clovelly	orthic A / yellow-brown apedal B	steep and/or south-facing slopes
Katspruit	orthic A / firm gley	poorly drained valley floors and in narrow strips along streams
Mispah	orthic A over rock	dolerite outcrops and along scarp edges

Table 2.4 Soil forms found in Giant's Castle Game Reserve (modified after Van der Eyk *et al.*, 1969; Garland, 1987b; Boelhouwers, 1988).

2.6 Vegetation

Two of the dominant factors which have influenced vegetation in the Drakensberg are altitude and the long history of controlled burning (Garland, 1987b). Three altitudinal belts of vegetation were recognised by Killick (1963) as the Montane, Subalpine and Alpine belt. These belts have generally been used in later studies (Edwards, 1967; Schulze, 1974; Granger, 1976; Boelhouwers, 1988) and are shown in Table 2.5.

The montane belt supports the *Themeda-Trachypogon* sub-climax community. It is dominated by *Themeda trianda* and *Trachypogon spicatus* grassland and is interspersed with small communities of *Protea* savanna. Pockets of shrub and woodland with *Leucosidea sericea* and *Buddleja salvifolia* are found on rocky soils, in kloofs and on streambanks (Garland, 1987b). The subalpine belt consists of *Themeda-Festuca* grassland where *Themeda trianda* is common, particularly on north-facing slopes, and *Festuca costata* is common on south-facing slopes. Subalpine fynbos exists along streams and steep slopes at the head of main streams where there is some measure of protection from fire. The greatest variety of species are found on south-facing slopes and are attributed to local moisture and climatic conditions (Granger, 1976). The alpine belt supports the *Danthonia-Festuca-Pentaschistis* association. Vegetation is characteristic of a harsh climate of wet summers and freezing of soils in winter (Boelhouwers, 1988). Sites protected from fire may support *Danthonia* tussock grassland and stands of alpine fynbos (Garland, 1987b). Vegetation burning is one of the main anthropogenic influences on the natural environment of the Drakensberg and aspects of the burning programme will be discussed briefly below.

VEGETAL BELT	ALTITUDE (m)	LOCATION	CLIMAX COMMUNITY
Montane	1280 - 1829	Valley floors to lowest basalt cliffs	*Podocarpus latilolius* Forest
Subalpine	1830 - 2865	Edge of Little Berg to just below summit	*Passerina-Phillippa-Widringtonia* Fynbos
Alpine	2866 - 3353	Plateau and peak areas	*Erica Helichrysium* Heath

Table 2.5 Vegetation belts and climax communities of the Drakensberg (after Killick, 1963).

2.7 Anthropogenic influence

A brief assessment of the anthropogenic history of Giant's Castle Game Reserve reveals to some extent localised influences on recent geomorphological development. The history of the area prior to the turn of the century is poorly documented, but the area which is now the Reserve was mostly uninhabited with the Amahlubi tribe who have resided on the fringes of what is now the Reserve boundary. The 1849 'rebellion' by Chief Langalibalele of the Amahlubi prompted Major Durnford of the Natal Carbineers to establish, in the mid 1870's, a base near what is now the Main Camp (Pearse, 1987). Some of the passes including the Ka-Langalibalele Pass and Giant's pass were dynamited, ostensibly to prevent Langalibalele escaping into Lesotho with his cattle.

The original homestead in Giant's Castle Game Reserve was built when the Reserve was established in 1903 and the Main Camp was subsequently developed closely upstream of it (Fig 1.3). During the first half of the 1900's cattle were farmed in the Game Reserve by Natal Parks Board staff and these were gradually phased out in the late 1960's and early 1970's. Horses were used extensively by the Reserve Management and may have numbered up to 80-100 at any one time in the late 60's, but were slowly reduced in numbers due to the increasing reliance on motorised transport. A number of jeep tracks were built in the early 1950's which provided access to the more remote areas of the Reserve and a link road was made to Loteni (south of Giant's). Most of the jeep tracks were progressively closed until the late 1970's and some rehabilitation of these tracks was attempted (Meiklejohn, *pers. commun*). There were a number of wattle woodlots located near the Main Camp and these were slowly removed after 1972. A burning programme was implemented when the Reserve was established and has been in operation since, on a biannual burn.

The age of the footpaths is difficult to determine. Some sections of the contour path were completed in 1965 but most of the other paths predate these. Bannerman Hut was completed in 1965 and Giant's Hut in 1969/70. Material for the construction of Giant's Hut was transported from the Main Camp along a jeep track which has since been closed. Material for Bannerman Hut was transported by horseback (Meiklejohn, *pers. commun.*).

The historical influence of the anthropogenic development of the Reserve must be considered when analysing contemporary rates of soil erosion and when determining or inferring the processes responsible. This line of discussion will be continued in Chapters 4 and 5 where results are contexualised into the broader framework of process-response mechanisms. The following chapter outlines the methodology used to determine the rates and controls of erosion from footpaths in the Reserve.

3. Methodology

Different methods have been implemented to determine footpath condition and to monitor changes in these conditions with time. The condition of a footpath refers to both the amount of soil lost and the related soil attributes (such as bulk density and moisture conditions) as well as the impact on vegetation adjacent to the footpath, which is in turn linked to the erosion process. The techniques of measurement range from localised assessment, such as transects across footpaths from fixed points (eg. Coleman, 1977; Tinsley and Fish, 1985) and the use of runoff plots (eg. Garland, 1988; Day *et al.*, 1994), to broader scale assessments through footpath surveys (eg. Bayfield, 1973; Lance *et al.*, 1989) and using aerial photography (eg. Coleman, 1977). Generally there is a trade-off in precision as the scale of assessment increases.

Two systems of measurement are utilised in this study. Firstly, six experimental runoff plots were installed on a footpath to determine specific localised erosion rates and to determine the effect of footpath gradient on sediment yield. This approach is outlined in Section 3.1. Secondly, on a broader scale, a point-based survey of four footpaths in the Reserve was conducted and the survey methodology described in Section 3.2. A comparison of the two systems of measurement is outlined in Section 3.3.

3.1 Experimental runoff plots

3.1.1 Runoff plot size

Runoff plots have traditionally been used to establish erosion rates for predetermined areas under specific soil, rainfall and vegetation cover conditions. Over the past decade, however, a variety of plot sizes have been cited in the literature. These show no conformity to any one size specification or standard and range from as small as 0.61m x 1.5m (Abrahams and Parsons, 1991) to 50m x 60m (Romero-Diaz *et al.*, 1991) (Table 3.1.). Only two series of runoff plots have been established on a footpath to date (Garland, 1987a; Day *et al.*, 1994).

Authors(s)	Runoff plot size (m)
Romero-Diaz *et al.* (1988)	50 x 60
Parsons *et al.* (1991)	18 x 35
Parsons *et al.* (1993)	18 x 29
Lal *et al.* (1989)	12.2 x 32.3
Lal (1985)	4 x 25
Hofmann and Ries (1991)	4 x 21.1
Hussein and Othman (1988)	4 x 20
Rydgren (1988)	4.5 x 13.5
Hart (1984)	3.7 x 18.3
Garland (1987a)	2 x 22
Snyman and Foche (1991)	2 x 15
Ulsaker and Onstad (1984)	3 x 10
Kirky and Mehuys (1987)	1.75 x 10
Abrahams *et al.* (1986)	1.8 x 5.5
Williams and Buckhouse (1991)	1 x 5
Day *et al.* (1994)	1 x 3
Abrahams and Parsons (1991)	0.61 x 1.5

Table 3.1 **Some examples of runoff plot sizes utilised during the last decade.**

Garland (1987a; 1988) established runoff plots on an 11° north-facing slope in the Kamberg Nature Reserve, Drakensberg (Fig. 1.2) to monitor footpath erosion rates and assess the influence of burning on erosion rates. The runoff plots measured 2 x 22m (conforming to the standard USLE plot size) and obtained the only data currently available for long-term sediment movement from a footpath utilising this technique. Some deficiencies in our understanding of the rates of erosion still, however, need to be addressed. First the issue of sediment rates from runoff plots in relation to variations in footpath gradient needs to be established and secondly, the influence of rainfall intensity and its relationship to quantities of runoff and sediment yield for individual rainfall events has not yet been assessed with respect to variations in the footpath gradient.

The second study involving footpath runoff plots was established in 1993 and is currently being monitored at Royal Natal National Park in the northern areas of the Drakensberg (Fig. 1.2). This project involves the monitoring of sediment yield from various artificial footpath surfaces in a high intensity-use area (Day *et al.*, 1994). Fourteen plots of two sizes (1m x 3m and 1m x 5m) were established longitudinally on an experimental footpath section. Site specific factors, particularly gradient, precluded larger plots being established. The limitations on plot size parallel the conditions for runoff plots in Giant's Castle Game Reserve and will be discussed below. Sediment yield data from the study are not yet available.

For the purposes of this study six erosion plots were installed on an established footpath near the Main Camp in Giant's Castle Game Reserve (Fig 3.1). The footpath provides access to both Giant's Hut and to the Hide and is utilised as a starting point to access the eastern areas of the Reserve (including Meander Hut) for both recreation and management purposes. The monitored section was 80m long which included the erosion plots and an automated electronic pedestrian counter. Both ends of the footpath section were demarcated by signposts which briefly informed the public of the aims of the project. The electronic counter was located in the centre of the experimental section and operated from a pressure sensitive pad situated across the footpath. The counter was accompanied by a sign post requesting pedestrians to step on the pad. The grass type adjacent to the footpath is *Themeda trianda* and soil type was identified as Hutton form. Hutton soils are considered to have low to moderate erodibility (Garland, 1988).

The plots were installed on the footpath longitudinally and cover six different gradients (Fig. 3.2). The highly variable nature of the footpath gradient imposed limits on the runoff plot length. Plot design was adapted from the design used by Williams and Buckhouse (1991), who established 1m x 5m plots for monitoring micro-watershed processes, and from the 1m x 3m design used by Day *et al.* (1994). For this study the runoff plot length was optimised at 3m to ensure that gradients were constant within the plots while still varying the individual gradient between plots. A further constraint on size was that the plots were required to be located sufficiently close together to facilitate monitoring of sediment yield and runoff and to minimise any spacial variations in rainfall.

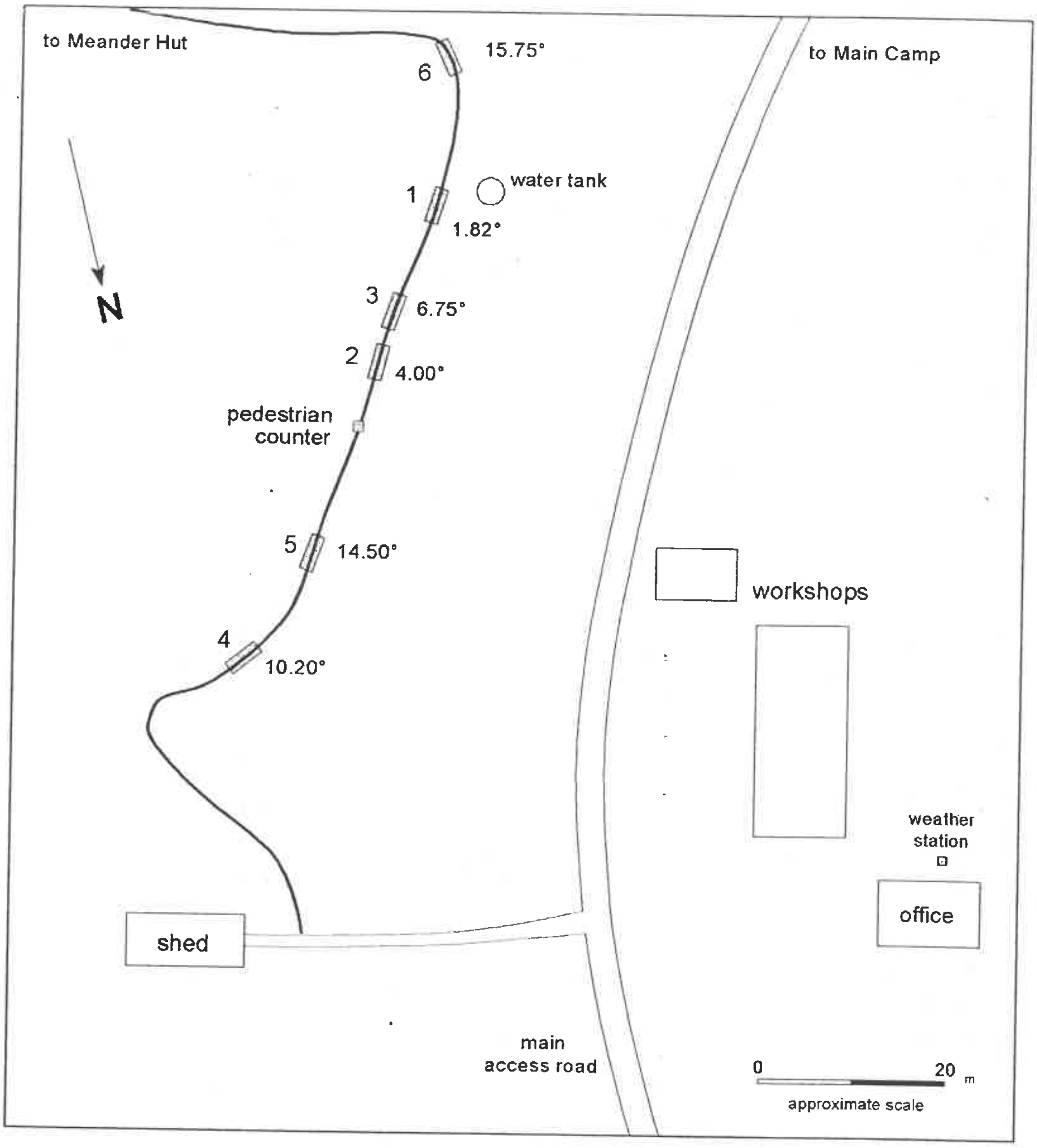


Figure 3.1 Plan view of runoff plot location indicating plot number, gradient and location of the Natal Parks Board weather station.

The width of the plots was dictated by the width of the footpath and the comfort of pedestrians, who were directed to walk through the plots. Footpath width where the plots were installed was 50cm. Since the sediment generated from the footpath and from the adjacent natural surface would be difficult to distinguish, plot widths were optimised at 1m. This width ensured that pedestrians would not be encouraged to walk alongside the plots. A further consideration on plot size was the potential quantity of runoff that can be produced per unit area. A $1m^2$ plot could theoretically produce up to 10 litres of runoff from a 10mm rainfall event if all the rainfall were converted to runoff. Since one of the objectives of the study was to determine the quantity of runoff generated and the costs of a tipping bucket system to monitor runoff were prohibitive the plot size was optimised at $3m^2$. A practical application of this is that it allows direct comparisons with data from the same runoff plot size from Royal Natal National Park, when these data became available.

Figure 3.2 **Runoff plot installed on a footpath in Giant's Castle Game Reserve.**

(A marks the runoff plot, B the conduiting and C the sediment trap. Plot width is 1m).

3.1.2 Runoff plot design

Galvanised iron sheeting (0.5mm gauge) was used as shuttering to delineate the plot areas. The steel was cut into strips 250mm x 1250mm which were then inserted to a depth of 50-80mm into the ground with 100-150mm end-to-end overlap. This isolated the plots from runoff entering or exiting the system other than through the constructed opening. The 170-200mm protrusion of the shuttering above the ground minimised rainsplash in or out of the system. If rainsplash did occur above the height of the shuttering it was assumed that splash into the system was equivalent to splash out. Where pedestrians would have to step over the shuttering the ridge was covered with a rubber hose and the shuttering was reinforced with steel pegs inserted on the outer side of the shuttering.

The plots were drained from the lowest corner by means of a specially designed corner piece, constructed from galvanised iron sheeting, so as to ensure that no leakage occurred. The corner piece linked the shuttering to a length of galvanised iron conduiting (1-2m in length) which transported the runoff and sediment to a sediment trap. The conduiting was covered by a simple roof system which prevented rainfall from collecting in the conduiting but could be removed to brush out sediment which may have settled before reaching the trap. The sediment traps were adapted from the design of wash traps used by Young (1960) and measured 600 x 600 x 400mm in size. Runoff and sediment from the plots was collected in three buckets within the trap which were arranged to overflow into one another, holding a total capacity of 27 litres. The buckets facilitated emptying during the lower volume runoff events. If the runoff volume exceeded the bucket capacity the overflow would be collected in the trap which could hold up to a maximum total capacity of 130 litres. Volumes of runoff in excess of this would overflow through a vent at the back of the trap.

The plots were installed in two phases. The shuttering and sediment traps were installed on the 2nd and 3rd of September 1993 and the guttering two weeks later. Disturbance of the soil was kept to a minimum. The plots were given a settling time of 6 weeks before the monitoring began on the 18th of October 1993. During this settling period a total of 124mm of rainfall fell on 14 rainfall-days.

3.1.3 Monitoring

The emptying procedure was demonstrated to members of the Natal Parks Board Staff who subsequently emptied the traps on a daily basis at 07:30. Containers with a two litre capacity were provided to store runoff and sediment. Once the traps were emptied, the containers with samples were stored for collection and later removed for laboratory analysis. Logistical difficulties pertaining to both field monitoring (up to 250kg of sediment and runoff were collected per rainfall event) and laboratory analysis (up to a five day laboratory procedure per rainfall event) precluded a continuous monitoring.

The plots were regularly checked for disturbance and, although some damage to the shuttering by trampling did occur, public cooperation in the monitoring section was generally good. At no time were the plots seriously disturbed and the shuttering remained in place for the duration of the monitoring. The sediment traps were kept locked to prevent tampering. The pressure pad was, however, broken on one occasion when the cable linking the pressure pad to the counter was detached (ostensibly by a careless or perhaps inquisitive hiker). The counter failed on two other occasions due to moisture build-up in the circuitry. This resulted in intermittent user-intensity data and a loss of 53 days out of 119 recorded (see Chapter 4).

Soil samples were collected from the footpath to enable comparisons to be made with the sediment collected in the traps. The samples were collected from the centre of the footpath tread surface to a depth of 50mm adjacent to each plot, so as to avoid disturbance within the plot. Samples were also collected from the adjacent natural surface to allow comparisons with the tread surface soil texture. Infiltration capacities for the plots were determined using the apparatus and procedure outlined in Finlayson and Statham (1980). This involved the use of a 100mm internal diameter pipe which was inserted into the footpath tread to a depth of 50mm. The infiltration rate was determined by measuring the drop of water level within the pipe until a constant reading was obtained. Measurements were again taken adjacent to the traps to prevent disturbance within the plots. The infiltration readings and soil samples are assumed to approximate the values within the corresponding plot.

Rainfall data for the monitoring period were obtained from the Natal Parks Board automated weather station located near the workshop and which is within 100m from the runoff plots (Fig 3.1). Total rainfall received was monitored at 60-minute intervals. Technical problems precluded the use of a shorter monitoring period.

3.1.4 Laboratory procedure

The laboratory analysis of the runoff plot samples involved determining the quantity of runoff and the mass and particle size distribution (texture) of the sediment. Although various methods of particle size analysis are available (Black *et al.*, 1973; Allen, 1981; Syvitski, 1991) the use of a vibrating sieve stack is the most practical for analysis of the coarse (sand and gravel) component of soil with realistic limits of 0.063mm and 16mm (Whalley, 1981). The fine soil particles, smaller than 0.063mm (silt and clay component), were analysed with a centrifugal particle size analyser (Shimadzu SA-CP3 Centrifugal Particle Size Analyser).

The laboratory analysis procedure for each rainfall event was divided into three stages (Fig. 3.3). An outline of the procedure is as follows:

STAGE 1

- **The sample containers were first sorted according to rainfall-days. For each day the containers were then sorted according to the respective runoff plot.**
  This could reach up to a maximum of 130 litres of water and sediment per trap, per rainfall-day for the higher intensity and longer duration rainfall-days. The total sample mass was determined by weighing.

- **The sediment and runoff for each trap was then transferred to separate containers for a 24 hour settling period.**
  The relationship between the size of a particle X and the time taken to settle through a height h is calculated using Stoke's equation (Day, 1973; Townsend, 1973). The equation can be expressed as:
  $X^2 = 18\eta h / g(\rho_S - \rho_L)t$ where η is the viscosity of the water, h is the height through which the particles settle, g is the acceleration of gravity, ρ_S is the particle density and ρ_L is the liquid density. For a 300mm height within the settling containers, a clay particle density of 2.60 g/cm^3 (Day, 1973) and water temperature at 25°C particles up to 1.8μm will have settled to the base of the container. Deviations from the theoretical value can, however, be caused by non-sphericity of the individual particles (Allen, 1981).

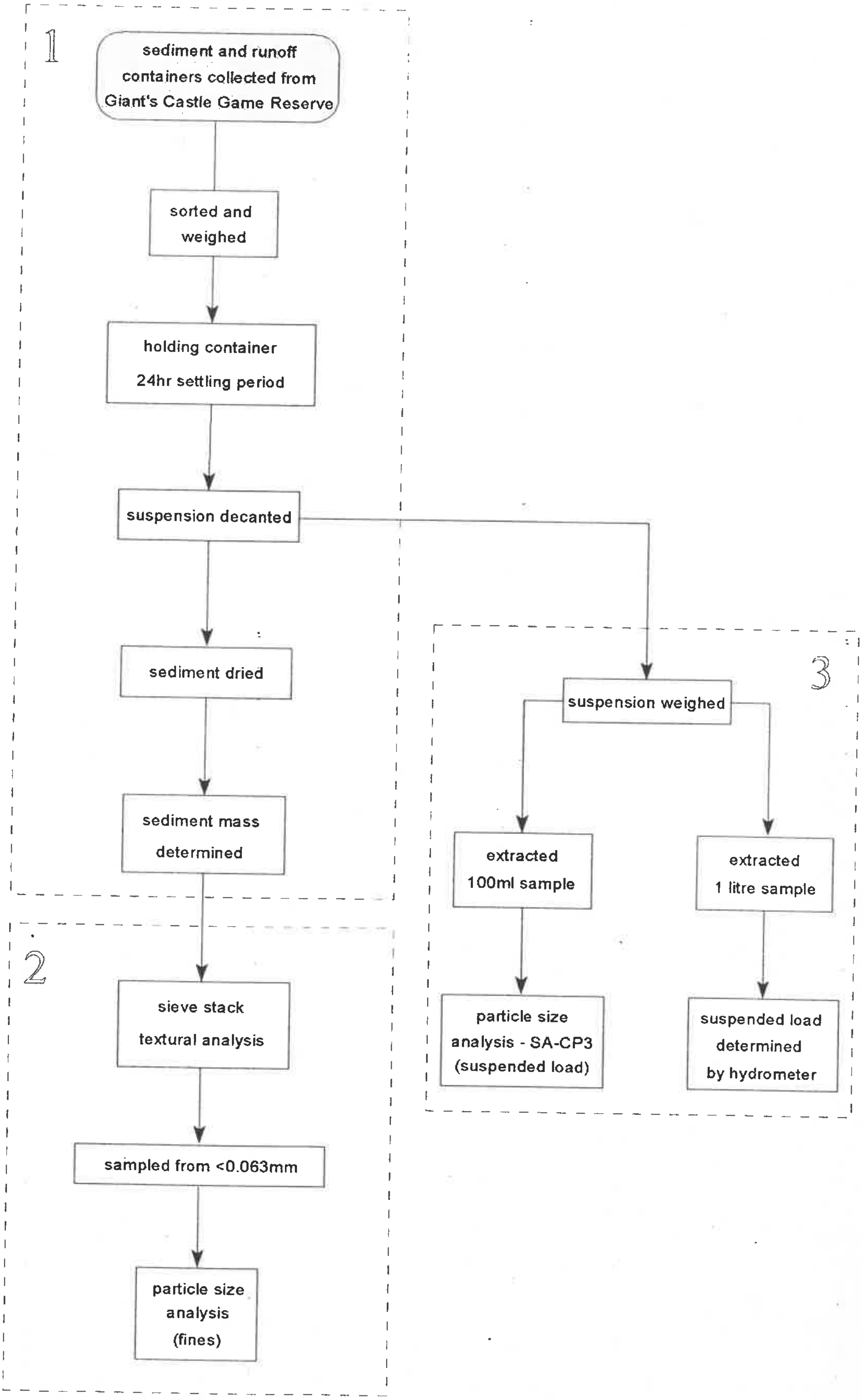


Figure 3.3 The three stages of laboratory analysis of plot sediment and runoff as used in the present study

- **The suspension was decanted.**

  After the settling period, separation by decanting was undertaken to a height of 20mm above the sediment. This caused minimal disturbance to the precipitated sediment. The procedure for textural analysis (particle size distribution) of the precipitated sediment is followed to the end of stage 2 while the procedure for particle size analysis of the decanted suspension is outlined in stage 3.

- **The sediment was dried.**

  The sediment was placed in an oven and dried at 105-110° C for a minimum of 24 hours (Whalley, 1981).

- **The sediment was weighed.**

  This mass was subtracted from the initial total mass to determine the actual quantity of runoff.

STAGE 2

- **The texture of the dried sediment was analysed by means of a vibrating sieve stack.**

  The general procedure outlined by Day (1973) and Briggs (1977) for sieve stack analysis was followed. Standard 8in (200mm) sieves at regular phi units from -3ϕ (8mm) to 4ϕ ($63\mu m$) were utilised (Fig. 3.4). The phi notation is a logarithmic transformation of millimetre values of particle size. The standard transformation is $\phi = -\log_2 X$ where X is the particle diameter in millimetres (Briggs, 1977) although some further modifications to the equation have been presented (Allen, 1981).

Sieve shaking time and sample size specifications have varied with author. McManus (1965) specifies a sieve time of 10 minutes for 4in (100mm) sieves. For 8in (200mm) sieves Day (1973) specifies a 3 minute period while a 5 - 10 min period is given by Briggs (1977) with a sample size between 0.1 and 1.0 kg. Whalley (1981) specifies a 9 minute period with maximum loads of 0.1 - 0.15 kg for coarse sand and 0.04 - 0.06 kg for fine sands. In an analysis of sieve shaking time on sieve efficiency Dalsgaard *et al.* (1991) found no systematic difference in particles distributed in a sieve stack when time was increased from 10 minutes to 60 minutes. Dalsgaard *et al.* (1991) also found that although sieving efficiency increases with decreasing load the coefficient of variation increases with decreasing load. For the purposes of this study sieving time was taken as 10 min and sample size limited to a maximum of 1.0 kg (Briggs, 1977) since splitting a sample can decrease precision of results (Emmerling and Tanner, 1974; Dalsgaard, 1991). Shaking vibration was set at 50Hz as higher vibrations resulted in visible loss of finer particles from percolation through the sieve contacts. The sieves were carefully cleaned with a camel-hair brush between sieving samples. Gravel clasts retained in the -3ϕ sieve (> 8mm) were measured (a, b and c axes) in the manner outlined by Briggs (1977). All particles smaller than 4ϕ were collected in a tray that forms the base of the stack for further analysis (see below).

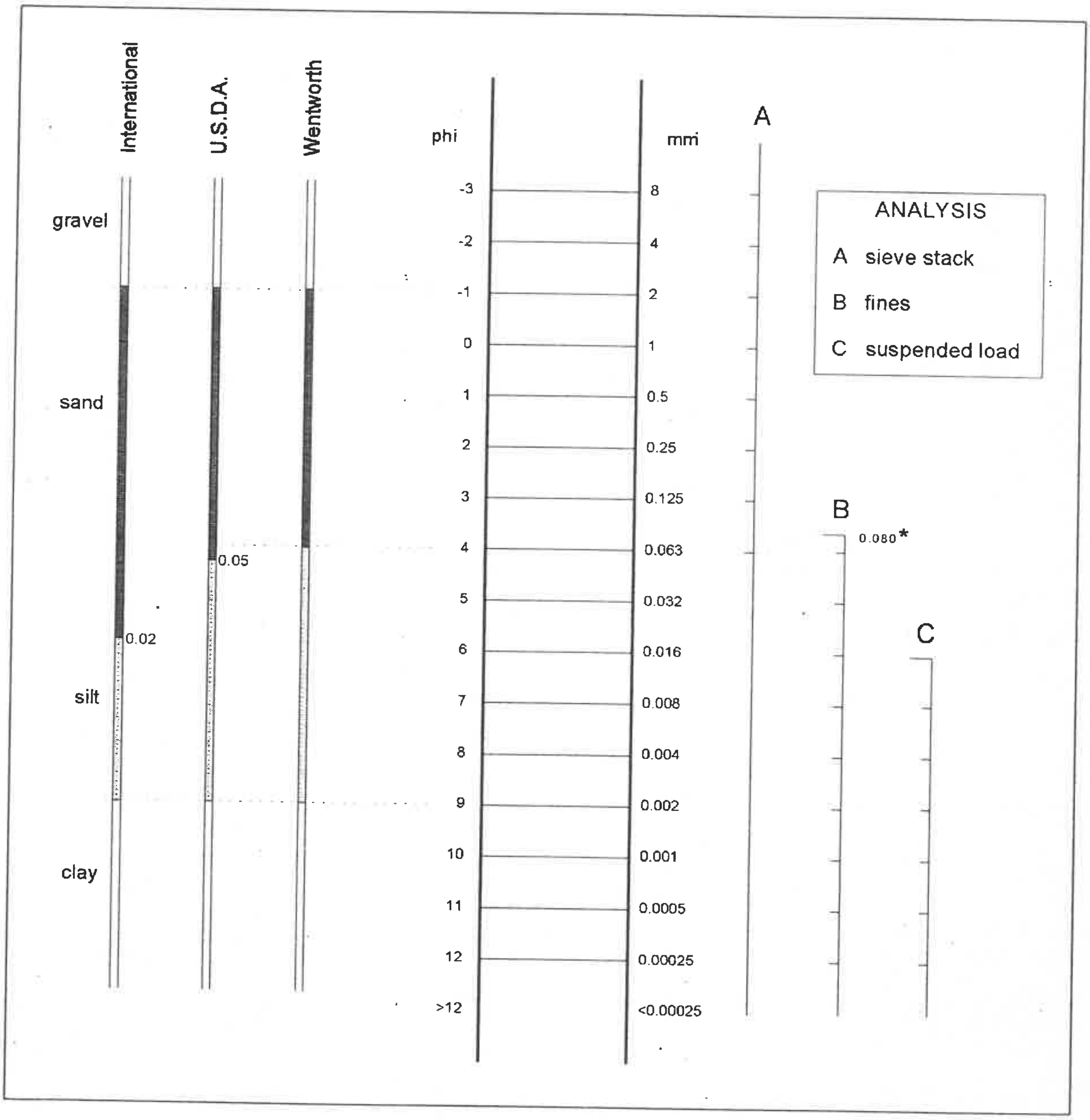


Figure 3.4 Particle size classification and analysis (adapted after Townsend, 1973 and Briggs, 1977)
* (Analysis undertaken from 0.08mm to safeguard continuum of data from A)

Organic matter from soil samples can be removed with hydrogen peroxide (H_2O_2) (eg. Dalsgaard, 1991). Although this treatment is effective when used judiciously it may cause problems should further reactions of the decomposition products occur (Drosdoff and Miles, 1938; Day, 1973). Further problems could have been encountered with the solvents used in the preparation of samples for the centrifugal particle size analyser. Chemical treatment of the samples was thus avoided. The organic matter content in the samples was, however, generally very low and where organic matter was present this was removed manually and weighed separately.

- **A sample was removed from the > 4ϕ tray.**

  Particle size classification into sand, silt and clay differs according to the classification system (cf. Fig. 3.4). Townsend (1973) indicates that the United Stated Department of Agriculture (U.S.D.A.) specifies 0.05mm (50μm) as the boundary, while the International Classification places the boundary at 0.02mm (20μm). The finest sieve used was 0.063mm (63μm) which corresponds to the Wentworth scale (Briggs, 1977) for the sand/silt boundary. Thus for practical reasons the Wentworth scale was followed and the silt/clay (fines) component will hereafter refer to all particle sizes below 63μm. The silt/clay boundary is 2μm. To determine the particle size distribution of the silt and clay component by centrifugal particle size analysis a sample was taken by coning and quartering (Allen, 1981) from the > 4ϕ (< 63μm) tray.

- **Particle size distribution of the fine fraction was then determined with the particle size analyser.**

  The particle size analyzer (SA-CP3) required consistent sample preparation and treatment for optimum consistency of results. The sample was mixed with 100ml of 20% glycerol/distilled water solution and Teepol solution was added as dispersant (10 drops per litre) as specified in the instrument manual. Dispersion efficiency was tested by observing the interface of clear liquid and the turbid lower layer for different Teepol concentrations under slow settling, as suggested by Allen (1981). The solution was agitated for one minute and a portion transferred to the analyser chamber for gravitational and centrifugal analysis. The analysis range interval was from > 4ϕ (< 63μm; upper limit 80μm) to >12ϕ (0.25μm) (Fig. 3.4). The upper limit allowed some overlap with the material retained in the 63μm sieve to ensure a data continuum. This mass fraction was added to the corresponding sieve fraction. The procedure was repeated twice, unless the first two results were within 10% of the results for each phi interval, in which case the procedure was repeated once.

STAGE 3

- **The decanted suspension was weighed.**

- **A one litre sample was removed for suspended load determination by hydrometer.**
  The solution was agitated for one minute and the one litre sample decanted from a depth of 50mm below the meniscus. The hydrometer was calibrated against distilled water at room temperature for each determination. Results from the first two steps of stage 3 gave the mass of suspended load.

- **Suspended load particle size analysis.**
  The suspension was again agitated for one minute and sampled four times with a 25ml pipette at 50mm depth. The total 100ml suspension was then used for particle size analysis. A Teepol solution was added as dispersant (at a concentration of 10 drops per litre). The solution was agitated for one minute and a portion transferred to the particle size analyzer cell for centrifugal analysis. The analysis interval selected was from 8ϕ (4μm) to >12ϕ (0.25μm) (Fig. 3.4) to cover the predicted particle size range calculated from Stoke's equation (see stage 1). The procedure was repeated in the manner outlined in stage 2 above. Due to the overall relatively low proportions of fines in the samples, all phi soil mass proportions within the respective silt and clay components were combined for individual samples to give total silt and total clay components.

Logistical constraints only permitted the first ten rainfall events to be fully analysed by the above procedure. Thereafter the laboratory procedure was conducted only to the end of stage 1. Textural analysis of the samples removed from the footpath tread surface and the adjacent natural surface followed the procedure outlined in stages 1 and 2.

3.2 Footpath surveys

Although there is a generally followed technique for footpath attribute measurement at each survey point (eg. Bayfield, 1973; Garland *et al.*, 1985) no standard has been set for the spacing distance of a point-based survey. Spacing is dependent on local conditions (such as footpath length and consistency of footpath morphology) and on amount of available field time. Although different spacings have been utilised in previous research, ranging from 5 paces to 500m, a 100m interval has been the most common (Table 3.2).

Author(s)	Survey point spacing
Bayfield (1973)	5 or 10 paces
Bratton *et al.*(1979)	500m
Coleman (1981)	not specified
Garland *et al.* (1985)	100m
Bayfield (1987)	50 paces
Jubenville and O'Sullivan (1987)	100m
Lance *et al.* (1989)	100m

Table 3.2 Point spacing for previous footpath point-based survey research

Access was granted to a data base of footpath conditions observed in 1989 in Giant's Castle Game Reserve. These data were from a footpath survey conducted by the Natal Parks Board in which most of the footpaths in the Drakensberg were surveyed at a specified 100m point spacing (Thomson, *pers. commun.*). Although some of these data are utilised in this study the intention here is not purely an analysis of the Natal Parks Board survey. The approach undertaken here has been two fold. Firstly, a new survey of the footpaths was conducted in 1993 with the intention of establishing variations in footpath morphology (such as footpath depth) and relating these to localised environmental conditions (such as footpath gradient). The second component of the survey was a comparison of data from the two surveys which would enable a comparison of footpath morphology over a four year period from 1989 to 1993. Changes in morphology would then reflect footpath recovery or soil loss from the footpath. The techniques employed for both surveys are outlined in Sections 3.2.1 and 3.2.2. Subsequent comparisons of calculations of soil loss from footpaths with the soil loss data from the runoff plots enables the comparison of local, scale-specific process rate monitoring with a larger scale inductive approach to process study. The methodology for this procedure is outlined in Section 3.3.

3.2.1 Natal Parks Board footpath survey data base

The Natal Parks Board 1989 path survey was class-based with measured parameters for each survey site placed into predetermined classes on a pre-printed data sheet (Appendix I). Two examples of such classes have been extracted and are displayed in Table 3.3.

SITE NUMBER				
PATH WIDTH				
< 50 cm	0	0	0	0
50 - 75 cm	1	1	1	1
75 - 100 cm	2	2	2	2
> 100 cm	3	3	3	3
PATH SLOPE				
< 3°	0	0	0	0
3 - 6°	1	1	1	1
6 - 10°	3	3	3	3
> 10°	6	6	6	6

Table 3.3 Examples of the site attributes and footpath morphology attributes class rating in the Natal Parks Board Survey (extracted from the survey sheets, Appendix I)

A number of the measured attributes are subjective and the classification is thus open to interpretation by the surveyor. When assessing the survey results, problems were encountered with locating the precise starting points of the surveyed footpath sections which precluded point by point matching with the second survey conducted in 1993. The width and depth classification alone were thus extracted to enable general comparisons with data from the present study. In the present study some new parameters were measured and all exact results were noted. The survey procedure for the present study is outlined in the following section.

3.2.2 Footpath survey 1993

Four footpath sections totalling 21km of footpaths were surveyed in 1993. These included two sections of the contour paths (Bannerman Hut contour path and Ka-Langalibalele Pass contour path) and two approach paths which start in the vicinity of the main camp and direct hikers to the contour path (Bannerman Hut approach path and Giant's Ridge path) (A-D, Fig. 1.3).

All hikers are requested by Reserve Management to fill in forms at the Main Camp prior to proceeding on their hike. Although the overnight hikers tend to fill in the provided forms it has been observed that day hikers do not abide by this request. Back records of the register are not kept. The user-intensity of the footpaths could then not be established by this method. Footpath user-intensity for the four footpaths was monitored by use of automated pedestrian counters. These were installed on the footpaths in June 1994 (Fig. 1.3) and operated for a six week period after which two of the counters were vandalised.

The survey procedure was adapted from the procedure outlined in Bayfield (1973; 1987) and Garland *et al.* (1985). Survey-point spacing (100m) was measured with a trundle wheel. The first survey point for any footpath section was sited 5m beyond the footpath beacon or beyond the footpath intersection. At each site the following parameters were determined:

- footpath width
- footpath depth
- footpath gradient
- footpath downslope orientation (to magnetic north)
- cross-slope gradient
- cross-slope orientation (to magnetic north)
- vegetation type(s)
- soil type

In the event of the point lying within 1m of a water break the survey point was resited 3m back from the water break to avoid the influence of localised sedimentation. Footpath width was measured, and depth cross-sectioned at an interval of 50mm (Fig. 3.5). Where footpath width was in excess of 500mm the depth cross-section interval was increased to 100mm. Footpath gradient was recorded with an abney level across the survey point and downslope orientation was recorded with a Brunton compass. Similarly cross-slope gradient was recorded with an abney level on the upslope side of the footpath a distance of 3m from the edge of the footpath. Downslope cross-slope orientation was measured with a compass.

The dominant grass type was noted and other minor grass types, if present, were recorded. Soil form was identified and zoned for the footpaths sections. At 1000m intervals two soil samples were extracted from the centre of the path tread to a depth of 50mm with a small core sampler (Blake, 1973) to determine bulk density of the footpath tread.

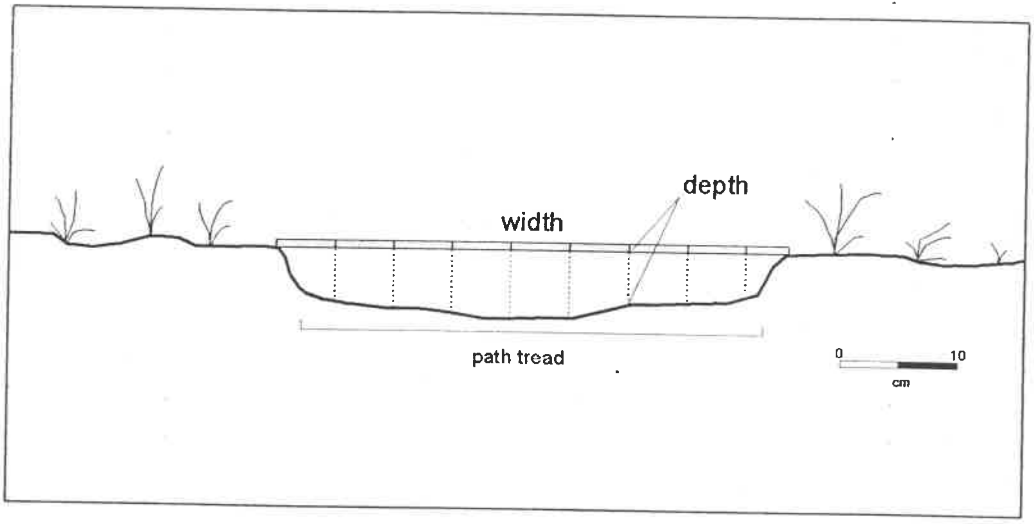


Figure 3.5 Path width and depth measurement

For short sections of some of the footpaths, secondary paths have developed running parallel to, and in close proximity to, the original (primary) footpath (Fig. 3.6). These are formed from hikers leaving the original footpath and walking next to it, often as a consequence of poor under-foot conditions. At survey sites where secondary footpaths were observed, the widths were recorded and depths profiled in the manner outlined above.

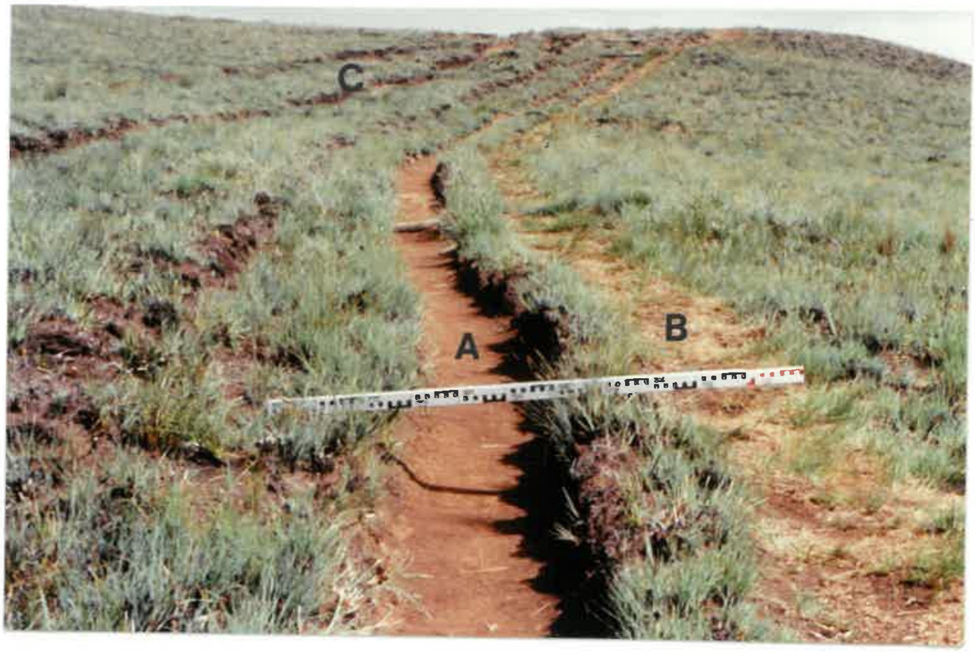
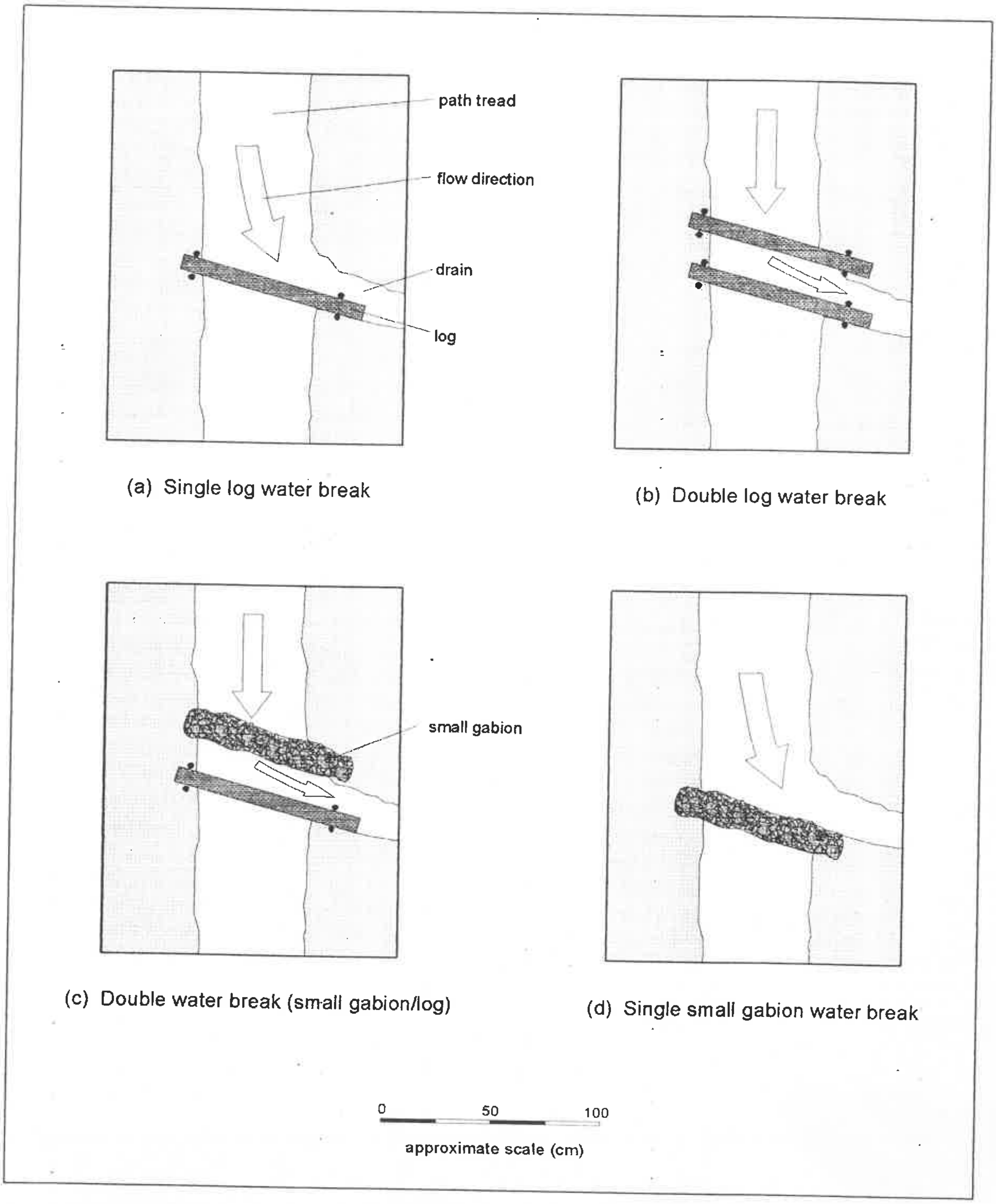


Figure 3.6 Multiple footpaths on the Bannerman Hut approach path
(A indicates the primary path with water breaks installed on it,
B indicates a newly forming secondary path and C indicates additional secondary paths)

All of the footpaths, with the exception of the Ka-Langalibalele route, had water breaks installed to divert the flow of water off the footpath. Four types of water breaks were identified. These were the single log, the double log, the log/gabion and the single gabion systems (Fig. 3.7 a-d). The objective of the drains is to divert the flow of water (and thus sediment) from the footpath. Where the footpath tread is below the adjacent surface a small drainage channel is constructed to facilitate water flow off the footpath. The number and type of water breaks between each survey site were recorded. The installation, function and maintenance of these water breaks will be discussed below.

3.3 Comparison of runoff plot results and survey results

A comparison of the two methods of assessing erosion rates would provide an indication of the applicability of the small scale process study to larger scale, yet less specific determinations (and *vice versa*) and allow for an evaluation of the merits of both monitoring systems. Problems of scaling up from experimental studies to larger systems arise from the initial conditions of the experimental design and unrealistic boundary conditions (eg. Parker and Schumm, 1982). Further difficulties arise with the extrapolation of the monitored rainfall events to long-term conditions.



(a) Single log water break

(b) Double log water break

(c) Double water break (small gabion/log)

(d) Single small gabion water break

Figure 3.7 Water break types used in Giant's Castle Game Reserve

A number of assumptions thus need to be made to enable such comparison. With respect to runoff plot design, particularly plot length, it is assumed that the plot length represents similar soil loss conditions on a corresponding length of open footpath. In terms of rainfall, only a portion of the rainfall events for the four year period were collected by the runoff plots. As such, the data collected from the plots cannot precisely reflect sediment yields over the four year period. In addition, although 60-minute intensity data were collected during runoff plot monitoring there was no rainfall intensity data available for that extended period. Thus rainfall intensities during the monitored period could not be placed in context of the four year period. An approach to contextualising the runoff plot rainfall data into the four year period by total rainfall amount and the calculations on conversion of the two scales to a similar unit for comparative purposes (tons/km/a) is outlined in Chapter 6.

4. Runoff plots and footpath survey results

Data presented in this Chapter are the results obtained from the fieldwork and laboratory procedures outlined in Chapter 3. Results of the runoff plot monitoring and from the path surveys are provided in Sections 4.1 and 4.2 respectively. The original laboratory and field data are too extensive to include in the dissertation, however condensed versions are provided in this chapter and in Appendix II and III. The interpretations and discussions of these results and comparisons with previous findings by other authors are presented in Chapters 5 and 6.

4.1 Runoff plots

4.1.1 User-intensity

User-intensity data obtained for the monitored footpath section during the period of runoff and sediment monitoring was interrupted by three failures of the pedestrian counter. This resulted in a loss of data during periods of the runoff plot monitoring (Table 4.1). The counter system operates on a cumulative total basis and all data are lost if the electrical current fails. Results from the automated counter (Table 4.1) show conversions for three periods to weekly averages. These data show that user-intensity has varied between 97 and 121 users per week for parts of the monitoring period. Persistent failure and vandalism of the counter prohibited further readings after 16/02/94.

4.1.2 Runoff and Sediment yield

The six runoff plots were numbered according to increasing gradient (Fig. 3.1 and Table 4.2). Sediment yield and runoff were collected for 22 rainfall days between 19/10/93 and 18/01/94.

Date	Recording period (days)	Counter reading	Average per week
19/10/93 - 03/11/93	14	193	97
04/11/93 - 20/11/93	16	failed	-
21/11/93 - 24/11/93	4	failed	-
25/11/93 - 21/12/93	27	468	121
22/12/93 - 23/01/94	33	failed	-
24/01/94 - 16/02/94	24	342	100

Table 4.1 User-intensity recorded for the pedestrian counter during the runoff plot monitoring period.

Overtopping of the sediment traps occurred on two rainfall days (19/11/93 and 17/01/94). These data are thus incomplete and therefore excluded from the totals for sediment yield and runoff. The yields and runoff quantities for the remaining 20 individual rainfall events are shown in Table 4.3. The totals are compared with the runoff plot gradients in Figures 4.1, 4.2 and 4.3. Particle size analysis was completed for the first ten rainfall events and results are outlined in Section 4.1.3 while rainfall characteristics are provided in Section 4.1.4.

Plot no.	1	2	3	4	5	6
Path gradient	1.83° (1° 50')	4.00° (4° 00')	6.75° (6° 45')	10.20° (10° 12')	14.50° (14° 30')	15.75° (15° 45')

Table 4.2 Footpath gradients within the runoff plots in Giant's Castle Game Reserve.

DATE	A						B					
plot no.	1	2	3	4	5	6	1	2	3	4	5	6
19/10/93	1284	623	791	972	2051	3556	37277	17949	15965	34579	17557	57192
20/10/93	11	6	2	15	17	15	2801	1955	2538	457	2784	2167
21/10/93	533	270	272	362	913	1560	27708	17670	19808	31608	26110	23878
26/10/93	30	36	97	90	260	102	16244	14640	13934	15010	15777	18171
11/11/93	137	79	53	76	419	797	76293	26238	34240	59117	108188	128266
18/11/93	232	107	62	76	192	286	11744	11949	9955	14842	15928	24074
26/11/93	28	11	23	21	56	63	6165	5615	4570	5501	6167	10277
28/11/93	4	3	4	4	4	52	6032	3215	4056	5972	7299	10237
29/11/93	84	22	37	23	191	231	8147	8851	6176	9645	8224	12208
03/12/93	3	4	5	0	24	73	11057	7516	7234	16083	16362	22417
08/12/93	269	160	258	250	487	512	23901	21779	19014	24485	25664	73327
10/12/93	2	1	1	0	7	3	1376	727	2046	1502	1841	2021
14/12/93	10	3	10	7	15	34	3372	2182	3319	3173	3719	6066
15/12/93	7	8	10	3	58	80	21532	14793	16251	32126	22638	41342
16/12/93	12	8	11	9	79	108	10692	6921	5412	4017	6196	10625
22/12/93	8	3	8	4	51	68	11064	11367	8173	13910	8173	13596
27/12/93	117	2	31	58	44	473	11825	8521	10068	4099	6179	23967
29/12/93	3	5	7	31	9	28	4758	5106	4825	8152	7639	10173
30/12/93	17	8	26	29	224	46	30705	21540	31321	32712	30836	32942
01/01/94	42	18	28	13	69	116	9786	10364	6192	10101	8228	10953
TOTAL	**2833**	**1375**	**1737**	**2041**	**5170**	**8202**	**332479**	**218896**	**225098**	**327090**	**345508**	**533899**

Table 4.2 Sediment yield (**A**, in grams) and runoff (**B**, in litres) for the six plots during the monitoring period.

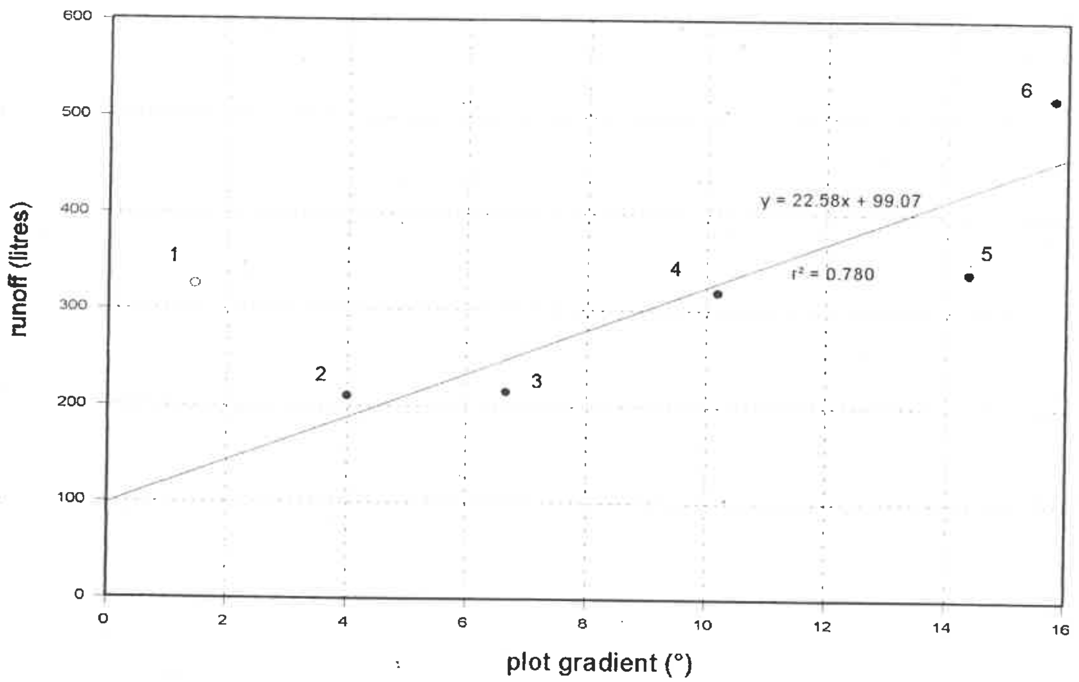


Figure 4.1 Total plot runoff in relation to plot gradient for the 1993/94 monitoring period.

Total runoff for the six plots shows a general increase in runoff with gradient (Fig. 4.1). Plot 1 (the lowest gradient plot with a gradient of 1.83°) displays the third highest total quantity of runoff for the monitoring period. This can in part be explained by the tread bulk densities and infiltration capacities of the runoff plots (Table 4.4).

Plot no.	1	2	3	4	5	6
Bulk density (g/cm^3)	1.66	1.49	1.45	1.42	1.49	1.44
Infiltration capacities (mm/hr)	231	458	523	459	518	460

Table 4.4 Tread bulk densities and infiltration capacities for the six runoff plots.

Mean bulk densities of runoff plots 2 to 6 vary between 1.42 and 1.49g/cm^3 (mean = 1.46g/cm^3) while plot 6 has a higher mean bulk density of 1.66g/cm^3. This indicates either a higher degree of compaction or different soil properties (eg. texture) for plot 1 in comparison to plots 2 to 6. Since compaction by visitor use should be consistent throughout the monitored section the difference in bulk density must be related to soil properties. Soil textures of the runoff plots are described in Section 4.1.3.

Differences in bulk densities and textures will result in different infiltration rates. Plot 1 has an infiltration capacity equal to approximately half that of the other 5 plots, which all have similar infiltration capacities (mean for plots 2 to 6 = 484 mm/hr with a standard deviation of 34 mm/hr). Plot 1 will be expected to generate higher quantities of runoff and hence greater flow velocities when compared with a hypothetical plot of the same gradient having a higher infiltration capacity. This will increase the potential for detachment and entrainment of soil particles.

In general the total runoff and total sediment yield for the plots increases with path gradient (Fig. 4.1 and 4.2). The total runoff quantities obtained for plots 2 to 6 show an increase in runoff with increasing gradient (Fig. 4.1). Linear regression of runoff against gradient for plots 2 to 6 gives an r^2 value of 0.780 which suggests that the relationship tends strongly towards being linear. The runoff generated from plot 1 is higher than the regression equation for plots 2 to 6 predicts, due to the lower infiltration capacity and the corresponding increases in runoff.

The exact nature of the increase in sediment yield with gradient (Fig 4.2) lends itself to one of two interpretations. Firstly, although sediment yield for the runoff plots show plot 1 to have the third highest yield there is a gradual increase for path gradients (2,3,4) and increasingly higher sediment yields for the higher gradient plots (5,6) (Fig 4.2). Some threshold between the gradients of plots 4 and 5 is apparent, after which sediment yield increases rapidly. The central point for the threshold is estimated by calculation of the intercept between lines drawn through 2,3,4 and 5,6. The intercept value is 13.36°. This calculation is not ideal due to the low number of points, however there is a strong correlation with a r^2 value of 0.987 for the three plots 2,3 and 4.

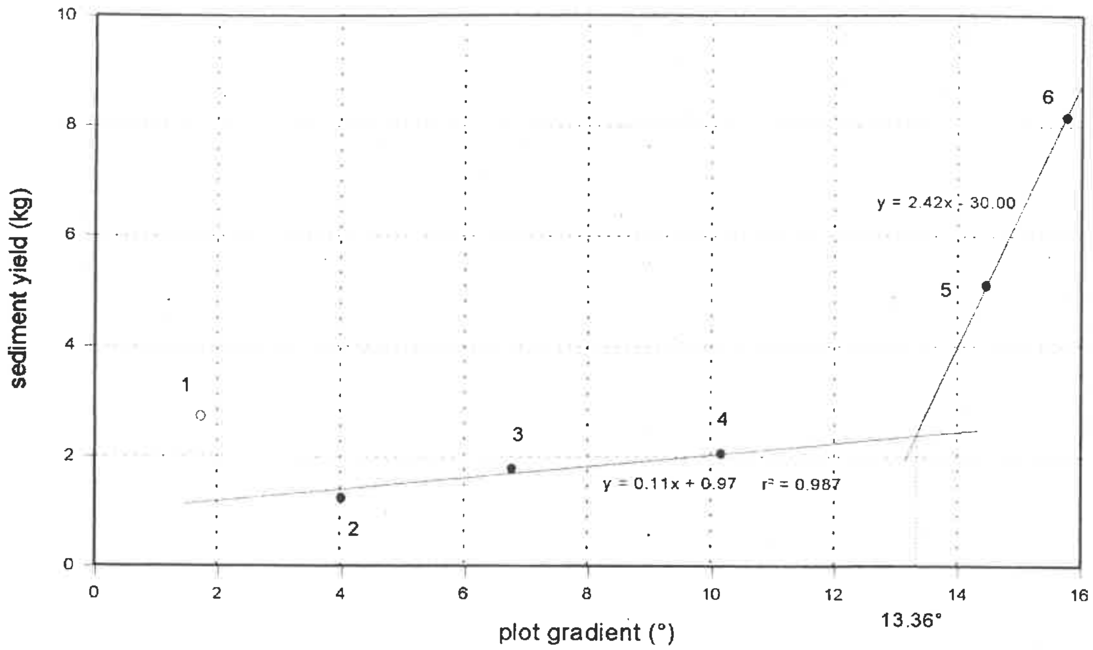


Figure 4.2 Plot sediment yield in relation to plot gradient.

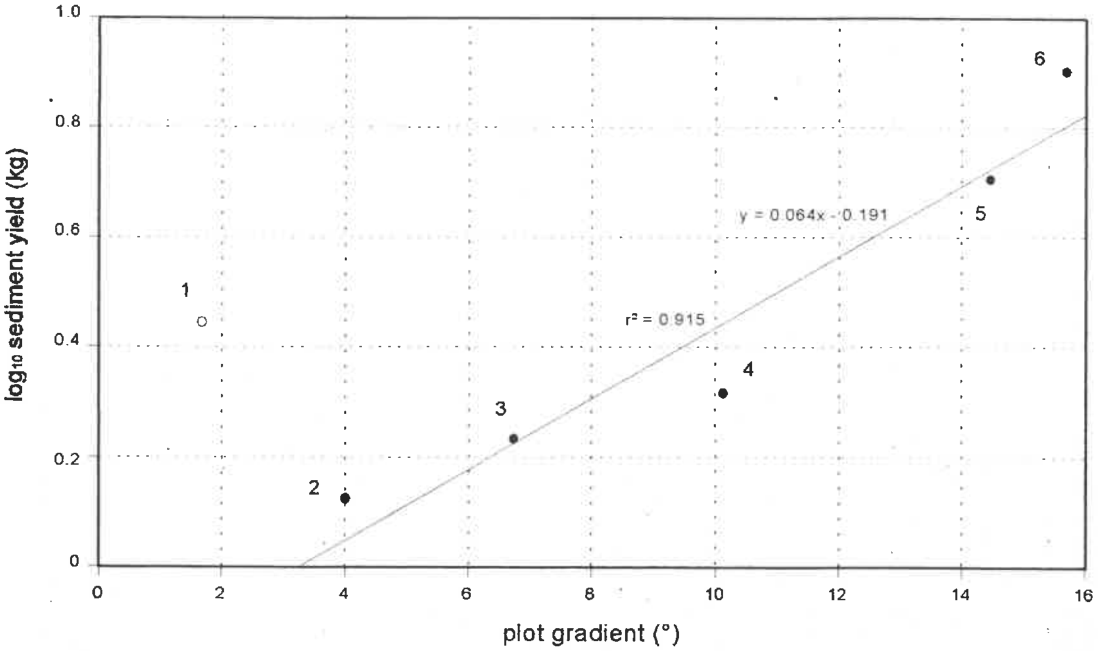


Figure 4.3 Log_{10} of runoff plot sediment yield in relation to plot gradient

The second interpretation of the total sediment yields is that the data represents an exponential relationship of sediment yield against plot gradient for plots 2-6 (Fig. 4.2). Linear regression of the $\log_{10}$ of sediment yield of the five points gives a r^2 value of 0.915, indicating a strong linear relationship (Fig. 4.3) while regression of the natural logarithm of sediment yield produces the same r^2 value. There does, however, still appear to be a curvi-linear relationship within the logarithmic relationship.

Figure 4.4 illustrates a comparison of total runoff and total sediment yield for the six plots. Linear regression of plots 2 to 6 gives a line of best fit with the equation:

$y = 0.00216x - 3.436$ with
$r^2 = 0.886$

Including plot 1 into the linear regression alters this to:

$y = 0.00216x - 3.581$ with
$r^2 = 0.868$

The two regressions have the same gradient for the line of best fit with similar y-intercepts and similar r^2 values. This suggests that although plot 1 has higher sediment yields and runoff quantities than the other plots, runoff-sediment yield relationships appear to conform to the relationships for the other 5 plots.

The nature of the sediment generated from within the runoff plots may provide insight into determining the process responsible for the erosion phenomena. Particle size characteristics for the runoff plots' sediment of the first 10 monitored rainfall days are outlined in the following section.

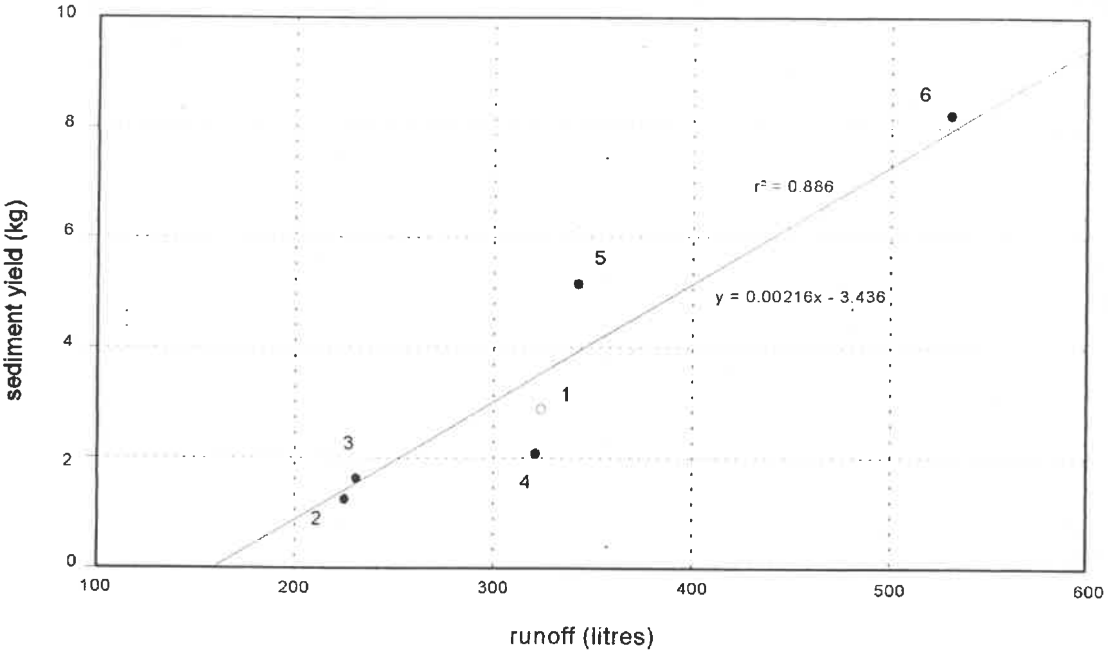


Figure 4.4 Total runoff in relation to total sediment yield for the six plots

4.1.3 Sediment particle size characteristics

Mean, skewness and sorting values are graphical measures used to describe a particle size distribution. They are obtained from the cumulative percentage graphs for particle size distribution. A summation of the skewness and sorting value classifications are provided in Table 4.5.

Skewness	Value	Sorting	Value
Very negatively skewed	-1.0 - -0.3	Very well sorted	< 0.35
Negatively skewed	-0.3 - -0.1	Well sorted	0.35 - 0.50
Symmetrical	-0.1 - 0.1	Moderately well sorted	0.50 - 0.70
Positively skewed	0.1 - 0.3	Moderately sorted	0.70 - 1.00
Very positively skewed	0.3 - 1.0	Poorly sorted	1.00 - 2.00
		Very poorly sorted	2.00 - 4.00
		Extremely poorly sorted	> 4.00

Table 4.5 Skewness and sorting classification for particle size distributions (after Briggs, 1977).

Particle size analysis of the A and B horizons for samples collected from the undisturbed surface adjacent to the footpath in the monitored section are shown in Figure 4.5. The A horizon is approximately 120mm thick and has an organic matter content of 3.5% which decreases to 0.2 % for the upper regions of the B horizon. Particle size distribution (texture) for the upper 280mm shows a similar mean phi value for both the A and B horizons, with a slight increase in coarser particles in the B horizon. Silt and particularly clay components are small, with a decrease in silt and clay fractions with depth. The clay fraction decreases from 2.0% in the A horizon to 1.1 % in the B horizon.

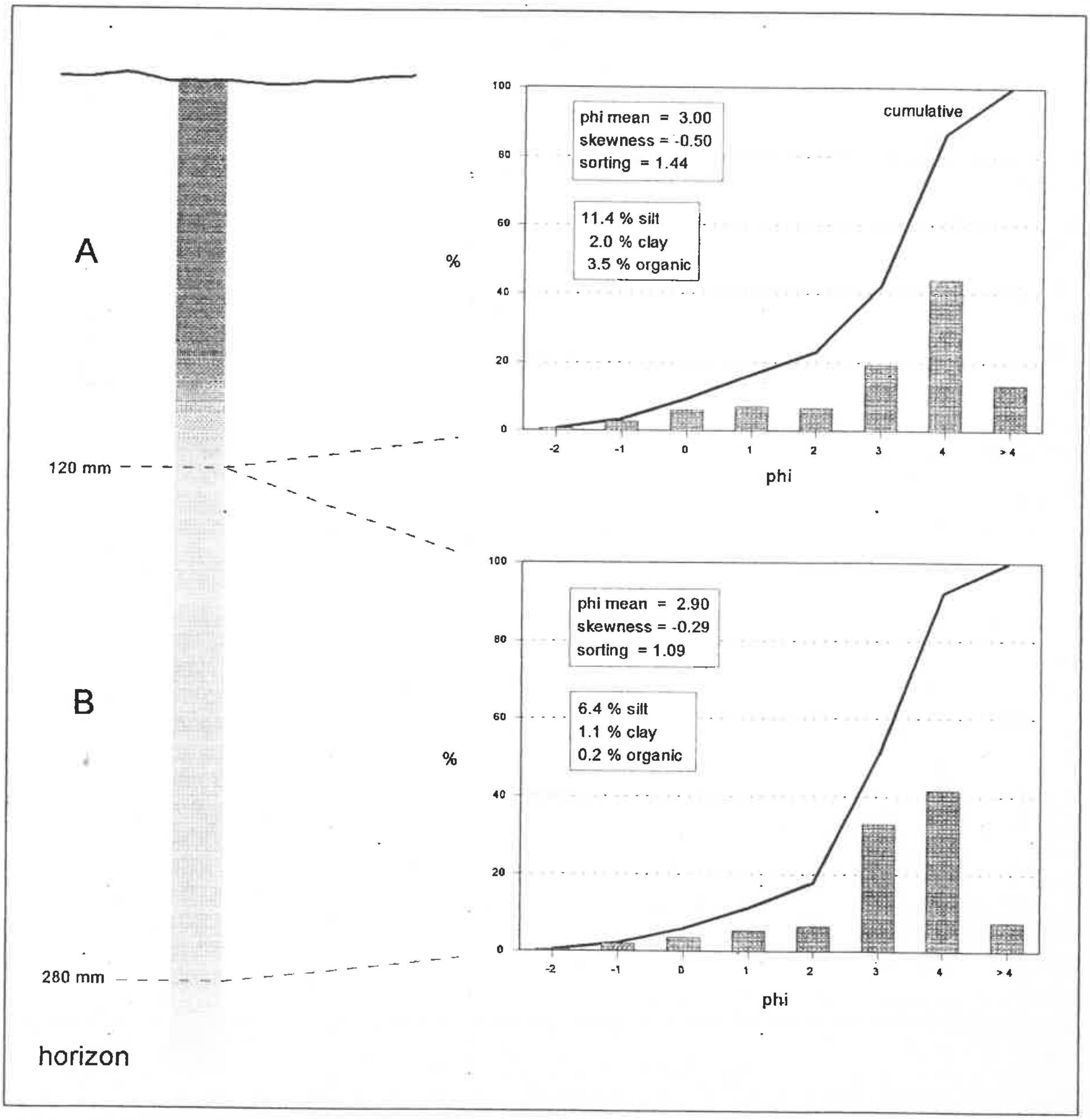
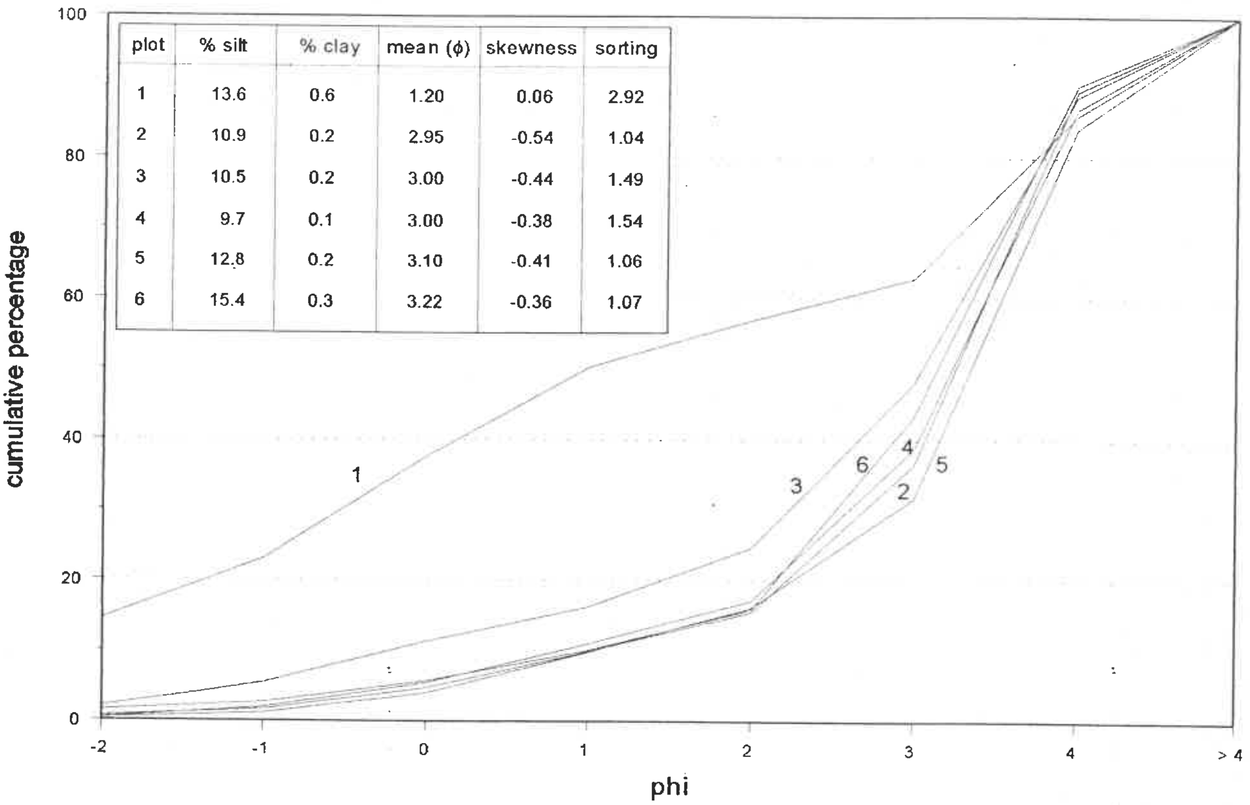


Figure 4.5 Particle size distribution of A and B horizons from the undisturbed surface adjacent to the footpath in the centre on the monitored section.



plot	% silt	% clay	mean (ϕ)	skewness	sorting
1	13.6	0.6	1.20	0.06	2.92
2	10.9	0.2	2.95	-0.54	1.04
3	10.5	0.2	3.00	-0.44	1.49
4	9.7	0.1	3.00	-0.38	1.54
5	12.8	0.2	3.10	-0.41	1.06
6	15.4	0.3	3.22	-0.36	1.07

Figure 4.6 Footpath tread particle size distributions for the runoff plots.

The particle size distributions of samples of the tread surfaces taken adjacent to each plot show the source material for the sediment generated from each plot (Fig. 4.6). Plot 1 has a distribution dissimilar to plots 2-6 with a greater component in the sand fraction. The clay values are, however, low for all the plots with clay proportions decreasing in relation to the adjacent undisturbed soil (Fig. 4.5). With the exception of plot 1 sorting and skewness values for adjacent and tread material are similar, displaying very negatively skewed and poorly sorted distributions.

Particle size distributions of the sediment obtained from the plots for the monitored period are provided in Figure 4.7 a-f. These show a fining of sediment in relation to the tread material for all runoff plots. The particle size distribution characteristics for the 6 runoff plots for individual rainfall days are provided in Appendix II. a-f. A summary of the mean values of these characteristics is shown in Table 4.6. This illustrates a shift in mean ϕ values for all plots towards the finer particle size range for the sediment in comparison to the path tread.

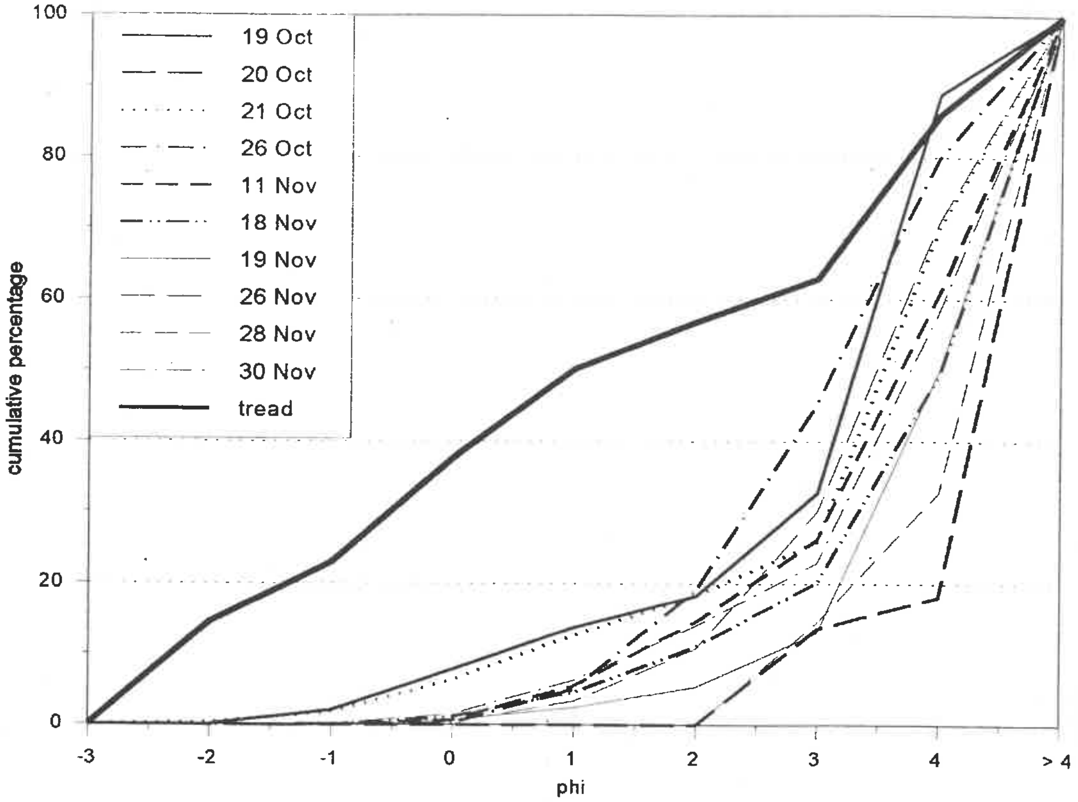


Figure 4.7a Runoff plot 1 footpath tread and sediment yield distributions.

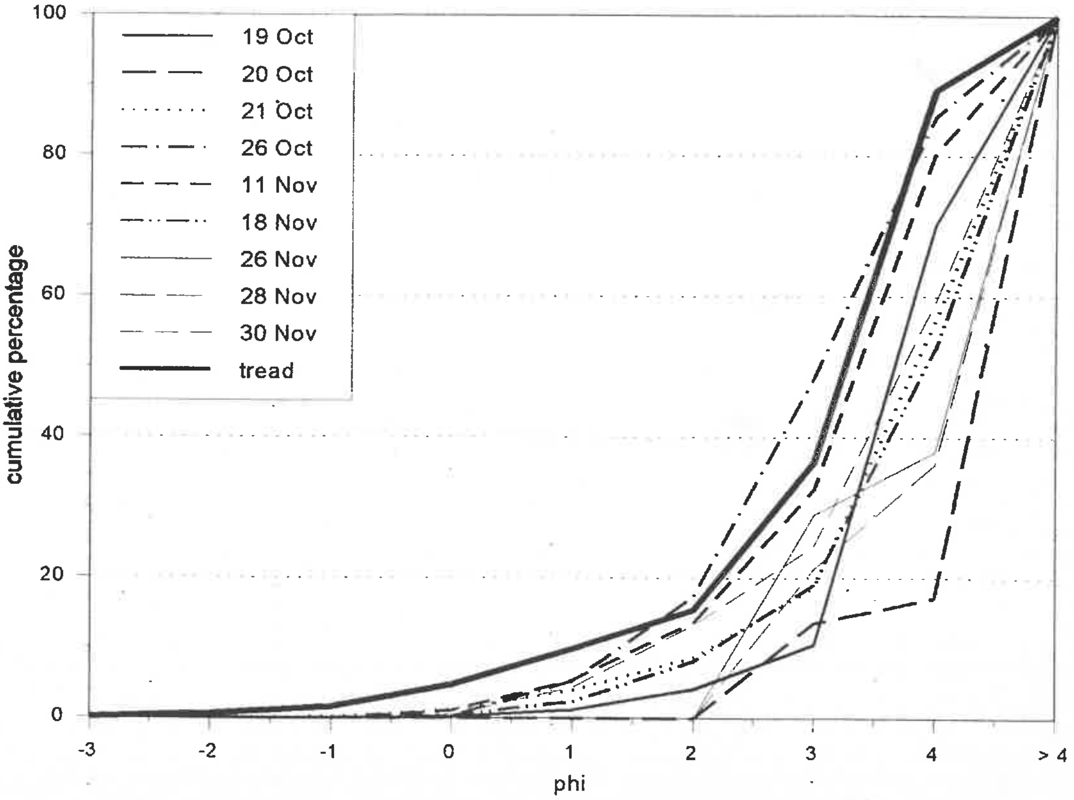


Figure 4.7b Runoff plot 2 footpath tread and sediment yield distributions.

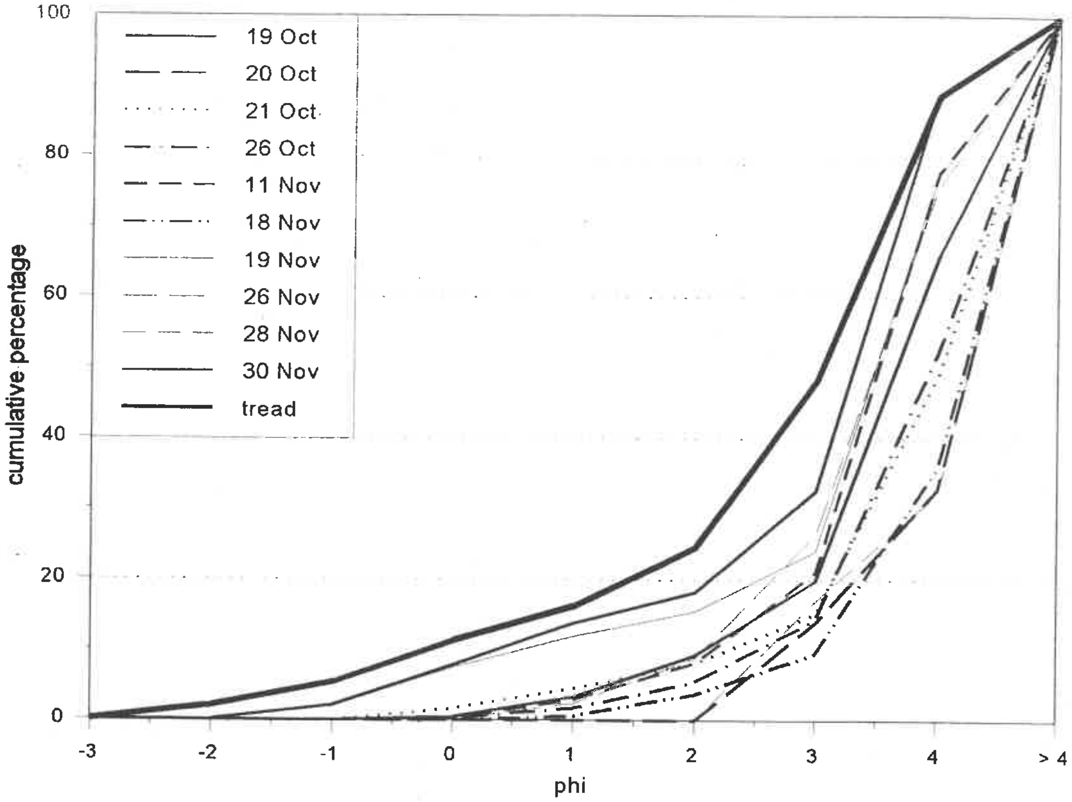


Figure 4.7c Runoff plot 3 footpath tread and sediment yield distributions.

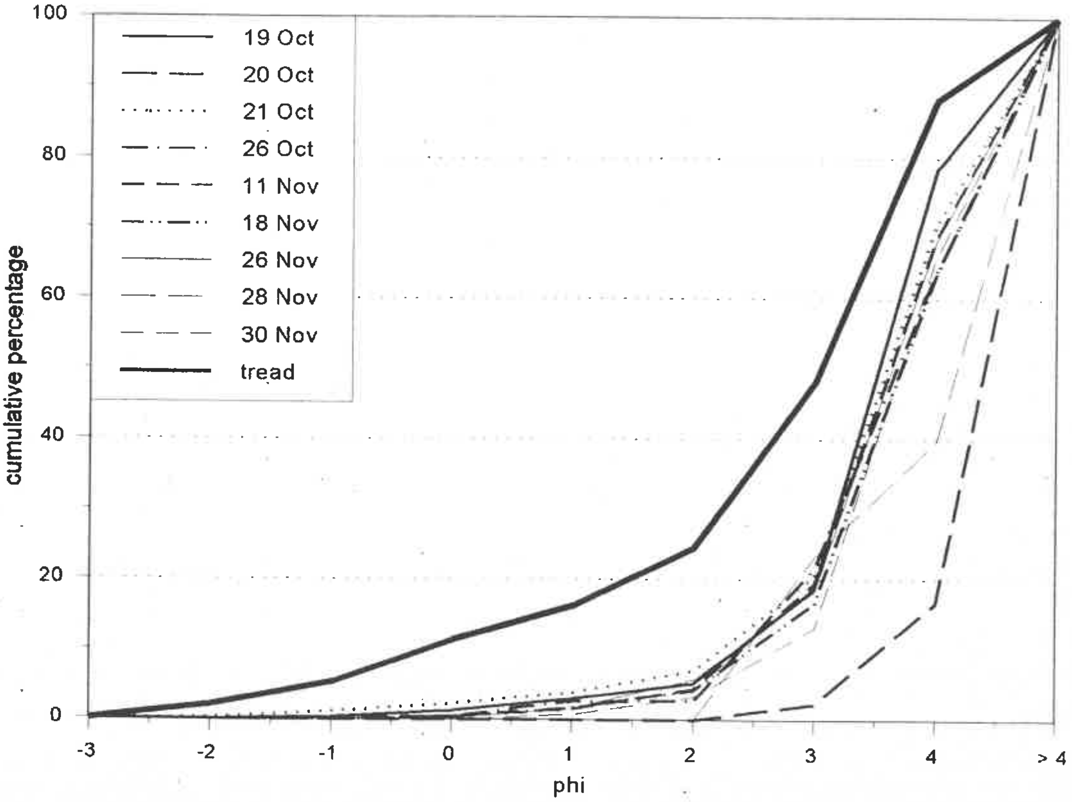


Figure 4.7d Runoff plot 4 footpath tread and sediment yield distributions.

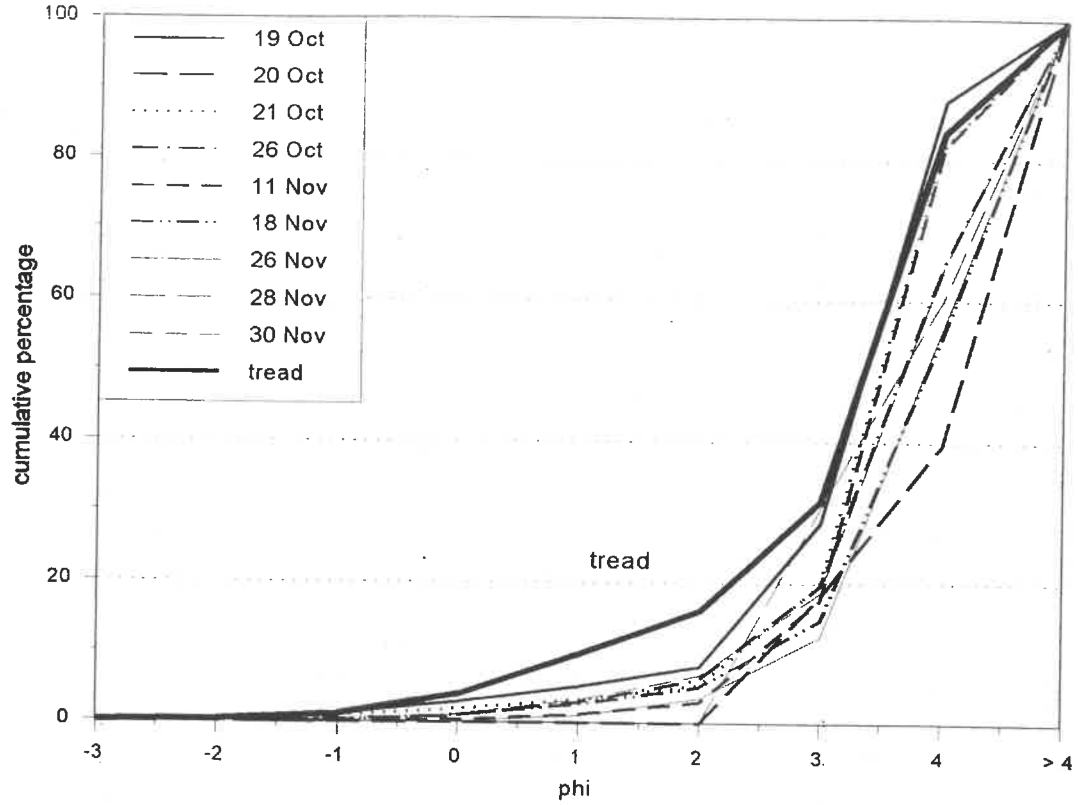


Figure 4.7e Runoff plot 5 footpath tread and sediment yield distributions.

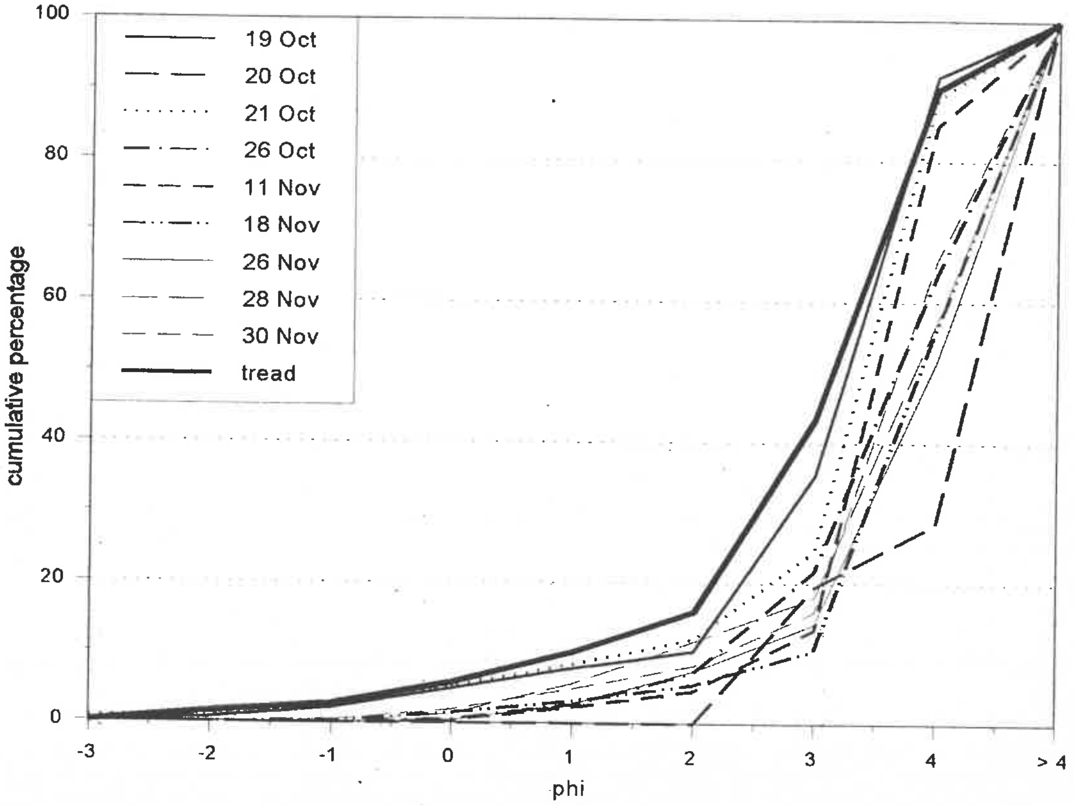


Figure 4.7f Runoff plot 6 footpath tread and sediment yield distributions.

The same pattern is reflected in the respective proportions in the sand, silt and clay components. The skewness values show a shift towards more symmetrical distributions for the sediment for all plots except plot 1. The sorting values show a shift from generally poorly sorted tread material to moderately sorted sediment. The organic matter contribution to the total sediment mass is negligible.

Plot	Source (mean)	% sand	% silt	% clay	% organic	mean (ϕ)	skewness	sorting
1	Sediment	57.5	32.8	9.6	0.1	3.69	-0.33	1.04
	Tread	86.2	13.6	0.6	0	1.2	0.06	2.92
2	Sediment	55.0	35.3	9.5	0.1	3.73	-0.35	0.87
	Tread	88.9	10.9	0.2	0	2.95	-0.54	1.04
3	Sediment	57.6	37.5	4.9	0.1	3.77	-0.29	0.86
	Tread	89.3	10.5	0.2	0	3.00	-0.44	1.49
4	Sediment	59.5	35.7	4.8	0.1	3.77	-0.1	0.82
	Tread	90.2	9.7	0.1	0	3.00	-0.38	1.54
5	Sediment	65.4	30.5	4.2	0	3.70	-0.15	0.84
	Tread	87.0	12.8	0.2	0	3.10	-0.41	1.06
6	Sediment	63.0	31.7	5.1	0	3.69	-0.21	0.84
	Tread	84.3	15.4	0.3	0	3.22	-0.36	1.07

Table 4.6 **Runoff plot total sediment and footpath tread particle size distribution characteristics.**

4.1.4 Rainfall monitoring

Total annual rainfall and the number of rainfall days for the hydrological years (April to March) 1986 to 1994 for Giant's Castle Game Reserve are summarised in Table 4.7. Total rainfall compares favourably to the mean annual rainfall for Giant's Castle Game Reserve, previously calculated by

Tyson *et al.* (1976) as 1038mm (see Section 2.4.1). The number of rainfall days recorded over the last eight years, however, shows an increase from 101 days (Tyson *et al.*, 1976) to a mean of 127 days.

Hydrological year	Total rainfall (mm)	No. raindays
1993/1994	1122	120
1992/1993	692	94
1991/1992	1042	122
1990/1991	1193	136
1989/1990	795	147
1988/1989	1144	143
1987/1988	1549	132
1986/1987	1070	125
mean	1076	127

Table 4.7 **Total rainfall and number of raindays for hydrological years 1986-1994 (April to March) at the Main Camp in Giant's Castle Game Reserve.**

Rainfall is important in that it can be used to correlate rainfall erosivity with quantities of runoff and soil loss. Various erosivity indices have been previously used to correlate rainfall characteristics for individual rainfall events with soil loss and runoff (eg. Ulsaker and Onstad, 1984; Salako *et al.* 1991). The approach adopted in this section is an investigation of the correlation of a variety of erosivity indices with runoff and sediment yield for individual rainfall events in order to determine which is the most appropriate for this environment.

Eight erosivity indices were selected for the study. The simplest index is the total amount of rainfall (A). Rainfall intensity was calculated as the maximum rainfall recorded in any 60 minute period (I_{60}). The square of the maximum 60 minute intensity (I_{60}^2) was also calculated as it has previously been correlated to soil loss (cf. Foster and Meyer, 1975 and Ulsaker and Onstad, 1984). Another single variable erosivity index used to estimate soil loss is the total kinetic energy (E) (Wischmeier and Smith, 1958). For the present study, however, the equation for kinetic energy used by Elwell and Stocking (1973) in Rhodesia (Zimbabwe) and Schulze (1978) in Natal is used, in which:

$$E = [29.82 - (127,51 / I)] \text{ J m}^{-2} \text{ mm}^{-1}$$

where the intensity is in mm/hr. It may be deduced then from the above equation that a threshold intensity of 4.28 mm/hr is assumed for rainfall energy to have any effect (Schulze, 1978).

A compound erosivity index produced from the combination of two or more single variable indices is often the best estimator for soil loss (Ulsaker and Onstad, 1984). Three compound parameters are used in this study namely, the product of total rainfall energy and maximum 60-minute intensity (EI_{60}), the product of total rainfall amount and maximum 60-minute intensity (AI_{60}) and the product of rainfall energy, maximum 60-minute intensity and amount ($EI_{60}A$). The last index is the quantity of runoff (RO).

Specific values for the various rainfall erosivity indices are provided in Appendix III. Relationships of the erosivity indices with sediment yield and runoff quantities were analysed using simple linear regression (Tables 4.8 and 4.9). The coefficient of determination (r^2), with a maximum value of 1 and a minimum value of 0, indicates the fraction of total variance that is explained by the linear relationship between the variables (Wonnacott and Wonnacott, 1972; Till, 1980). Coefficients of determination (r^2) for sediment yield are displayed in Table 4.8.

Plot	A	I_{60}	I_{60}^2	E	EI_{60}	AI_{60}	$EI_{60}A$	RO	mean
1	0.19	0.69	0.69	0.20	0.46	0.52	0.39	0.55	0.46
2	0.00	0.43	0.44	0.03	0.09	0.12	0.02	0.22	0.17
3	0.14	0.54	0.50	0.18	0.31	0.37	0.21	0.37	0.33
4	0.00	0.47	0.57	0.06	0.12	0.11	0.00	0.26	0.20
5	0.12	0.64	0.71	0.27	0.48	0.41	0.07	0.63	0.42
6	0.56	0.70	0.70	0.63	0.83	0.78	0.87	0.82	0.73
mean	0.17	0.58	0.60	0.23	0.38	0.38	0.26	0.47	

Table 4.8 **Coefficients of determination (r^2) for sediment yield and various erosivity indices.**

(A = amount of rainfall, I_{60} = maximum 60 minute intensity, I_{60}^2 = square of maximum sixty minute intensity, E = total kinetic energy, EI_{60} = product of E and I_{60}, $EI_{60}A$ = product of E, I_{60} and A, RO = runoff)

The strongest mean erosion index linear correlations are for the I_{60} and I_{60}^2 erosivity indices. Sixty percent of the variance of sediment yield can be explained by the I_{60}^2 factor. The weakest correlation was for the total amount of rainfall (17%). When the correlations are analysed for the respective plots, the steepest runoff plot (plot 6) has the strongest mean correlation for the eight factors (73%) and runoff plot 2 the weakest (17%). If plot 1 is excluded, the data then show a trend of increasing linear correlation with increasing plot gradient (Fig. 4.8).

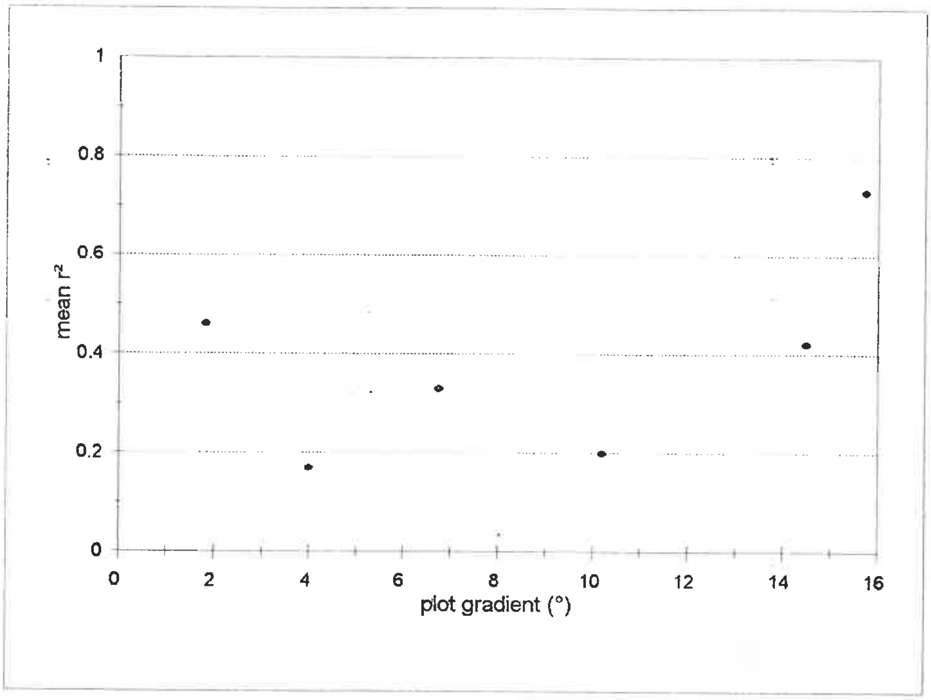


Figure 4.8 Mean r^2 values for erosivity indices (Table 4.8) and sediment yield in relation to runoff plot gradients.

Coefficients of determination (r^2) for runoff and erosivity indices are shown in Table 4.9. Mean values for the indices are all high relative to the sediment yield linear correlations. The lowest correlations (62%) are the total rainfall amount (A) and the maximum 60-minute intensity (I_{60}). The highest correlation (84%) is for the product of kinetic energy and maximum 60-minute intensity

(EI_{60}), with the $EI_{60}A$ index also showing a strong linear correlation (77%). No trend of mean correlation is evident for runoff and plot gradient.

Plot	A	I_{60}	I_{60}^2	E	EI_{60}	AI_{60}	$EI_{60}A$	mean
1	0.70	0.84	0.88	0.64	0.97	0.90	0.96	0.84
2	0.44	0.54	0.56	0.59	0.64	0.47	0.46	0.51
3	0.65	0.50	0.52	0.90	0.89	0.66	0.88	0.77
4	0.70	0.69	0.77	0.61	0.92	0.47	0.92	0.71
5	0.51	0.33	0.36	0.70	0.72	0.39	0.56	0.53
6	0.68	0.84	0.85	0.66	0.89	0.86	0.83	0.80
mean	0.62	0.62	0.66	0.68	0.84	0.68	0.77	

Table 4.9 **Coefficients of determination (r^2) for runoff and various erosivity indices.**

(A = amount of rainfall, I_{60} = maximum 60 minute intensity, I_{60}^2 = square of maximum 60 minute intensity, E = total kinetic energy, EI_{60} = product of E and I_{60}, $EI_{60}A$ = product of E, I_{60} and A)

4.2 Footpath surveys

4.2.1 Surveyed footpath descriptions

Four footpaths were surveyed in Giant's Castle Game Reserve in 1993 as outlined in Section 3.2. The Bannerman Hut approach path links the main camp to the contour path and is a route commonly used to get to Bannerman Hut (C, Fig 1.3, p.14). The footpath begins at the intersection with the World's View path near the bridge crossing the Bushman's River and lies predominantly on north-facing slopes with a total path length of 5691m. The Giant's Ridge path begins at the intersection with the Ka-Langalibalele path and ends at the contour path 2.3km from Giant's Hut (D, Fig 1.3). This path lies on alternating north-and south-facing slopes and is used to access

Giant's Hut, and less frequently Giant's Pass. It has a total length of 6422m. Both paths begin almost at river level, pass up initially over the Clarens Formation sandstone and continue mostly over the basalts up to ~2300m, occasionally passing over dolerite intrusions.

The two sections of the contour path that were surveyed in detail form part of the contour path which, in its entirety, extends north to the upper regions of the Injasuti River valley in the northern area of Giant's Castle Game Reserve, and south into Highmoor. The Bannerman Hut contour path is the section from the Bannerman Hut approach path intersection to the Bannerman Pass path intersection, with a path length of 4168m (B, Fig 1.3). It is used as an access to Bannerman Hut and/or Bannerman Pass. The Ka-Langalibalele contour path is from the Bannerman Hut approach path intersection to the Ka-Langalibalele pass path, with a length of 4605m (A, Fig 1.3). This path is used less frequently as a link between the two mountain huts. Typical hikes are from the Main Camp to either of the two huts. A less common hike is from the Main camp to Giant's Hut for the first overnight stop and then from Giant's Hut to Bannerman Hut for the second overnight stop. Return is then via the Bannerman Approach path. The journey may be taken in either direction. With hikers using this option the Bannerman Hut contour path will be traversed twice with the other paths traversed only once. The two sections of the contour path assessed here vary in altitude between 2200 and 2300m.

Simple statistical descriptions of the four path sections are provided in Table 4.10. The mean cross-sectional area provides a good indication of the overall extent of soil loss on a path section. It is derived from the product of the width and the mean depth for each survey site. Where secondary paths were recorded the cross-sectional areas were considered individually and not as a cumulative total for that survey site. The number of secondary path sites was taken as the proportion of the total number of sites for that path section. User-intensity is expressed as a proportion of the maximum user-intensity recorded for the surveyed paths, the Giant's Ridge path, which recorded 905 users over a two month period.

Table 4.10 indicates that the two contour path sections are different from each other in morphology and user-intensity, although similar in path gradient, orientation and cross-slope gradient. The number of survey sites where secondary footpaths were recorded differs considerably for the two contour paths. The Bannerman contour path section recorded 67% of the sites with secondary footpaths, whereas on the Ka-Langalibalele contour path section none were recorded. Cross-sectional areas for the secondary footpaths in total were calculated to be 2.7 times the mean cross-sectional area of the single footpaths. The cross-sectional areas of the approach paths, although similar to each another, only represent intermediate values for the four path sections. The two approach paths are predictably more orientated up the hillslopes than the two sections of the contour path as they direct hikers from the lower altitude of the Main Camp to the higher altitudes of the contour path.

Footpath attribute	Ka-Langalibalele pass contour path	Bannerman Hut contour path	Bannerman Hut approach path	Giants Ridge path
Length (m)	4705	4168	5691	6422
No. of survey points	46	41	55	65
Mean width (cm)	49	54	54	53
Mean maximum depth (cm)	11	14	12	13
Mean cross-sectional area (cm²)	510	651	601	586
Mean footpath gradient (°)	2.8	3.2	5.9	5.3
Mean cross-slope gradient (°)	13.9	12.7	11.9	12.3
No. of secondary path points (%)	0	67	34	29
Mean path - slope orientation (°)	72	70	54	46
User-intensity (per month)	90	190	367	453
User-intensity (% max)	20	42	81	100

Table 4.10 Footpath attributes as surveyed in 1993.

The number and type of water breaks (Fig. 3.7) recorded for the surveyed path sections are summarised in Table 4.11. The Ka-Langalibalele section of the contour path had no water breaks installed. Both of the two approach paths have a high proportion of double log water breaks with smaller proportions of single and gabion/log water breaks. The Bannerman Hut contour path was the only section which had any single gabion water breaks installed. The Bannerman Hut approach path has the shortest overall spacing at a mean distance of 12.4m between water-breaks while the Bannerman Hut section of the contour path had the widest mean spacing of 31.3m. In contrast to the two approach paths, the Bannerman Hut contour path had a majority of single logs in comparison to the other water break systems.

Water-breaks		Ka-Langalibalele pass contour path	Bannerman Hut contour path	Bannerman Hut approach path	Giant's Ridge path
Number of:	single log	0	105	65	41
	double log	0	8	393	309
	gabion / log	0	11	0	13
	gabion	0	9	0	0
Total		0	133	458	363
Mean spacing (m)		-	31.3	12.4	17.7

Table 4.11 Type, number and spacing of water-breaks on the surveyed footpaths.

In general the two approach paths (Bannerman Hut and Giant's Ridge) appear similar in all attributes, but differ from the two contour path sections, which in turn differ from each other. In contrast to assessing the mean footpath attributes a more detailed assessment of the controls on the footpath morphologies is afforded by an analysis of the variables measured at each survey site. This is outlined below under the broad structure of Coleman's (1981) model.

4.2.2 Forces of resistance

Resistance to erosion is governed by soil and vegetation characteristics. The footpaths lie predominantly within the subalpine vegetation belt (see Section 2.6, p.27). Grass types adjacent to the two approach paths (C and D, Fig. 1.3, p.14) are predominantly *Themeda trianda* in the regions below 1950-2000m. Above this a mixed grass type occurs comprising mostly *Themeda trianda* and *Festuca costata* with smaller quantities of *Diheteropogon filifolius, Harpocloa flax* and *Koeleria capensis*, within which the two sections of the contour path are located (A and B, Fig. 1.3). The soil type for short sections of the approach paths below the Clarens sandstone is of the Clovelly form. Above the sandstone the soil is predominantly of the Hutton form with short sections of the Mispah form where outcrops of basalt or dolerite occur. Where the contour path crosses streams, the Katspruit form may be recognised locally.

4.2.3 Recreational forces

User-intensity monitoring of the surveyed footpaths was discontinued after the initial 62 days due to vandalism of the monitoring system. This was related to the closing of Bannerman Hut for five weeks during this 62 day period due to repeated forced entry and vandalism. The implications of this are that the user-intensity data do not provide a fair reflection of the relative use of the paths, particularly the Bannerman Hut contour path. The figures for the Bannerman Hut approach path and for the Bannerman Hut contour path shown in Table 4.10 can thus be interpreted as minimum values, while the Giant's Ridge path and Ka-Langalibalele contour path are probably somewhat overinflated relative to the Bannerman Hut and Bannerman approach paths.

Compaction of the soil on a footpath is related to the intensity-of-use. Results from samples taken from the footpath tread surfaces for bulk density measurement are shown in Figure 4.9a and b. These display mean bulk densities taken at 1000m intervals along the path tread surface (see Section 3.2.2). Both approach paths show decreases in bulk densities from the beginning of the path near the Main Camp up to the contour path (Fig. 4.9a). Bannerman Hut approach path has overall higher bulk densities than Giant's Ridge path. The two sections of the contour path have lower mean tread bulk densities than the approach paths (Fig. 4.9b). Predictably, the Ka-Langalibalele contour path has the lowest mean, reflecting the lower user-intensity, with small changes in bulk density along the path. The Bannerman Hut path has a higher mean bulk density than the Ka-Langalibalele section of the contour path but has lower overall values than the approach paths. An unusual feature of the bulk densities of the Bannerman Hut contour path is the increase in bulk density towards Bannerman Hut.

Secondary (or multiple) footpaths (see Section 3.2.2), were evident on three of the path sections surveyed (Table 4.10). The mean cross-sectional area for the survey points which had secondary paths was calculated to be 2.79 times those survey points which had single paths, indicating a near three-fold increase in the total soil loss at specific sites. An important factor controlling the development of multiple paths appears to be the emergence of a narrow, deep primary path. Such a path makes walking uncomfortable, and allows vegetation to hang over into the path. Walking is then particularly uncomfortable when the grass is wet. Such a situation may encourage hikers to leave the path and walk next to it creating a second path. Width to maximum depth ratios for the

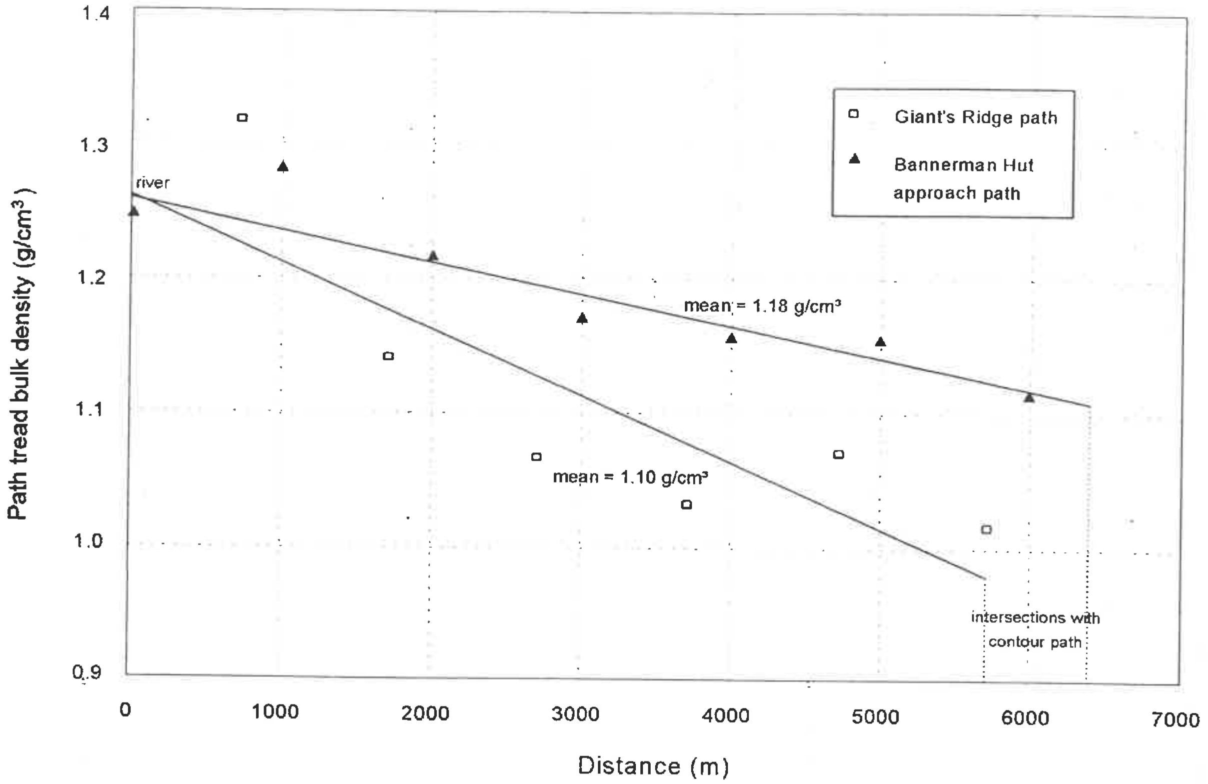


Figure 4.9a Path tread bulk densities for the Giant's Ridge path and the Bannerman Hut approach path.

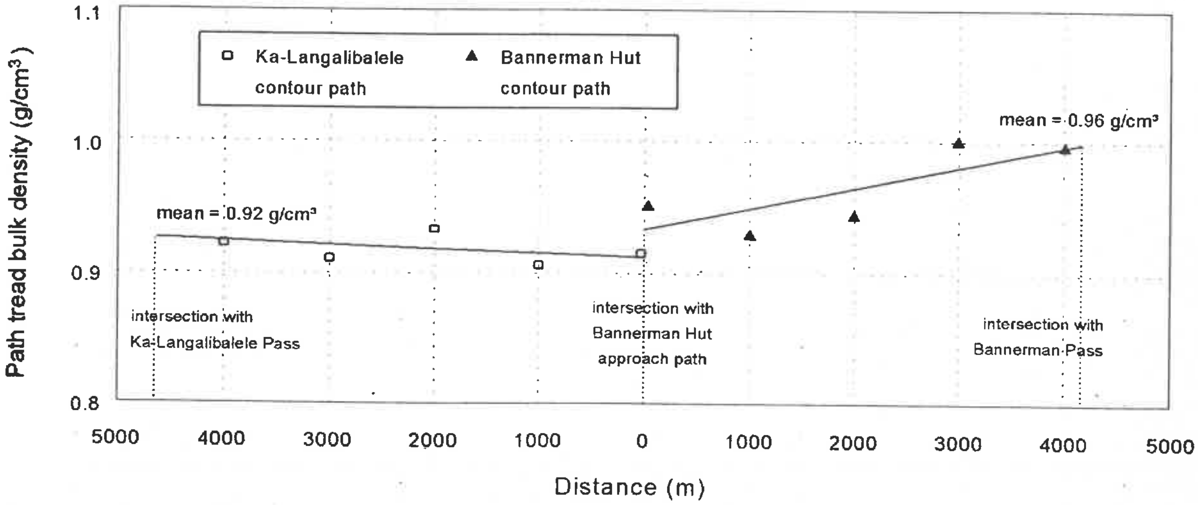


Figure 4.9b Path tread bulk densities for the Ka-Langalibalele and Bannerman Hut contour paths.

footpath cross-sections were calculated for each survey site and assigned into classes (Table 4.12).

Class	Width to maximum depth ratio	No. of single	No. of multi.	No. of multi.*	Class	Width to maximum depth ratio	No. of single	No. of multi.	No. of multi.*
1	0.00 - 0.50	0	0	0	*15*	7.01 - 7.50	6	1	0
2	0.51 - 1.00	0	0	0	*16*	7.51 - 8.00	4	2	1
3	1.01 - 1.50	0	2	2	*17*	8.01 - 8.50	2	0	0
4	1.51 - 2.00	2	11	11	*18*	8.51 - 9.00	6	0	0
5	2.01 - 2.50	11	5	5	*19*	9.01 - 9.50	4	0	0
6	2.51 - 3.00	11	13	13	*20*	9.51 - 10.00	1	0	0
7	3.01 - 3.50	15	9	9	*21*	10.01 - 10.50	1	0	0
8	3.51 - 4.00	14	4	4	*22*	10.51 - 11.00	2	0	0
9	4.01 - 4.50	16	7	7	*23*	11.01 - 11.50	0	0	0
10	4.51 - 5.00	10	1	0	*24*	11.51 - 12.00	0	0	0
11	5.01 - 5.50	11	0	0	*25*	12.01 - 12.50	0	0	0
12	5.51 - 6.00	12	1	0	*26*	12.51 - 13.00	2	0	0
13	6.01 - 6.50	10	2	1	*27*	13.01 - 13.50	0	0	0
14	6.51 - 7.00	5	1	0	*28*	13.50 - 14.00	2	0	0

Table 4.12 **Class intervals for path width to maximum depth ratios and number of observations for single paths and multiple paths in each class.**

(* indicates data excluding sites where rocky treads were recorded)

The number of observations in each class for survey points which had a single footpath and multiple footpaths are indicated in Figure 4.10. For survey sites where multiple footpaths were recorded, the lowest width to maximum depth ratio of the paths at the sites are included in the single footpath series.

A rocky tread provides a loose underfoot surface, making walking awkward or treacherous and increasing the potential for injury. This may encourage hikers to leave the main (primary) path and walk alongside it, creating a second path. The criteria for defining a rocky tread was set arbitrarily as the condition when the tread was too rocky to allow stepping between rocks onto the path surface. At six of the surveyed sites where multiple paths were recorded this situation arose. If these rocky tread occurrences are excluded from the data, a threshold for the existence of multiple paths is evident at class 9. This indicates that the probability of multiple path development increases below a width to maximum depth ratio of 4.50 (Fig. 4.11).

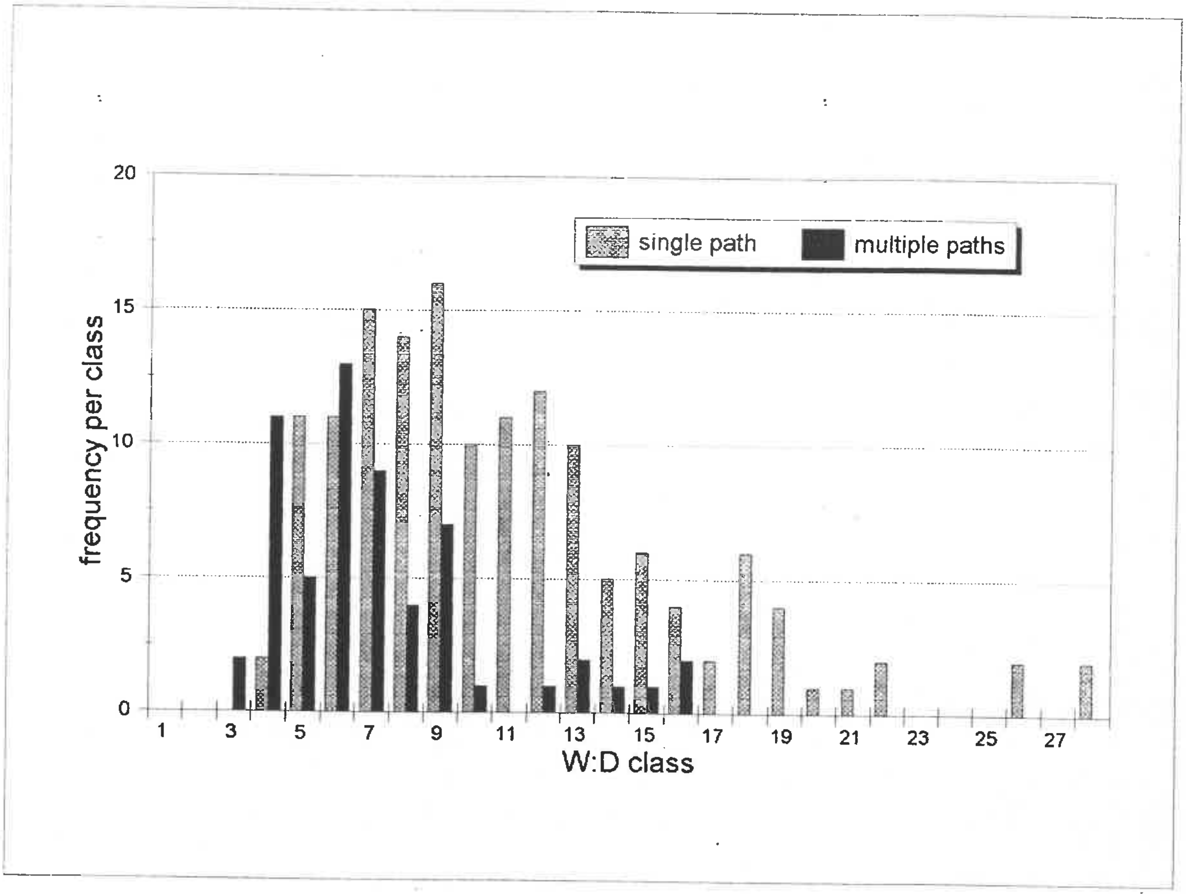


Figure 4.10 Occurrence frequency of width to maximum depth (W:D) class ratios for single and multiple footpaths (n = 206).

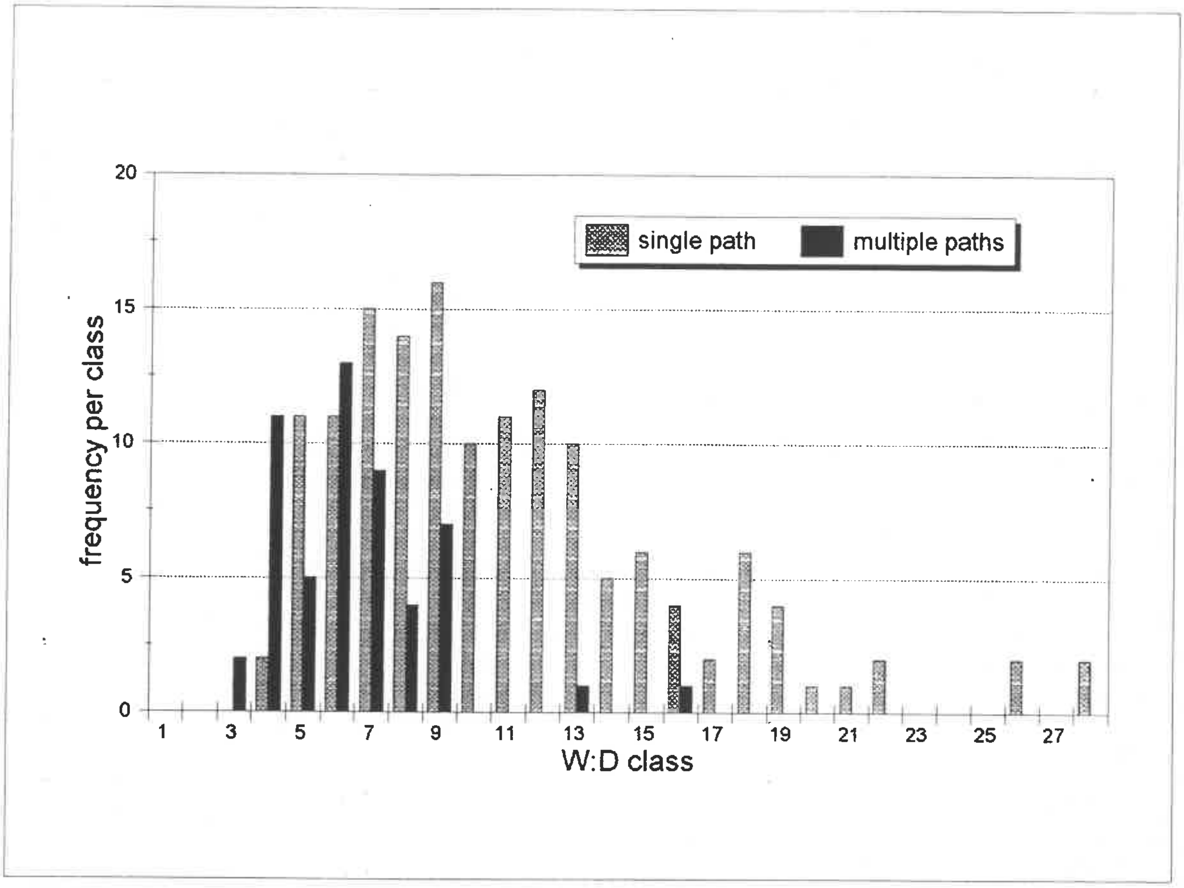


Figure 4.11 Occurrence frequency of width to maximum depth class ratios for single and multiple footpaths excluding rocky tread data (n = 200).

4.2.4 Geomorphological forces

Relationships between dependent variables (width, depth, cross-sectional area) and independent variables (cross-slope gradient, orientation and footpath gradient) were analysed using Pearson's Product Moment Correlation Coefficient (Klugh, 1970; Till, 1980) which has been used successfully in a similar application (Garland *et al.*, 1985). Correlation coefficients between variables for the four footpath sections are illustrated in Table 4.13 (all significant at least at the 95% limit).

Path Attributes	Ka-Langalibalele pass contour path	Bannerman Hut contour path	Bannerman Hut approach path	Giant's Ridge path
Width / depth	0.44	0.62	0.30	0.44
Path gradient / cross-slope gradient	0.15	0.02	0.34	0.42
Orientation / cross-sectional area	-0.04	-0.59	-0.06	0.28
Cross-slope gradient / cross-sectional area	0.14	0.01	0.07	0.46
Path gradient / cross-sectional area	0.13	0.25	0.41	0.50
Path gradient / width	0.10	0.06	0.34	0.42
Path gradient / depth	0.14	0.30	0.42	0.63

Table 4.13 **Product Moment Correlation Coefficients (r) for surveyed path attributes.**

Correlation values range between 0 and ±1.0. As a general rule, values for strong correlations are considered between ±1.0 and ±0.7, moderate correlations between ±0.7 and ±0.3 and weak correlations ranging between ±0.3 and 0 (Grau, *pers. commun.*). Table 4.13 indicates that all correlations are either moderate or weak. Notwithstanding this, comparisons of values provide insight into factors likely to influence the erosion process.

Correlations between path width and depth are moderate and range from relatively strong for the Bannerman Hut contour path (r = 0.62) to relatively weak for Bannerman Hut approach path (r = 0.30). Correlations between path gradient and cross-slope gradients are poor for the contour path sections but are somewhat stronger for the two approach paths.

The Giant's Ridge path is the only path where cross-slope gradient can explain some of the variation in cross-sectional area (r = 0.46). This path section has the lowest mean path - slope orientation (Table 4.10) indicating that the path is generally more orientated up the slope than the other path sections. The only path section in which there is a correlation between the path orientation and the cross-sectional area is the Bannerman Hut contour path (r = -0.59). The negative correlation indicates that as the path becomes more aligned with the orientation of the hillslope the cross-sectional area tends to increase.

Correlations between path gradient and path morphology (cross-sectional area, width and depth) are stronger for the approach paths than for the sections of the contour paths. For the two approach paths the correlation coefficients of path morphology and path gradient vary between 0.34 and 0.63. With the exception of the moderately strong correlation between width and depth the Ka-Langalibalele contour path section shows very poor overall correlations.

The implications of the above findings will be discussed in greater detail in Chapter 5. In Chapter 6 the Natal Parks Board 1989 survey results are compared to the 1993 survey results to determine soil loss from the footpaths over a four year period. Thereafter the soil loss from the runoff plots and that estimated from the surveys are compared.

5. Discussion

Discussion of the results outlined in the previous chapter is divided into two sections. In the first section (5.1) discussion deals with the runoff and sediment yield from the plots, soil particle size characteristics, rainfall characteristics and user-intensity. The second section (5.2) is a discussion of the footpath survey results. Initially an empirical description of the footpaths is provided, after which the discussion broadly follows the themes of Coleman's model of forces of resistance, recreational forces and geomorphological forces and their influence on footpath morphometry. Implications and proposals for management are introduced in this chapter although a more in-depth synopsis is provided in Chapter 7.

5.1 Runoff plots

5.1.1 User-intensity

Few data are available on user-intensities for footpaths in the Drakensberg. Garland (1988) suggests that a moderately-used footpath has a user-intensity of 60 persons per month. Data collected for this study from automated counters on footpaths in Giant's Castle Game Reserve indicate user-intensities up to 450 per month in the vicinity of the Main Camp and as low as 90 per month for a section of the contour path (Table 4.10). This suggests that for Giant's Castle Game Reserve an intensity of less than 90 per month would be considered a relatively low intensity-of-use.

The maximum user-intensity of 468 recorded over a 27 day period in the monitored section (Table 4.1) equates to over 500 users per month, corresponding to a period during the summer school holidays. The lowest intensity of 193 over a 14 day period, equates to approximately 400 users per month. Although the user-intensity data from the monitoring period was intermittent it can be concluded that the intensity-of-use of the monitored section containing the plots was generally high in comparison to the user-intensities recorded for the other footpaths in the Reserve. The failures of the counters also precluded any assessment of changes in sediment yield with user-intensity and generally it can be stated that the soil loss from the runoff plots is representative of a well-used footpath.

5.1.2 Runoff and sediment yield

The higher tread bulk density, infiltration capacity and different tread texture of runoff plot 1 sets it apart from plots 2 to 6. The different conditions within the plots are probably related to a difference in lithology underlying plot 1. The monitored section is located in the Clarens Formation sandstones, however a more detailed investigation of underlying bedrock which was exposed in an inspection pit dug adjacent to plot 1 revealed a layer of finer-grained sandstone similar to the subordinate lenses described by Du Toit (1954) and Eriksson (1983) (see Section 2.2, p.16). This change in lithology appears to have modified soil textural properties and bulk density in relation to the other five plots. On natural surfaces Hofmann and Ries (1991) found that, amongst other factors, soil bulk density was related to runoff. This and the corresponding decrease in infiltration capacity results in higher rates of runoff and greater potential for sediment removal by runoff.

Soil erodibility is related to soil texture, organic matter content, and permeability (Wischmeier *et al.*, 1971; Kirby and Mehuys, 1987). Due to the low organic matter contents of the tread surfaces, erodibility differences must arise from texture and permeability (or infiltration) differences. The other five plots show soil textural characteristics similar enough to allow comparisons between them. Although the actual process of soil erosion will generally be the same for all the plots discussion of quantities of runoff and rates of erosion plot 1 will be considered separately from the other five plots.

Total runoff quantities generated from the plots were found to increase with increasing footpath gradient (Fig. 4.1). Although the infiltration rates for plots 2 to 6 are similar, the higher footpath gradients produce greater quantities of runoff due to the increase in runoff velocities, and the relationship between runoff and gradient is linear for plots 2 to 6. Sandy topsoils and dominantly silty topsoils are prone to liquefaction as a result of raindrop impacts when water saturated. This provokes increasing pore water and pore air pressures (De Ploey, 1985). Liquefaction lowers the infiltration rate and runoff starts at a critical rainfall intensity which equals the infiltration capacity. Monti and Mackintosh (1979) measured infiltration capacities of less than 1mm/minute (60 mm/hr) in heavily used recreational areas; values considerably lower than those found in this study but which may be related to contrasting soil characteristics as illustrated in the differences between plot 1 and the other five plots.

One possible interpretation of the relationship between sediment yield and footpath gradient indicates a threshold value of 13.36° for footpath gradient, above which erosion rates increase rapidly (Fig. 4.2). Bryan (1977) recognised that gradient is of critical importance and although the concept of a critical angle for the onset of severe erosion was suggested, no such angle was determined. Coleman (1981), however, found a threshold gradient between 15° and 17° to distinguish active from stable paths in the English Lake District. This indicates that thresholds may well be recognised as an explanation of variations of erosion rate with gradient.

An alternative interpretation is that of a logarithmic relationship between sediment yield and gradient. This is strongly supported by regression of the logarithm (either $\log_{10}$ or $\log_e$) and sediment yield values against gradient, which produces a high correlation value of 0.915 as illustrated in Figure 4.3. Although some previous findings show the extent of erosion to increase linearly with path gradient (Bayfield, 1973; Dale and Weaver, 1974; Auerswald and Sinowski, 1989), Coleman (1981) interpreted extent of erosion as increasing with the square root of the slope gradient.

Both the above interpretations have value in describing changes in rates of erosion with gradient. For management purposes the first interpretation is the most practical, suggesting that gradients above an effective range of 10-13° need to be avoided. The second interpretation is, however, probably the more accurate reflection of the situation since it combines five values into one analysis, rather than the combination of three and two values for determining the threshold value in the first interpretation. Although gradient is obviously an important influence other factors may also contribute to the process and rate of erosion. These are discussed below.

Soil is eroded both as primary particles and as aggregates of primary particles (Nwadialo and Mbagwu, 1991). This process comprises two stages: detachment and transport by both raindrops and runoff (Ekwue, 1991). For footpaths, Bryan (1977) suggests that the onset of erosion is determined by the balance between flow velocity and soil resistance to detachment. The amount of soil detached by a single raindrop has been closely correlated to the shear strength of the soil (Cruse and Larson, 1977) which is in turn related to the degree of compaction. Compaction and disaggregation or shearing of the footpath tread by trampling are important modifiers of the natural erosivity of the soil. Compaction of the soil alters the hydrological conditions as well as the physical, chemical and microbiological processes occurring in it (Starodubova, 1985). Resistance of a soil to erosion increases with increasing compaction as a direct linear function (Lyle and Smerdon, 1965). Compaction of the soil should thus lead to an increase in the resistivity of the footpath tread to erosion relative to the adjacent natural surface. For net soil losses to exceed natural erosion rates the increase in soil resistance must therefore be negated by the scuffing influence of walking and the associated disaggregation, in combination with the increases in runoff generated from the footpath surface and runoff channelled from the adjacent natural surface.

The recreational effects of sediment generation are thus an important contributor to the erosion process. Although soil erosion by recreational influence has been reported in many studies (eg. Bayfield, 1973; Bryan, 1977; Coleman, 1977, 1981; Tinsley and Fish, 1985; Auerswald and Sinowski, 1989), few attempts have been made to understand the mechanics of the trampling process. The most wear of the footpath tread appears to result from soil deformation and smearing, related to the shearing forces associated with the action of the toe rather than the compaction forces associated with the heel during walking (Quinn *et al.*, 1980). With increasing slope steepness the shearing forces become more important while the compressive forces decrease (Quinn *et al.*, 1980). This phenomena would contribute to increasing sediment yields from the steeper footpath gradients where the shearing action of the foot has a greater impact on a steeper footpath, thus increasing the extent of disaggregation of the tread surface, while compaction has a greater influence on shallower gradients where soil resistivity will be increased.

Runoff generated from the plots shows a general linear increase with total quantity of soil loss (Fig. 4.4). The similarity between regression equations, both including and excluding plot 1, suggests that the runoff-sediment yield relationship for plot 1 is broadly similar to that of the other five plots. This indicates that the erosion processes operative are likely to be similar even though the actual rates of erosion differ considerably with respect to gradient.

Although Yair and Klein (1973) have cast doubt on the generally accepted assumption that runoff and erosion increase with increasing slope, findings in the present study confirm this generalisation for the erosion of footpaths. Further data, both long-term from these plots and from different environments, are required to confirm the type of relationships listed above and their spatial application. In addition, further knowledge on flow velocities and flow depths on footpaths will be important in the development of erosion models. Comparisons of the sediment yield data with other findings are discussed in Section 6.4.

5.1.3 Particle size characteristics

Erosion of the footpath in the monitored section has mostly removed the A horizon. As a result the footpath tread surface lies predominantly within the B horizon, up to a depth of 200mm in places. The decrease in the fines content of the path treads in comparison to the adjacent soil B horizon (Fig. 4.5 and 4.6) is reflected in the sediment particle size distribution characteristics which indicate a corresponding increase in the proportion of silt and clay components in comparison to the tread material (Fig 4.7a-f). Some mechanism of preferential removal of the fine particles from the tread surface is thus indicated. For practical purposes the term 'particle size' will hereafter include the contributions of aggregates unless otherwise stated.

Runoff plots 2-6 have very negatively skewed tread particle size distributions while the sediment generated from the plots shows a shift towards more symmetrical distributions, including greater percentages of silt and clay than the tread material (Table 4.5). The converse is evident for plot 1 where the tread of the plot has a symmetrical particle size distribution and the sediment is very negatively skewed. Although this difference between tread and sediment for plot 1 is apparent, the particle size distribution of the sediment is similar to that of the sediment of other plots. This is probably related to a similar process of detachment and entrainment of particles regardless of the difference in parent material. The sediment generated from the plots is moderately sorted in comparison to the generally poorly sorted tread material. Some degree of sorting of particles is expected due to the relationship between flow velocity and particle size as illustrated in the Hjulstrom curve (eg. Press and Siever, 1986).

As outlined in Chapter 1, no general relationship has been established between the eroded and the matrix soils obtained for runoff plots. Some further comments on particle selectivity are provided below. Proffitt *et al.* (1993) found the rainfall detachment process to be aselective with respect to sediment size under simulated conditions, although other findings show the size distributions to differ (Moss *et al.*, 1979; Alberts *et al.*, 1980; Poesen and Savat, 1980). In laboratory experiments Poesen and Savat (1980) indicate that sheetwash and rill flow selectively transport coarse grains more effectively. In contrast, on runoff plots of "eroded" and "uneroded" surfaces, Mbagwu (1988) found a preferential removal of finer particles (< 0.5mm) for the eroded plot and no change in distribution of the uneroded plot. Recent findings by Durnford and King (1993) indicate that the silt and clay discharges generally decreased with time due to the accumulation of sand on the soil surface. This armouring effect of the sand resulted in supply limitations to the silt and clay component under low-intensity rainfall events. Disruption of the soil by cultivation would reduce the effect.

Few studies have dealt with particle size characteristics on footpaths. Starodubova (1985) found a deficiency of "fine earth" on footpaths in the Crimean Mountains although further details of particle sizes are not provided. In Sweden, Bryan (1977) found selective entrainment of fine textural separates, leaving larger separates and resistant aggregates on the tread surface, which he suggested contributed to turbulence and enhanced erosional capacity. On runoff plots which incorporated footpaths located in the Drakensberg, Garland (1988) found an increase in the sand content of the plots at the expense of the finer materials. Garland maintains, however, that changes in particle size distribution could not be explained by preferential erosion and that relative decreases in clay content may be associated with a slower replacement by weathering than the coarser components. Their non-replacement in the short-term would result in relative decreases. Garland further states that the decline in clay and organic matter could not be sustainable in the long term and that at some stage the lower limits would be reached. If this were not the case the soil would eventually consist of mineral sand, which was not observed. It is thus likely that this situation existed within the runoff plots in the present study where, since this is a well established footpath, the tread is at the lower limits of clay and organic matter due to slow replacement rather than preferential erosion. As silt and clay is produced it is readily mobilised on the surface and entrained in runoff resulting in higher proportions of silt and clay in the sediment in relation to the tread.

The higher silt and clay components of the sediment in relation to the tread may further be attributed to the breakdown of aggregates by trampling and scuffing by the footpath users. This would "prepare" finer material on the footpath tread surface for transportation by runoff. The shearing effects attributable to pedestrians increases with slope (Quinn *et al* , 1980) and thus an increase in fines available for transportation may be expected with increasing gradient. This scuffing and shearing will also disrupt the surface and minimise the armouring effect of coarser material on the tread surface (cf. Durnford and King, 1993). Conversely, however, with the decrease in forces of compaction with increasing gradient (Quinn *et al.*, 1980), the extent of disaggregation of the tread surface may decrease and cause a decrease in the availability of fines for transportation on higher gradient footpaths. The difference between the particle size distributions of the sediment for different gradients in the runoff plots shown in Table 4.5 indicate only a small increase in the sand component of the sediment with increasing footpath gradient. This is attributed to increases in runoff velocities and discharge which facilitate the entrainment of larger particle sizes. To the knowledge of this author no data on this aspect of footpath erosion have been previously recorded in order to enable comparisons.

Previous findings show that significant positive correlations between total soil organic matter and aggregate stability against water forces exist generally for soil (Hafez, 1974; Chaney and Swift, 1984; Mbagwu and Piccolo, 1989). Further findings show organic matter to generally be positively related to the degree of soil detachment (Ekwue, 1991). The low organic matter contents of the footpath tread surfaces (see Section 4.1.3) indicates poor potential for amendment of aggregate stability and detachment and this may well contribute to overall greater potential for the removal of finer soil particles. Since no vegetation was growing on the footpath in the monitored section, where organic matter was recorded in the collected sediment this most likely originated from the adjacent surface and was washed onto the footpath.

Some caution on experimental procedure and possible influences on particle size characteristics needs to be noted here. The particle size distributions may not completely reflect the particle size distribution of the tread surface and the particles that are initially detached and entrained in runoff from the tread surface. Although the effect of transporting soil samples together with rainwater in bottles has been shown not to influence aggregate size distribution, provided wave motion was kept to a minimum (Cleary *et al.*, 1987), some concern must be expressed on sample collection and laboratory procedure. Generally, the main disruptive forces exerted on aggregates are caused by wetting of aggregates and on the intensity of drying. The lower the moisture content prior to wetting the larger the disruptive forces of differential swelling and escape of entrapped air. Combined with intense drying this can result in finer aggregate size distribution (Emerson and Grundy, 1954; Kemper and Rosenau, 1984; Semmel *et al.*, 1990). Aggregate breakdown may occur by wetting after initial detachment from the tread surface, possibly during transportation to the sediment trap or within the sediment trap prior to removal. Thus the initial aggregate size at the time of detachment and initial entrainment by rainfall and runoff may differ from that measured later. Further, analysis of runoff and sediment samples collected from the field may have been delayed up to two weeks before laboratory analysis could be undertaken. Such periods of submergence and saturation of sediment may have influenced the degree of aggregation of particles, particularly in the absence of the stabilising effect of organic matter (cf. Mbagwu and Piccolo, 1989). Changes to aggregate size distribution may also have incurred during the drying procedure. All samples were, however, treated in a similar manner and results have value at least on a comparative basis.

5.1.4 Rainfall erosivity

Correlation between rainfall parameters and both runoff and sediment yields are discussed below. Due to the scarcity of published data from runoff plots located on footpaths, these data are compared with results from previous research on rainfall indices obtained from natural surfaces and/or from research in agriculture unless otherwise stated.

The correlations between rainfall intensity and sediment yield for the runoff plots in this study, shown in Table. 4.8, correspond to findings by Wischmeier and Smith (1978) and Foster and Meyer (1975) for rainfall intensity and square of intensity respectively. This differs, however, from the findings of Ulsaker and Onstad (1984) who found poor correlations ($r^2 = 0.36$ and 0.49 respectively) at 30-minute durations. The weak correlation of rainfall amount and sediment yield in this study follows the findings of Wischmeier and Smith (1958), however, Ulsaker and Onstad (1984) found it to be one of the strongest indexes ($r^2 = 0.66$). Ulsaker and Onstad (1984) also found the total kinetic energy of the rainfall event to be a relatively good erosivity index ($r^2 = 0.64$). The relationships for rainfall energy related factors in this study were, however, weak. Both EI and AI indexes were found to be poor reflections of sediment yield, which differs from the findings of

Ulsaker and Onstad (1984) in Kenya and Lal (1976a, b) in western Nigeria. The EI_m ($m = 6$ min) was also used successfully as an erosivity index in southern Nigeria (Salako *et al.*, 1991). All relationships involving the energy of rainfall in this study were only derived from six rainfall events (Appendix III) due to the relative scarcity of rainfall events above 4mm/hr (see Section 4.1.4). This low number of variables may thus not effectively represent relationships between rainfall energy and sediment or runoff. All other indices were derived from the 15 rainfall events where rainfall interval data were available

Correlations of sediment yield with runoff as shown in Table 4.8 were also generally poor in this study, although previously found by Ulsaker and Onstad (1984) to be strong ($r^2 = 0.71$). The correlations with runoff are, however, stronger in the higher gradient plots ($r^2 = 0.63$ and 0.82 for plots 5 and 6 respectively) and may be related to higher velocities and greater quantities of runoff.

Hudson (1971) found a correlation coefficient of 0.94 for the KE > 25 index in Zimbabwe (formerly Rhodesia). This index, which is also used in the SLEMSA model (Elwell, 1981) could not be applied in this study since no rainfall events were measured at this intensity. This was not due to an absence of such intensity events but rather due to the length of recording interval which precluded the recording of short, high intensity events. The EI index, at 30-minute duration, has previously been shown to be applicable in southern Africa on a tentative basis (Smithen and Schulze, 1982). Data from footpath soil loss show the EI index (at 60-minute durations) to be applicable for runoff but not for soil loss.

In only one other study have rainfall characteristics been related to soil loss from footpaths. Under different treatments of vegetation burning Garland (1988) recorded low correlations for the EI index relative to the rainfall intensity, measured at 24-hour and 60-minute durations, and total rainfall. Garland's (1988) results for soil loss correspond to some degree with the results for this study where rainfall intensity was most strongly correlated to soil loss. The I_{60} and I_{60}^2 indices also show increases in correlations with increasing gradient for plots 2-6 while rainfall amount was poorly correlated to soil loss.

One of the major problems associated with determining relationships and with comparisons with previous findings is the difference in rainfall durations. Previous studies have considered maximum durations of 30 minutes and trends have been to decrease the durations below 30 minutes with increasing success (eg. Ulsaker and Onstad, 1984; Salako *et al.*, 1991). This may to some extent account for the dissimilar correlations in comparison to previous findings. The correlations for intensity are, however, much stronger than those of the other factors, suggesting that in this environment the sediment yields can be explained most successfully by rainfall intensity. The final finding of significance with sediment yield is the apparent overall increase in mean correlations of sediment yield and erosivity indices with increasing gradient. This may be related to the apparent increased potential for sediment entrainment in runoff from higher gradients. Such findings have, however, not been recorded in the literature to date.

Mean correlations for runoff and rainfall indices show strong correlations for all factors (Table. 4.9). The strongest correlation is for the EI_{60} index, with generally stronger correlations for the compound indexes than the single variable indices. The absence of a general trend for mean correlations and runoff plot gradient may be a result of the overall high correlation values. These types of relationships have not previously been documented for footpaths although Salako *et al.* (1991) computed correlations for field runoff plots. Their findings show strongest correlations for total rainfall amount and total kinetic energy, but all correlation values are lower than those found in this study. This may be related to the lower infiltration and faster generation of runoff from the compacted path treads.

5.2 Footpath surveys

5.2.1 General footpath descriptions

The highest and lowest mean cross-sectional areas for the four surveyed footpaths are for the two sections of the contour path: the Bannerman Hut and the Ka-Langalibalele sections (Table 4.10). The Bannerman Hut contour path has a 28% higher mean cross-sectional area than the Ka-Langalibalele section. These two sections are, however, continuous and have similar environmental settings (Fig. 1.3, p.14). The mean footpath orientations are virtually the same (72° for Ka-

Langalibalele and 70° for Bannerman Hut contour paths). Cross-slope gradients for the two contour path sections are similar (12.7° and 13.9°) with the higher mean cross-slope gradient recorded for the Ka-Langalibalele section. It is unlikely that the difference in mean footpath gradient for the two contour path sections (2.8° and 3.2° for the Ka-Langalibalele and Bannerman Hut paths respectively) will account for the difference in the mean cross-sectional areas.

More important in distinguishing between the extent of erosion of the two sections of the contour path is the user-intensity and the footpath history. Although the user-intensity of the Bannerman Hut contour section was recorded as more than twice the intensity of the Ka-Langalibalele section (Table 4.10) it is likely that the difference in intensities is even higher due to the closing of Bannerman Hut for five weeks during the two month monitoring period. A further consideration is that of the relative ages of the footpaths. The dates of construction of the Bannerman Hut paths are not known although the Ka-Langalibalele section was constructed, mostly by cut-and-fill, in the late 1960's and post-dates the Bannerman Hut paths (Meiklejohn, *pers. commun.*). In the early 1960's horses were used to transport material up the Bannerman approach path and along the contour path for the building of Bannerman Hut, which was completed in 1965 (Meiklejohn, *pers. commun.*). Horses are generally more damaging to vegetation and disruptive to soil than hikers (Weaver and Dale, 1978) and these previously higher user-intensities coupled with the relative ages of the footpaths may well account for the greater cross-sectional areas as well as the greater number of multiple footpaths, rather than conditions such as footpath gradients.

The two approach paths have intermediate values of cross-sectional area for the four surveyed footpaths (Table 4.10). All general attributes are similar for the two approach paths. The Bannerman approach path has a slightly higher mean overall path gradient than the Giant's Ridge path (5.9° and 5.3°) and mean cross-sectional areas of 601cm^2 and 586cm^2 respectively. This indicates that higher mean footpath gradients do not necessarily imply a greater extent of erosion since the Bannerman Hut contour path has a mean gradient of 3.2° and a mean cross-sectional area of 651 cm^2. The two approach paths have approximately one third of the survey sites where multiple paths were recorded. The highest number of multiple path sites was recorded for the Bannerman Hut contour path (67%) while none were recorded on the Ka-Langalibalele section. The number of multiple path sections appears to be a result of recreational forces and is generally controlled by hiker response to the path conditions. A further discussion pertaining to multiple footpaths is provided in Section 5.2.3.

The Giant's Ridge and Bannerman Hut approach paths have similar mean path-slope orientations of 46° and 54° respectively. These values can be expected to be lower than the corresponding values for the contour path since the approach paths generally direct hikers from lower altitudes near the Main Camp to the contour path, at higher altitudes. These footpaths should thus be more aligned to the hillslopes. The Giant's Ridge path recorded the highest present-day user-intensity, however the Bannerman Hut approach path may well have a higher intensity-of-use than recorded due to the closing of Bannerman Hut as outlined above. Both approach paths have similar mean cross-slope gradients, although up to 2° lower than the sections of the contour path. This difference can be attributed to the contour path being located nearer in altitude and position to the Main Escarpment, where gradients are generally steeper. The Bannerman Hut approach path is located on north-facing slopes while the Giant's ridge path alternates between north- and south-facing slopes, but lies predominantly on north-facing slopes.

The number, type and spacing of water breaks along the four footpaths shown in Table 4.11 indicates a similar trend to that of the footpath attributes described above. The two approach paths have a short mean separation of water breaks and have a high proportion of double water log systems. The Bannerman Hut contour path has a greater mean spacing and a higher proportion of single log systems, and some single gabion systems which are not present on the other footpaths. The Ka-Langalibalele section has no water breaks installed. It is probably the location of the two contour paths which has restricted both the number and type of water break installations. Due to the distance from Main Camp transportation of material is difficult. This would also account for the predominance of single water break systems on the contour path where breaks do occur. Although the gabion system uses local rock material this is not always readily available and the mesh wrapping still requires transportation to the site. In total very few of the gabion-type structures have been installed.

The relationship between water break type and frequency and the extent of footpath erosion is not clear. The Ka-Langalibalele contour path section, which has no breaks installed, has a cross-sectional area which is 85% of that of the Bannerman Hut approach path (which has the highest frequency of water breaks). In contrast the Bannerman Hut contour path has an 8% greater cross-sectional area than the corresponding approach path, yet has a greater water break spacing. This indicates that the water break spacing alone cannot explain the mean variations in cross-sectional area and some interaction must exist between the water break structures, user-intensity and the geomorphological forces operative at the break site.

The most significant consideration with respect to the water breaks is that no research has as yet been conducted on the efficiency of the systems, the optimum installation attitude and spacing, and the maintenance of the structures. Little *et al.* (1977) is frequently quoted by Natal Parks Board staff as a guide for footpath construction and installation of water breaks. This text, however, quotes no basis for scientific argument. As a consequence it may well be possible that water breaks, if installed incorrectly, or at the incorrect spacing are enhancing erosion by causing greater turbulence on the footpath tread, particularly if overtopping occurs. Further, the breaks are removing both runoff and sediment from the footpaths. The runoff plots described above indicate that runoff on footpaths has the potential to entrain particles over less than a three metre distance. This questions the desirability of removing the sediment from the footpath and may suggest that retaining the sediment on the footpath may be a more successful technique in slowing the rate of overall soil removal from the footpath tread. The converse is that greater quantities of runoff will be generated if no breaks are installed. The understanding of the dynamics of water breaks is a separate study within the field of footpath erosion and the scope of the present research precludes further investigation of the topic at this point.

A more detailed examination of the footpath sections is provided in the following sections by the analysis of the variables measured at each site in relation to footpath morphology.

5.2.2 Forces of Resistance

The resistance to footpath erosion is governed primarily by vegetation and soil characteristics (Bryan, 1977; Coleman, 1981; Garland, 1990). The majority of the footpaths in the Drakensberg are well established, have bare tread surfaces and are well defined, preventing walkers from straying from the bare tread. Thus the influence of vegetation to resisting erosion is restricted to stabilisation of the sides of the footpaths and to the banks adjacent to footpaths where cut-and-fill construction techniques have been employed.

The grass type *Themeda trianda* predominates adjacent to the approach paths while a mixed grass type is found adjacent to the contour paths. Variations in mean cross-sectional area for the four surveyed path sections indicate that the contour paths sections have both the highest and the lowest cross-sectional areas, while the approach paths have intermediate values (Table 4.10). This suggests that variations in vegetation types cannot explain variations in the condition of the paths and although some overall change in resistance from predominantly *Themeda trianda* to a mixed grass type may be present, it could not be established. Such a situation is similar to that found by Jubenville and O'Sullivan (1987) in Alaska where vegetation type explained very little of the variance in soil loss.

Due to the almost complete absence of vegetation on the footpaths in the study area, resistance to erosion is governed primarily by soil characteristics, a situation similar to that described by Bryan (1977) for footpaths with bare tread surfaces. Based on differences in infiltration rates and lower potentials for runoff from different lithologies (Schulze, 1979), Garland (1990) regarded lithology as a suitable substitute for soil erodibility. The two sections of the contour path overlie basalt. The same applies for the two approach paths which have short sections below the Clarens Formation sandstone near the Main Camp and then overlie basalt. Thus, as with vegetation type, overall changes in mean cross-sectional area cannot be explained by soil type/lithology differences.

Some further comments on soil erodibility are appropriate here. Stoniness can be a control on erosion in general (Bunte and Poesen, 1994) and also for erosion on footpaths (Coleman, 1981). Although footpaths in this area of the Drakensberg can be stony near river and stream crossings, or where crossing bedrock outcrops, the majority of the footpaths are generally comprised of compacted B horizons. The influence of stoniness is thus localised and generally considered as a minor influence. Further, due to the tread surfaces being devoid of vegetation, even on the relatively low-use Ka-Langalibalele Pass contour path, the influence of organic matter on aggregate stability and on decreasing the degree of compaction are minimised.

Although quantification of the resistance to erosion is not achieved in absolute terms, it appears that vegetation and soil changes generally cannot explain variations in mean footpath morphometry and that the resistance to erosion can be considered as equivalent for the four footpath sections. Under the structure of Coleman's (1981) model, changes in morphology of the footpath must therefore be related to changes in the recreational and geomorphological forces.

5.2.3 Recreational forces

The impact of pedestrians on the path surface (tread) is two-fold. Firstly, it causes compaction of the soil (Quinn *et al.*, 1980) which is indicated by a lowering of the tread surface in relation to the adjacent natural surface. This compaction may decrease porosity to such an extent that the paths become practically impermeable, favouring runoff (Bryan, 1977; Starodubova, 1985). Secondly, it causes soil deformation and smearing or shearing of the soil (Quinn *et al.*, 1980). This may result in truncation of the soil horizons by water erosion (eg. Bryan, 1977). The relative importance of compaction and truncation by erosion on footpaths has not yet been fully investigated although Bryan (1977) found that soil truncation (independent of compaction) is related to intensity-of-use. Soil core samples taken from approach paths in the vicinity of the Main Camp indicate that compaction may account for as much as 20% of the cross-sectional area of a footpath on a path gradient less than 5°. The relative contribution of compaction and truncation to footpath morphology, however, requires further investigation and is considered beyond the scope of this study.

A further influence of trampling is the effect on aggregate size distributions. When pressure is exerted on soil, aggregation increases up to a threshold which is dependent on soil shear strength. Thereafter aggregation declines and drops close to zero. The decline in aggregation will increase soil erodibility with a tendency for the disaggregated particles to be removed (Bryan, 1977). Further findings by Bryan (1977) show that once vegetation is removed and soil becomes compacted by trampling a low user-intensity may maintain the path. Once vegetation damage has occurred, erosion can proceed with little human intervention and damage is cumulative from year to year if the vegetation is not allowed to recuperate, even under low user-intensity conditions.

Other research has shown relationships to exist between path use and path morphology (Dale and Weaver, 1974; Weaver and Dale, 1978; Coleman, 1981; Tinsley and Fish, 1985; Auerswald and Sinowski, 1989) as summarised in Section 1.2.2 (p.8). On the basis of the underestimation of user-intensity of the surveyed footpaths during the monitored period, discussed above, the present user-intensity will to some degree account for differences in mean cross-sectional areas between the path sections. Table 4.10 indicates that the Ka-Langalibalele Pass contour path section has the lowest mean cross-sectional area with the lowest user-intensity and it is unlikely that the relative intensity-of-use would have altered considerably had Bannerman Hut not been closed. With anticipated increases in the user-intensity for the Bannerman Hut approach path and contour path section during periods when the hut is open, and considering previous peak use periods such as during the building of the hut, it is concluded that intensity-of-use has an influence on path morphology. Without more accurate user-intensity data no further relationships can, however, be established.

Compaction of a soil by pedestrians increases the soil bulk density. The bulk density of a footpath initially has a linear positive correlation with user-intensity but is likely to reach a level beyond which further compaction does not take place (Liddle, 1975). Jusoff (1989) found bulk densities to increase from 0.99 g/cm^3 to 1.28 g/cm^3 for the first 15cm in 'recreation-used' areas. On a footpath compaction increases towards the centre of the tread surface (Ward and Berg, 1973; Starodubova, 1985). Starodubova (1985) found the bulk densities of tread surface to vary according to user-intensity and season of the year. Starodubova (1985) found the 0-5cm layer had bulk densities up to 2.2 g/cm^3, with a corresponding decrease in porosity of up to 20%. For every 0.1 g/cm^3 increase in bulk density the soil porosity was found to decrease by an average of 3%. In camping sites in the Colorado Rocky Mountains the compaction effect of visitor use was most pronounced to a depth of 5cm of soil at lightly and moderately used sites and up to 12.5cm at heavily used sites (Dotzenko *et al.*, 1967).

Bulk densities for the tread centre of the surveyed footpath sections range between 0.91 g/cm^3 and 1.32 g/cm^3 (Fig 4.9a, b). Bulk densities for the two approach paths are generally higher than those for the contour path sections. A general decrease in bulk densities is evident from the start of the approach paths towards the contour paths. This indicates that the intensity-of-use decreases away from the start of the footpaths, probably as a result of day hikers turning back when tired or short of time. The Bannerman Hut approach path has overall higher bulk densities than the other three footpaths which again indicates that the user-intensity recorded underestimates the intensity-of-use of the Bannerman footpaths.

The Ka-Langalibalele Pass contour path section has the lowest mean tread bulk density. This is predictable considering the lower user-intensity. The higher bulk density of the Bannerman Hut contour path section, but lower overall values than the approach paths, again relates to differences in user-intensity. The unusual feature of the bulk density variation for the Bannerman Hut contour path, the increase in bulk density towards Bannerman Hut from the intersection with the approach path, is probably related to higher user-intensities in the vicinity of the hut.

The formation of secondary (or multiple) footpaths running parallel and in close proximity to the original path generates a second drainage channel on the hillslope. This has the potential to increase the rate and quantity of soil loss at any particular site. The formation of these footpaths is a major problem showing a 2.79 fold increase in cross-sectional area at the surveyed sites. In addition, a branching network of footpaths is unsightly and detracts from visitor experience. The prevention of secondary path initiation should thus rate highly in path management objectives and the reasons for their initiation need to be understood.

Secondary footpaths need to be distinguished from the general broadening of footpaths associated with hikers trampling adjacent vegetation as described by Dale and Weaver (1974), Bryan (1977), Coleman (1981) and Bayfield (1987). Bayfield (1987) distinguishes between a bare width and a trampled width for footpaths in the Yorkshire Dales National Park. This trampled zone is not found in Giant's Castle Game Reserve except perhaps to a small extent and for short distances at the beginning of footpaths, or at footpath intersections. Even in the very high intensity zones near the Main Camp, where footpaths have been surfaced with concrete, the effect of trampling adjacent to the footpath is so minimal that the Natal Parks Board is required to cut the grass adjacent to the concrete paths to prevent it from hanging over the footpath. This grass dampens the legs of hikers in the early morning or after rains and some written complaints from the public to this effect were received by the Reserve Management!

It can generally be postulated that pedestrians leave a footpath due to poor underfoot conditions and thus walk next to it, initiating a second footpath. The controls governing the pedestrian behaviour are, however, not well understood. Although Auerswald and Sinowski (1989) observed a distinct tendency toward extensive branching of paths with an increasing number of pedestrian users, this was not quantified. Lance *et al.* (1989) found a trend for secondary paths to form where paths ran through wet hollows, and less frequently, where the new paths were narrower and firmer underfoot. There also exists a greater tendency for hikers to leave the path coming downhill (Bayfield, 1973). These observations are not sufficient to explain the existence of multiple paths in Giant's Castle Game Reserve. Firstly the user-intensities do not satisfactorily account for the relative number of secondary path sites on different path sections. Secondly, the secondary path sites exist regardless of changes in soil moisture characteristics and thirdly, the tendency for hikers to leave the path when walking downhill does not explain the reason for leaving the path.

A narrow, deep footpath can make walking uncomfortable and potentially hazardous, particularly if adjacent vegetation is hanging over the footpath and if the hiker is carrying a heavy backpack. Similarly, rocky treads make for poor underfoot conditions. Figures 4.10 and 4.11 indicate that rocky treads may initiate secondary footpaths irrespective of width to depth ratios. Since the number of rocky treads recorded was minimal, the focus here is on width to depth ratios excluding the rocky tread data. The threshold value of between 4.01 and 4.50 indicates that where width to depth ratios are below 4.50 the potential for a secondary footpath forming is increased, although a secondary footpath may not necessarily form.

In summary, the compaction of a footpath can only be controlled by regulating intensity-of-use. The recovery of vegetation is difficult to achieve where a footpath tread is compacted, however once a path surface is compacted, only a low user-intensity is required to maintain the footpath (Bryan, 1977). Thus the prevention of compaction and the regeneration of vegetation to stabilise a footpath will not be easily achieved and is probably best left to its own devices. The prevention of multiple path formation may, however, be possible due to the recognition of threshold for initiation. Recommendations for management will be outlined in Chapter 7.

5.2.4 Geomorphological forces

Results from relationships between footpath morphology (width, depth and cross-sectional area) and geomorphological variables (footpath orientation to slope, footpath gradient and cross-slope gradient) are outlined in Section 4.2.4. Since the two approach paths essentially guide hikers from low elevations to higher elevations some degree of correlation between footpath gradient and cross-slope gradient is expected. Conversely, this is not anticipated for the contour path sections which generally follow the contours but have short sections of changing altitude. Such a trend is noted in Table 4.13 where correlations for the approach paths are relatively stronger than those for the sections of contour path.

Correlations between path width and depth are moderate but are generally higher than other correlation values. Although width and depth can be anticipated to be inter-dependent, Coleman (1981) suggests that width tends to be influenced to a greater degree by recreational factors while depth is influence by geomorphological factors. This may explain the absence of strong correlation values, although Coleman's footpath width includes a trample zone adjacent to a bare tread surface which is generally not observed in the study area.

The overall weak correlations for the Ka-Langalibalele Pass contour path section show that none of the independent variables measured can explain variations in footpath morphometry. A similar situation exists for the Bannerman Hut contour path with the exception of a moderately strong negative correlation between footpath orientation and cross-sectional area. This suggests that the extent of erosion is explained to some degree by the orientation of the footpath to the slope. As the footpath becomes more orientated with the hillslope the cross-sectional areas show a general increase, independent of actual footpath gradient. Similar findings have been recorded elsewhere. Bryan (1977) observed that topography is significantly related to trail orientation and that where paths follow the fall-line severe water erosion hazard exists, regardless of slope angle. Bratton *et al.* (1979) also found a significant negative correlation between orientation and erosion. This type of relationship is, however, clearly not a general relationship for the footpaths measured in Giant's Castle Game Reserve since the two approach paths show very low correlation values for this relationship, indicating either its irrelevance under the different environmental conditions of the approach paths, or alternatively some other overriding factor(s) influencing footpath morphology.

Generally stronger correlations for footpath morphology (cross-sectional area, width and depth) and footpath gradient of the approach paths in contrast to the contour path sections suggests that the morphology of the approach paths is controlled to a greater degree by footpath gradient. Relationships between footpath morphology and path gradient have been established by other authors. Auerswald and Sinowski (1989) found that path depth increased linearly with path steepness. Weaver and Dale (1978) found trail depths tended to be greater on slopes than on level sites, although Jubenville and O'Sullivan (1987) found that slope gradient within the same vegetation type explained only 34.3% of the total variance in cross-sectional area. Garland *et al.* (1985) found a weak yet significant relationship between depth and path slope, depth and hill-slope, and depth and width. Trail width has been found to increase linearly with increasing path slope (Bayfield, 1973; Dale and Weaver, 1974) while Coleman (1981) showed that the extent of path erosion was found to increase with the square root of the slope angle.

Giant's Ridge path is the only surveyed section in which there is any meaningful correlation between cross-slope gradient and cross-sectional area. This footpath has the lowest path-slope orientation indicating that of the footpaths surveyed it is the most orientated to the hillslope (Table 4.10). The mean orientation value (46°) is not, however, considerably lower than the mean orientation value for the Bannerman approach path (56°) which shows a very poor correlation between cross-slope gradient and cross-sectional area. Thus no general trend can be recognised here.

Based on the assumption of higher user-intensities for the Bannerman approach path and particularly for the Bannerman contour path, some overall points emerge for the footpaths. The method of path construction and the path age must play a role in determining the morphology of the paths. It is apparent that as the use of the path increases, and the extent of erosion increases, the control of path design and construction on morphometry decreases. This is a result of the paths becoming more in equilibrium with the forces exerted on them and is illustrated by the stronger correlations between independent and dependent variables for the higher-use footpaths than for the Ka-Langalibalele Pass path, which is a relatively new footpath and has lower intensity-of-use. On higher mean path gradients (the two approach paths) the path morphometry is correlated to the path gradient. On lower mean path gradients with relatively high user-intensities (Bannerman Hut contour path) the orientation of the path to the slope is an important controlling factor.

It is apparent that, although some general trends have been recognised, multiple inter-relationships between variables as outlined above and between recreational and geomorphological variables may exist which may serve to explain more accurately variations the in footpath morphology.

6. Footpath erosion rates in perspective

This chapter compares the two techniques of measurement utilised in this study, namely the runoff plots and the path surveys. In order to enable a comparison of the data obtained by these methods a conversion to similar units is required. The procedures for these conversions are outlined in Sections 6.1 and 6.2. The comparison of the soil loss values for the two methods follows in Section 6.3 and the final section of the chapter (6.4) compares the footpath erosion rates determined for this study to those obtained by other authors within the Drakensberg and in areas beyond southern Africa.

6.1 Conversion of runoff plot sediment yields to annual estimates

To enable a comparison of soil loss on the runoff plot scale with the larger scale soil loss estimated from the footpath surveys, the runoff plot sediment yields require conversions of the 20 rainfall events to annual predicted soil losses. Since long-term detailed rainfall interval data are not available, direct comparisons of rainfall intensities and kinetic energies for the monitored events and the mean annual conditions could not be undertaken. To place the sediment yield data obtained during the monitoring period into the context of general rainfall characteristics the only feasible approach is a comparison of rainfall quantities.

Mean total annual rainfall for the inclusive period 1989 to 1994 (the period between the two surveys) was 969mm p.a. (Table 4.7). The total rainfall for the 20 monitored runoff plot events was 183mm. This implies that the monitored events accounted for 18.9% of the total mean annual rainfall. Following the same procedure for the number of rainfall days monitored in relation to the mean annual number of rainfall days since 1989 (124) indicates that the number of rainfall days monitored was 16.1% of the mean annual number of rainfall days. This indicates that 16.1% of the days monitored accounted for 18.9% of mean annual rainfall. Given the similarity in these values, the assumption has been made that the sample of 20 monitored rainfall days is proportionately representative of the annual soil loss (this clearly assuming that the monitored rainfall events are a representative sample of the annual rainfall intensity).

Based on the above, predictions for annual soil loss from the runoff plots can be tentatively extrapolated from the 20 rainfall events to a prediction of mean annual soil loss (Table 6.1). Calculations of the runoff plot annual prediction are the product of sediment yield (kg) from the 20 rainfall events with 124/20. This was in turn converted from the 3m plot length to 1000m by multiplying with 333.3 and presented as tons by dividing by 1000. This gives soil loss units of tons/(m.km)/a (Table 6.1).

Plot	1	2	3	4	5	6
Sediment yield (kg)	2.833	1.375	1.737	2.041	5.17	8.202
Plot annual prediction (kg/a) (sed yield x 124/20)	17.57	8.53	10.77	12.65	32.05	50.85
Estimated yield (tons/(m.km)/a) (plot annual prediction x 333.3 / 1000)	5.86	2.84	3.59	4.22	10.68	16.95

Table 6.1 Conversion of runoff plot sediment yields to annual estimates.

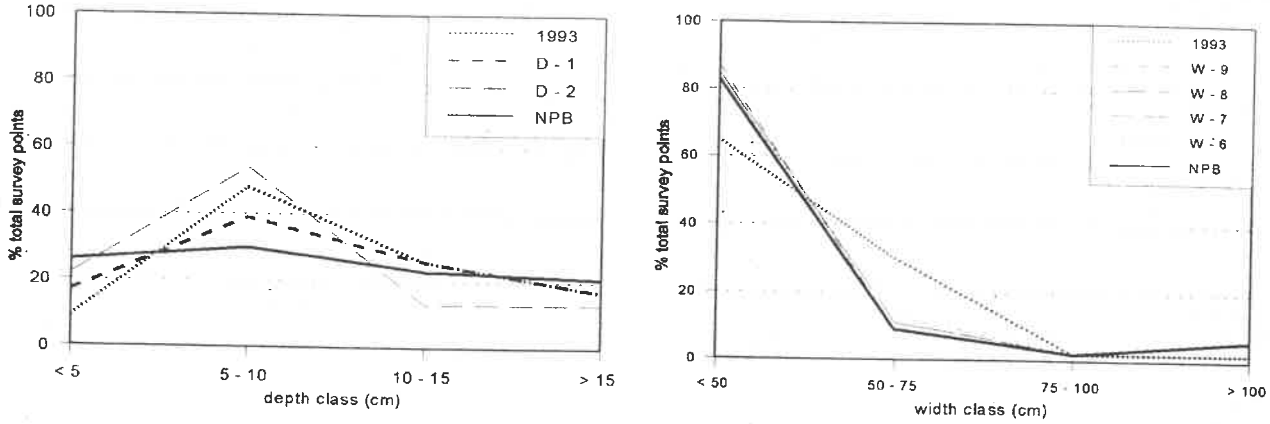
6.2 Annual soil loss estimate for surveyed footpaths

A comparison of the width and depth values measured between August and November 1993 and the September 1989 values of the Natal Parks Board has been undertaken in order to assess changes in footpath morphology over the four year period. Such changes in footpath morphology would then reflect soil loss or accretion of soil on the respective paths, provided the extent of compaction remained constant.

The Natal Parks Board survey is class-based, which precludes direct comparisons of width and maximum depth values. The values for width and maximum depth from the 1993 survey have thus been converted to classes following those utilised in the Natal Parks Board survey. These classes were then 'shifted' by subtracting a value from those measured in the 1993 survey and reassigning the values into the classes. This value would simulate the class distribution if the path tread was, for example 1cm narrower than that recorded in 1993. This procedure allows the 'shifted' class ratings to be compared to the Natal Parks Board survey classes and other values tested until the 'best fit' shift value is established. This value would then correspond to the estimated change in footpath width or maximum depth between 1989 and 1993. The results of this procedure are outlined in Figure 6.1 where class shifts are indicated for width and depth for the Ka-Langalibalele contour path, Giant's Ridge and Bannerman Hut approach paths. Shifts are indicated as D-x or W-x where D and W are the mean width and maximum depth values for the 1993 and x is the shift value in cm. No data for the Bannerman Hut contour path were available from the Natal Parks Board survey. The selected 'shift' values are listed in Table 6.2.

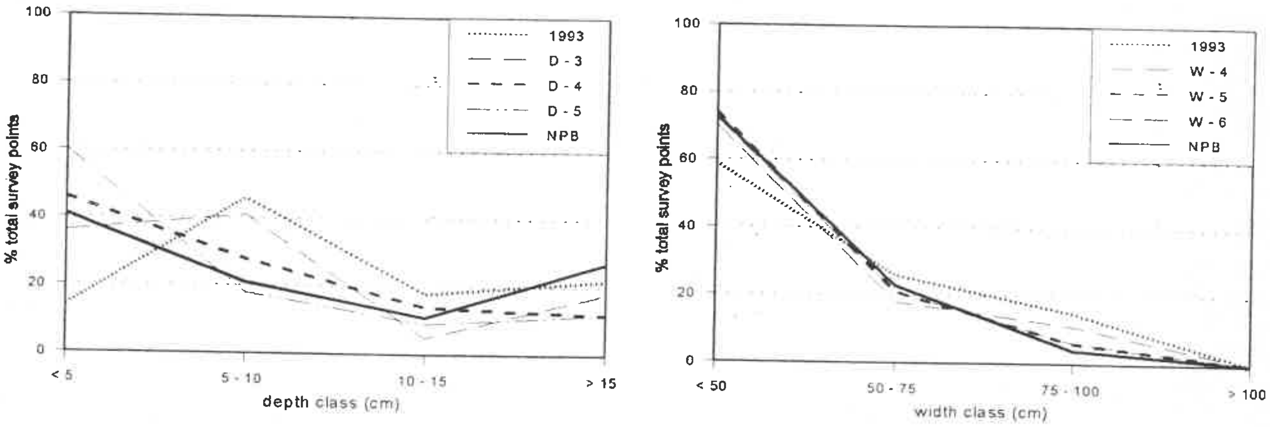
Changes in width and depth have been converted into changes in cross-sectional area (Table 6.2). These values are in turn converted to volume along the length of the footpath and, using mean soil bulk density, finally into soil loss in tons/km/a. The calculations estimate soil loss to be 13.0 tons/km/a for the Bannerman Hut approach path, 6.93 tons/km/a for the Giant's Ridge path and 3.24 tons/km/a for the Ka-Langalibalele contour path (Table 6.2). Although these values are at best only estimates of soil loss they permit a comparison with the runoff plot sediment yields, allowing for a comparison of the measurement techniques.

Before comparing the path survey results with those of the runoff plots some general comments on the survey results can be made. The low values of annual soil loss from the Ka-Langalibalele Pass contour path reflect the low user-intensity and the overall low footpath gradient. By comparison the two approach paths, which have higher mean gradients, have over 200% greater soil loss values, with the value for the Bannerman Hut approach path almost twice that of the Giant's Ridge path (Table 6.2). The difference between the values for the two approach paths cannot be explained by the data collected in this study since it appears that in most respects the environmental conditions of the two approach paths are similar. It must, however, be stressed that these values are estimates of soil loss and are subject to inaccuracies that may be introduced both by the field techniques employed and by the analysis of the class system and interpretation of class



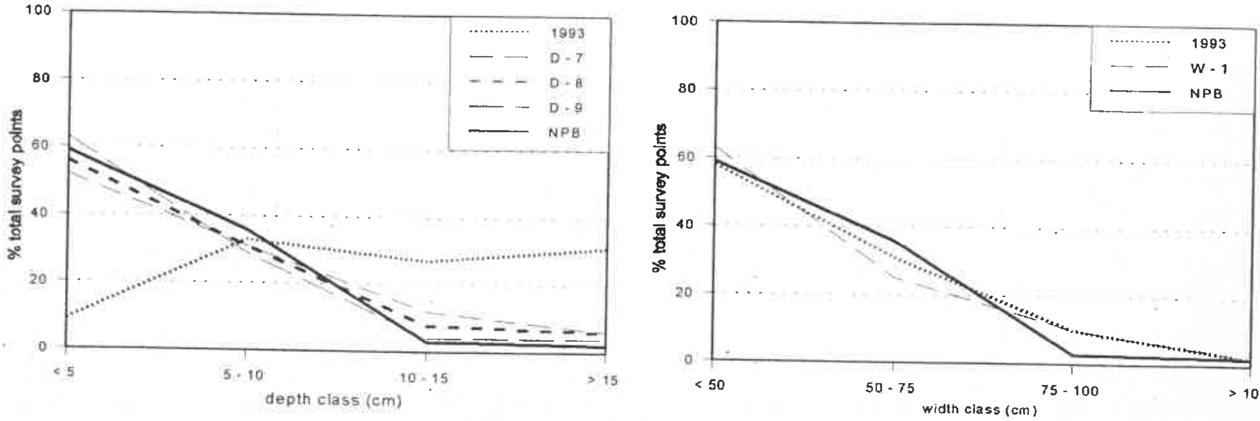
6.1a Ka-Langalibalele path depth classes

6.1b Ka-Langalibalele path width classes



6.1c Giant's Ridge path depth classes

6.1d Giant's Ridge path width classes



6.1e Bannerman Hut approach path depth classes

6.1f Bannerman Hut approach path width classes

Figure 6.1 Width (W) and depth (D) classes and 'shifted' classes (see accompanying text) for the 1993 and Natal Parks Board surveys.

shifts. An assumption inherent in the technique is that the degree of compaction remains constant and that changes in morphology reflect soil erosion. This assumption is not valid if user-intensity changes significantly during the four year period. Such a situation has been shown to occur during the monitoring of user-intensity during 1994, some months after the four year period between the surveys. The influences of such changes in user-intensity on the degree of compaction and on the associated effect on path depth are, however, not known.

	Bannerman Hut approach path	Giant's Ridge path	Ka-Langalibalele Pass contour path
1993 mean width (cm)	54	53	49
1993 mean depth (cm)	11	11	10
1993 mean c/sectional area (cm^2)	601	586	510
Shifted width (cm)	0	W - 5	D - 1
Shifted depth (cm)	D - 8	D - 4	W - 8
Altered c/sectional area (cm^2)	162	336	369
Change in c/sectional area (cm^2)	439	250	141
Path length (km)	5.691	6.422	4.605
Soil volume ($cm^3 \times 10^7$)	25.0	16.1	6.49
Mean tread density (g/cm^3)	1.18	1.10	0.92
Soil mass ($g \times 10^7$)	29.5	17.8	5.97
Soil mass (tons)	295	178	59.7
Soil loss (tons/a)	73.8	44.5	14.9
Soil loss (tons/km/a)	13.0	6.93	3.24

Table 6.2 Annual soil loss estimation for surveyed footpaths from 1989 to 1993.

A further consideration is that Coleman (1977) recognises that cycles of erosion and recovery may exist on footpaths and notes that it would be important to separate real trends in erosion from mere fluctuations. Thus some caution in the interpretation of the results and their implications for the management of footpaths needs to be taken since identifying these values as 'real trends' or as 'fluctuations' is not possible. The worst case scenario is that the results for annual soil loss from the surveys show that the footpaths are experiencing some degree of erosion, and that rates appear dependant on user-intensity and broadly on mean footpath gradient. A comparison of the two systems of measurement will assist in placing the survey results in perspective.

6.3 Comparison of runoff plot sediment yield and survey soil loss estimates

Comparing Tables 6.1 and 6.2 thus enables a comparison of the scales of measurement. An evident difficulty is that of the units of measurement. Data from the runoff plots estimates the soil loss in units of tons/(m.km)/a while the surveyed footpaths have units of tons/km/a. An assumption is made that the quantities of sediment generated from the natural surface within the runoff plots are negligible in comparison to that sediment generated from the footpaths. This effectively equates with the areal units for the path survey estimates. Based on this the units for the runoff plots are directly comparable to those of the survey data.

From Tables 6.1 and 6.2 it is apparent that the soil loss for the surveyed paths lies within the range of the soil loss from the plots and that there is some measure of agreement between the values for the two measurement techniques. A comparison of gradient shows that the soil loss values for the surveyed paths are, however, higher than the corresponding runoff plot values of similar gradient. There are three possible explanations for this. Firstly, the surveyed path gradients are mean path gradients and thus sections within those paths surveyed have higher gradients generating higher soil loss from above the threshold. Sections above the threshold would over-compensate soil loss for the lower gradients below the mean gradient values. Secondly, the plots are closed systems whereas the open paths in many instances act as drainage channels for the runoff from the adjacent slope. This increases the volume and velocity of runoff in an open path which would increase the potential for detachment and transport of soil particles. Lastly, although the two systems show some conformity of results the difference in technique and problems inherent in the assumptions outlined in the time scale conversions could introduce error and bias into the results.

Since the two techniques of soil loss measurement are based on certain assumptions, and difficulties are inherent in scaling upwards from a small to large scale (eg. Parker and Schumm, 1982), it cannot be stated which technique is a more accurate assessment of rates, or which may be overestimating or underestimating soil loss. Notwithstanding this, the agreement of results between the two systems shows some measure of compatibility of the two techniques, indicating that either technique of measurement gives a reasonable interpretation of rates of erosion from footpaths. Further, the agreement between the results indicates that if the surveyed path results represent a 'fluctuation' in erosion rather than a 'real trend' (Coleman, 1977), then the fluctuation is not considerably different from the real values for soil loss which may be established over a longer period of time.

6.4 Footpath erosion rates in perspective

Stocking (1984) suggests that normal erosion rates in Africa should be less than 5 tons/ha/a but may increase to in excess of 100 tons/ha/a where vegetation cover is poor. In comparison, scaling up from estimated annual sediment yields (Table 6.1) for the 3m^2 runoff plots to one hectare (10 000m^2) gives erosion rates between 28.4 and 169.5 tons/ha/a (Table 6.3) which indicates that erosion rates are potentially hazardous for steeper footpath gradients.

Figures for path erosion presented above are linear measurements (tons/km/a) while other forms of erosion are spatially extensive (eg. tons/ha/a). Soil loss from a footpath on a hectare of ground will consequently be much lower than from the traditional areal methods of representation (Garland, 1988). Further, the length of footpaths within a specified area can be any length which is greater than the shortest width of the unit area, depending on the extent of curvature of the footpath within the specified area. Thus a footpath with numerous switchbacks will have overall higher cumulative rates of erosion per unit area than a straight footpath located within the same unit area, even if the rates of erosion are the same per unit length of the footpath. Direct comparisons of areal data can thus be misleading.

Plot no.	1	2	3	4	5	6
Plot annual estimation (kg/a)	17.57	8.53	10.77	12.65	32.05	50.85
Plot annual estimation (kg/m²/a)	5.86	2.84	3.59	4.22	10.68	16.95
Estimated yield (tons/(m.km)/a)	5.86	2.84	3.59	4.22	10.68	16.95
Estimated yield (tons/ha/a)	58.6	28.4	35.9	42.2	106.8	169.5

Table 6.3 Runoff plot annual predicted values and estimated yields (from Table 6.1).

For a footpath of gradient 11° in a runoff plot at Kamberg in the central Drakensberg, Garland (1988) found soil losses to be 1.2 kg/m²/a. This increased to 2 kg/m²/a under burning treatment of the adjacent vegetation. By comparison, data from this study shows soil loss from the runoff plots to be higher with a range from 2.84 to 16.95 kg/m²/a (Table 6.3). Due to the proximity of Kamberg and Giant's Castle Game Reserve (Fig. 1.3) environmental conditions at the two sites should be broadly similar. Differences in erosion rates may be due to different user-intensities. Garland (1988) had a user-intensity of 60 persons per month, walked on one day of each month, whereas this study recorded an intensity generally in excess of 400 users per month. A further consideration is that Garland (1988) shows that the soil loss monitored in that study was during a period of lower than normal annual rainfall. These differences in results between the two studies highlight the need for long-term runoff plot data for the Drakensberg.

A scarcity of data exists for footpath erosion rates in and beyond southern Africa. Measured rates of footpath erosion obtained from previous research are shown in Table 6.4. Estimates of rates of erosion from both the runoff plots and from the survey data indicate that footpath erosion rates are not high in Giant's Castle Game Reserve in comparison to the data available, particularly for the low gradient and/or low intensity-use footpaths.

Author(s)	Location	Rate (kg/m^2/a)	Rate (tons/(m.km)/a)
Ketchledge and Leonard (1970)	Adirondacks, USA	37	37
Coleman (1979)	English Lake District	21	21
Anon (1986)	Otto's Walk, Drakensberg	0.5	0.5
Anon (1986)	Gorge Path, Drakensberg	13	13
Garland (1988)	Kamberg, Drakensberg	1.2	1.2
Present study	Giant's Castle, Drakensberg	2.84 to 16.95	2.84 to 16.95

Table 6.4 Some measured rates of footpath erosion (modified after Garland, 1988).

(Conversion to tons/m.km/a by converting kg to tons (/1000) and converting 1m² to km (*1000))

7. Conclusion

The Drakensberg is an important ecological and recreational resource area and thus the erosion caused by footpaths is a serious concern. Although erosion rates in the Drakensberg are generally low, localised soil erosion from footpaths can exceed the soil loss tolerance for an area (Garland, 1987a). The intention of this study was to determine the rates and controls of erosion associated with footpaths in order to base both the conservation of existing footpaths and the planning of new footpaths on a clearer understanding of the mechanisms involved in the erosion phenomena.

Little data exist on the actual rates of erosion of footpaths. Similarly, little is known of the controls on the erosion process in the Drakensberg and the associated influence on the rates of sediment generation. A two-fold approach was adopted in this study of footpaths in Giant's Castle Game Reserve. Firstly, rates of soil loss were monitored from six runoff plots installed on an intensively used footpath and secondly, surveys of four footpaths in the Reserve were taken in order to assess broader geomorphological and recreational influences on the morphology of footpaths. This chapter summarises the main findings of this study and outlines recommendations for the management of existing footpaths and for the planning of new footpath routes.

Data obtained from the runoff plots indicate that sediment yield and runoff generally increase with increasing gradient. A linear relationship exists between total sediment yield and total runoff ($r^2 = 0.886$) indicating an increase in total sediment with total runoff. The relationship between runoff and footpath gradient indicates a linear increase in runoff with gradient ($r^2 = 0.780$). In terms of sediment yield, the logarithm (either natural or base 10) of sediment yield was found to be related to footpath gradient. A more practical interpretation of sediment yield, however, indicates a computed footpath gradient of 13.36° as the threshold after which erosion rates increase rapidly. This is similar to the findings of Coleman (1981) who established the existence of a threshold gradient between 15° and 17° in the English Lake District. Runoff plots are, however, effectively closed systems. They prevent runoff from the hillslope, which would increase both the runoff rates and the total quantity of runoff on the footpath, from being channelled into the footpath. The threshold value may therefore effectively be lower than 13.36°. More data, particularly long term data which incorporates the hillslope component in some manner, are required in order to verify these findings.

Textural analysis of the sediment and samples taken from the footpath tread surfaces indicate an increase in the proportion of fines in the sediment generated from the footpath in relation to the tread material. The tread material was also found to be generally coarser than the adjacent natural surface. Although this indicates that some mechanism of preferential erosion may be taking place, it is more likely that the relative decrease in fines (particularly clays) can be attributed to their slower replacement by weathering rather than by preferential erosion (cf. Garland, 1988). The higher silt and clay components of the sediment may also be attributed to the breakdown of aggregates by pedestrian trampling and scuffing which would "prepare" finer material on the footpath tread surface for transportation.

The characteristics of rainfall are important in that they can be used to correlate rainfall erosivity with sediment yield and runoff. Of the eight erosivity indices tested for this study the strongest mean correlations for sediment yield emerge for the rainfall intensity (recorded over 60-minute intervals) and the square of the rainfall intensity. This corresponds to findings by Wischmeier and Smith (1978) and Foster and Meyer (1975) respectively for natural plot treatments and to the findings of Garland (1988) for rainfall intensity on runoff plots incorporating footpaths. Poor correlations were found for indices related to kinetic energy and to total rainfall amount, and for correlations between runoff and sediment yield. A general trend of increasing correlations with increasing gradient for all indices was noted for the runoff plots. This may be related to the increased potential for sediment entrainment by runoff from higher gradients.

Further findings associated with rainfall characteristics show the strongest correlation between runoff and erosivity indices for the EI_{60} index. All indices showed high correlations, however, with generally stronger correlations found for the compound indices than for the single variable indices. No general trend was recognised for changes in mean correlations with gradient, probably as a result of the high overall correlation values.

Although a general trend has been to decrease the monitoring period for rainfall intensity to 30 minutes and shorter (eg. Ulsaker and Onstad, 1984; Salako *et al.*, 1991), the 60-minute interval data available from the Natal Parks Board in Giant's Castle Game Reserve proved adequate for relating rainfall erosivity to sediment yield and runoff in this study. These indices require further testing under different environmental conditions to verify their spacial application for both footpaths and under natural conditions. Where possible, shorter rainfall interval data may allow more realistic comparisons with findings of other authors.

Results from the point-based surveys of four footpaths in the Reserve indicate that mean cross-sectional area of footpaths cannot be attributed solely to mean footpath gradient. The two sections of the contour path, with mean path gradients of 2.8° and 3.2°, had both the highest and lowest mean cross-sectional area of the footpaths surveyed. The two approach paths had intermediate values for mean cross-sectional area and mean gradients of 5.3° and 5.9°. Similarly mean cross-slope gradients and mean path-slope orientation cannot explain the mean cross-sectional areas of the paths. It appears, however, that the overall extent of erosion of the surveyed paths, indicated by cross-sectional area, is dependent on the user-intensity and on the relative ages of the paths.

These mean assessments do not, however, provide an indication of localised variations in path morphology. An assessment of the parameters measured at the surveyed sites provides a better understanding of the processes governing site-specific rates and extent of erosion. Coleman's (1981) footpath morphology model of the interaction of geomorphological and recreational forces with the resistance of soil and vegetation is used as a theoretical framework for assessing the survey data. The general resistance to erosion is determined by soil and vegetation characteristics. Findings in this study indicate that changes in vegetation type and in soil form cannot adequately explain variations in footpath morphometry. Under the structure of Coleman's (1981) model changes in path condition must therefore be related to recreational and geomorphological influences.

compaction

In addition to the scuffing and shearing influence on the soil surface, pedestrians cause compaction of the soil thus altering the soil physical properties and lowering the tread surface in relation to the adjacent natural surface. Compaction of a soil by pedestrians increases the bulk density of the soil. Soil samples removed from the centre of the tread on the surveyed footpaths indicate that bulk density decreases from the Main Camp towards the contour path. This is related to higher user-intensities in the vicinity of the Main Camp. The Ka-Langalibalele contour path section had the lowest overall bulk densities which is indicative of the lower user-intensity of the path, and of the lower mean cross-sectional area of the surveyed footpaths. The converse applies to the other three surveyed footpaths where bulk densities reflect relatively high user-intensities.

A further important recreational influence is the formation of secondary footpaths. These secondary paths create a second drainage channel running parallel to the primary path. Their existence is not only unsightly, but increases the overall path cross-sectional areas by an average of 2.79 fold at the surveyed sites where multiple paths were recorded. A threshold width to maximum depth range of 4.01 to 4.50 was determined as the control over the initiation of a secondary footpath since a narrow, deep path makes walking uncomfortable. Where width to depth ratios are below this range the potential for secondary footpath initiation increases.

The geomorphological influences on footpath morphometry were assessed by correlating independent site-specific variables such as footpath gradient, hillslope gradient and orientation with dependant variables of footpath morphometry. Although no strong correlations were recorded, a comparison of the moderate and weak correlations which were recorded provide insight into the factors controlling the erosion process. Some important considerations emerge. Although the Ka-Langalibalele section of the contour path showed overall weak correlations, the cross-sectional areas recorded for the higher intensity-use Bannerman Hut contour path section could in part be explained by the orientation of the path to the slope (cf, Bryan, 1977: Bratton *et al.*, 1979). This suggests that where possible footpaths should not follow the direct fall-line of the hillslope. The two approach paths, which have higher mean path gradients than the contour path sections, showed weak correlations for orientation but generally stronger correlations between footpath morphometry and path gradient.

In considering geomorphological influences within the context of the recreational forces some overall points emerge for the footpaths. As the cumulative use of the path increases, and the extent of the erosion increases, the control exerted as a consequence of the initial path construction on footpath morphometry decreases. This is as a result of the paths adjusting in an attempt to attain equilibrium with the forces exerted on them, as illustrated by the stronger correlations obtained for the older and more used footpaths. Where footpath gradients are low and user-intensity high (Bannerman Hut contour path), path morphometry is dependant on orientation to the slope. Where footpath gradients are higher and user-intensity high (Bannerman Hut approach path and Giants Ridge path), morphology shows some correlation to path gradient. Although these trends have been recognised, further multiple inter-relationships may exist between the recreational and geomorphological variables which may explain more accurately the variations in footpath morphometry.

Estimates of annual rates of erosion were determined for the runoff plots and for the surveyed footpaths. Extrapolation of sediment yield from the runoff plots indicate that annual estimates range between 2.84 and 16.95 tons/km/a, depending on footpath gradient. A comparison of a Natal Parks Board footpath survey conducted in 1989 with the survey data obtained during this study indicate that three of the surveyed footpaths have respective annual sediment yields of 3.24, 6.93 and 13.0 tons/km/a. Since both the above techniques of determining rates of erosion are based on certain assumptions and with problems inherent in scaling upwards from small to large scale, it cannot be concluded from this study which technique has provided the greater accuracy in assessing the rates of soil loss. Notwithstanding this, the similarity of results obtained for the runoff plots and the surveys suggests that both systems provide a reasonable assessment of rates of erosion from footpaths. The data further suggest that, if the results from the surveyed footpath represent a 'fluctuation' in erosion rather than a 'real trend' (Coleman, 1981), such fluctuation is not considerably different from the real values.

Although Stocking (1984) indicates that normal rates of erosion in Africa should be less than 5 tons/ha/a, increasing up to 100 tons/ha/a where vegetation cover is poor, direct areal comparison with soil losses obtained from footpaths can be misleading. Footpaths are effectively a quasi-linear entity, thus complicating comparisons with standard areal measurements. Notwithstanding this, scaling the runoff plot sizes up to units of tons/ha/a indicate values between 28.4 and 169.5 tons/ha/a, suggesting potentially hazardous erosion rates for specific sites of higher gradient. Comparing the erosion rates determined in this study with the scarce data available on footpath erosion rates both in southern Africa and worldwide indicates, however, that the overall rates in Giant's Castle Game Reserve are not exceptionally high.

7.1 Recommendations

The findings of this study point toward recommendations for the management of the existing path network, and towards improved planning for the construction of new paths. These are listed below:

- The footpath gradient of 13.36° which was derived from the runoff plot data indicates a threshold after which erosion rates increase rapidly. Below this threshold, erosion rates appear to increase only gradually with increasing path gradient suggesting that when new footpath routes are planned, path gradients in excess of a practical range of 10-13° need to be avoided. Where path gradients on existing footpaths exceed this range careful maintenance and monitoring of footpath conditions need to be implemented.

- A threshold footpath width to maximum depth range of between 4.01 and 4.50 was established below which the potential for multiple footpath development increases. This width to depth range provides management with an approach to predicting potential sites or zones of secondary path initiation. It is recommended that where secondary paths exist, rehabilitation of the primary paths be undertaken as natural rehabilitation appears to be slow. Paths under rehabilitation need to be clearly indicated as closed routes and where possible, water breaks installed on the newly formed footpaths. A further consideration is that the potential for secondary footpath development is clearly also dependent on the presence of rocky tread surfaces, independent of the width to depth ratio. Although this is a difficult situation to rectify, particularly where the footpaths cross exposed bedrock sites, the situation can be relieved by removing loose clasts from the primary footpath tread surface.

- Findings from the footpath surveys indicate that under low gradient conditions with high user-intensities, footpaths aligned with the orientation of the hillslope show an overall greater extent of erosion independent of the footpath gradient. This indicates that, even under low footpath gradient conditions, care should be taken when designing new path routes to avoid orientating the footpath directly up or down the hillslope.

- As a technique for assessing footpath conditions monitoring changes in time, surveying is perhaps more favourable than the static or fixed-point method which utilises a rigid bar between two points (eg. Coleman, 1977; Tinsley and Fish, 1985). Surveying allows a greater number of readings to be taken from a variety of environmental conditions on a footpath, thus reducing bias incurred by unusual local conditions, such as cross-slope modifications of drainage. The disadvantages of the advocated technique are longer periods in the field and some measure of loss of site-specific precision. It is, however, a less time consuming and a less labour-intensive procedure than monitoring runoff plots. A recommendation for future footpath surveys is that the class-based system of measurement be avoided and that all actual values be recorded. The survey point spacing also requires accurate measurement (such as with a trundle wheel) to facilitate comparisons with subsequent surveys.

7.2 Directions for future research

During the course of research various avenues of further research related to footpath erosion, considered to be beyond the scope of the study, have been highlighted. These pertain to both specific and general issues which would assist in furthering understanding of the erosion process and the influence of footpaths on the ecological stability of the area. Some suggestions for future research on footpaths in the KwaZulu/Natal Drakensberg are provided below.

- In terms of specific measurements, data are required on the rates of erosion from natural surfaces in order to enable comparisons with erosion rates from footpaths. Although this study has determined erosion rates from selected footpaths, future research will require an assessment of the extent to which footpaths accelerate natural erosion rates. In addition, more long-term data are required on the rates of erosion of footpaths under different environmental conditions. This will also assist in identifying possible fluctuations or cyclic patterns pertaining to erosion rates (cf. Coleman, 1981).

- The influence of water breaks on modifying erosion rates and mechanisms is as yet hypothetical. This conservation technique is ubiquitous in the Drakensberg yet similar structures are seldom reported in the international literature. A thorough assessment into their efficiency, particularly with respect to water break type, attitude of installation and maintenance is required in order for their use to be optimised.

- In terms of general assessment, there is a need to ascertain the optimum level of use at which a balance between public access and recreation on the one hand, and protection of the resource on the other, can be achieved (Frissell *et al.*, 1980). The carrying capacity concept, when first applied to recreation, primarily reflected the ability of individual plant species to resist damage by trampling. Although there have been relationships established between path use and morphology, a need still exists for determining the actual physical carrying capacity of footpaths, particularly in the Drakensberg. The carrying capacity concept also needs to be placed within the context of the Limits of Acceptable Change planning system (eg. Martin *et al*, 1989) which redefines the question of "how much is too much?" to "how much change is acceptable?" Such shift in focus directs management attention away from the numbers of users toward management for desired social and ecological conditions as discussed by Frissell *et al.* (1980) and Martin *et al.* (1989). In short there is a need for establishing the carrying capacity of footpaths within the framework of social and ecological acceptance of change which is presented in such a manner so as to be of practical value to management.

Notwithstanding the above recommendations for future research, this study has achieved a greater understanding of both the rates of footpath erosion and the factors controlling the erosion process in the Giant's Castle Game Reserve. The above findings provide management with recommendations upon which to base both the conservation of the existing footpath network and guidelines for the planning of new footpath routes.

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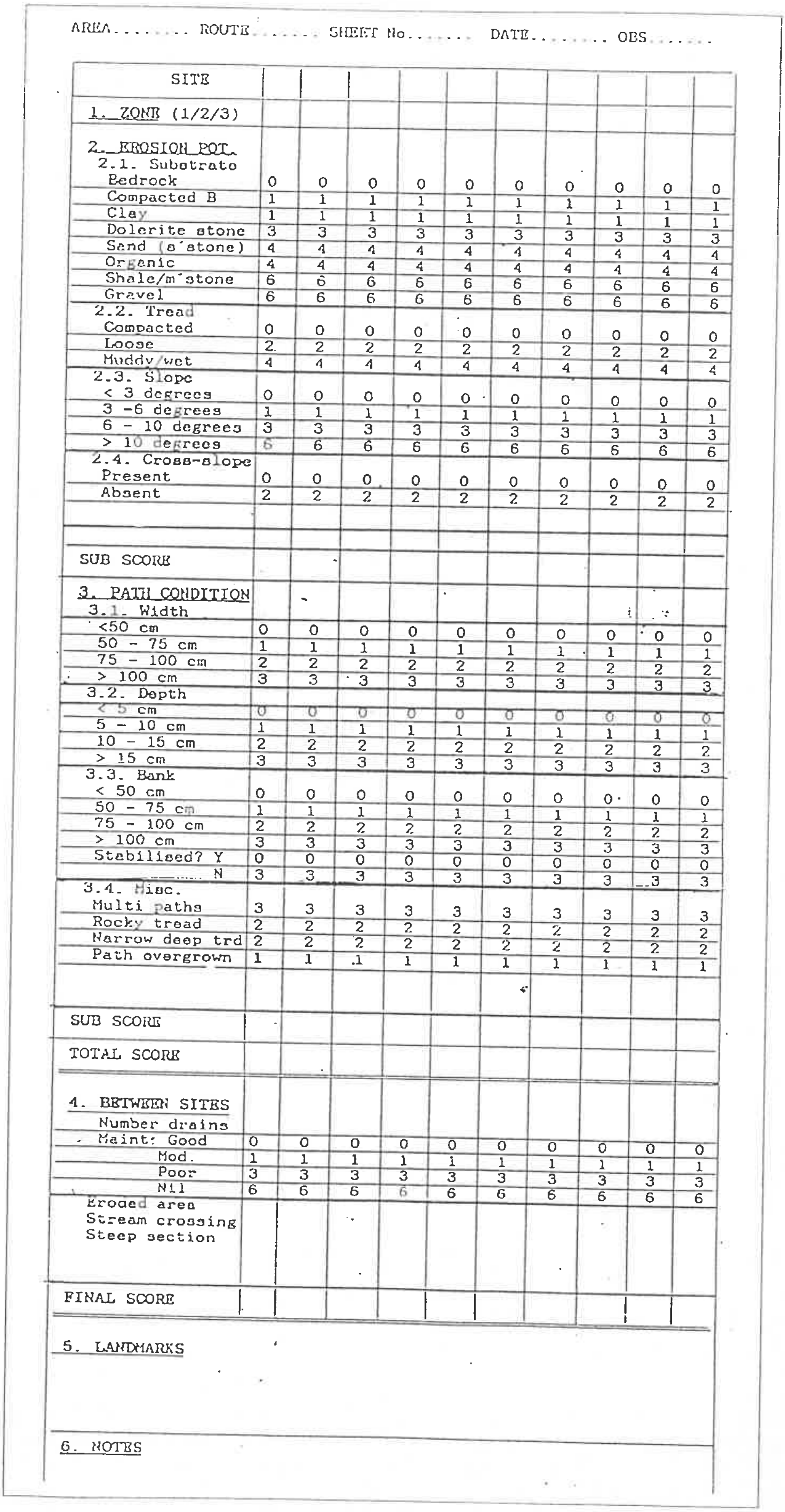
Appendix I



AREA........ ROUTE....... SHEET No....... DATE........ OBS.......

SITE										
1. ZONE (1/2/3)										
2. EROSION POT.										
2.1. Substrate										
Bedrock	0	0	0	0	0	0	0	0	0	0
Compacted B	1	1	1	1	1	1	1	1	1	1
Clay	1	1	1	1	1	1	1	1	1	1
Dolerite stone	3	3	3	3	3	3	3	3	3	3
Sand (s'stone)	4	4	4	4	4	4	4	4	4	4
Organic	4	4	4	4	4	4	4	4	4	4
Shale/m'stone	6	6	6	6	6	6	6	6	6	6
Gravel	6	6	6	6	6	6	6	6	6	6
2.2. Tread										
Compacted	0	0	0	0	0	0	0	0	0	0
Loose	2	2	2	2	2	2	2	2	2	2
Muddy/wet	4	4	4	4	4	4	4	4	4	4
2.3. Slope										
< 3 degrees	0	0	0	0	0	0	0	0	0	0
3 -6 degrees	1	1	1	1	1	1	1	1	1	1
6 - 10 degrees	3	3	3	3	3	3	3	3	3	3
> 10 degrees	6	6	6	6	6	6	6	6	6	6
2.4. Cross-slope										
Present	0	0	0	0	0	0	0	0	0	0
Absent	2	2	2	2	2	2	2	2	2	2
SUB SCORE										
3. PATH CONDITION										
3.1. Width										
<50 cm	0	0	0	0	0	0	0	0	0	0
50 - 75 cm	1	1	1	1	1	1	1	1	1	1
75 - 100 cm	2	2	2	2	2	2	2	2	2	2
> 100 cm	3	3	3	3	3	3	3	3	3	3
3.2. Depth										
< 5 cm	0	0	0	0	0	0	0	0	0	0
5 - 10 cm	1	1	1	1	1	1	1	1	1	1
10 - 15 cm	2	2	2	2	2	2	2	2	2	2
> 15 cm	3	3	3	3	3	3	3	3	3	3
3.3. Bank										
< 50 cm	0	0	0	0	0	0	0	0	0	0
50 - 75 cm	1	1	1	1	1	1	1	1	1	1
75 - 100 cm	2	2	2	2	2	2	2	2	2	2
> 100 cm	3	3	3	3	3	3	3	3	3	3
Stabilised? Y	0	0	0	0	0	0	0	0	0	0
N	3	3	3	3	3	3	3	3	3	3
3.4. Misc.										
Multi paths	3	3	3	3	3	3	3	3	3	3
Rocky tread	2	2	2	2	2	2	2	2	2	2
Narrow deep trd	2	2	2	2	2	2	2	2	2	2
Path overgrown	1	1	1	1	1	1	1	1	1	1
SUB SCORE										
TOTAL SCORE										
4. BETWEEN SITES										
Number drains										
Maint: Good	0	0	0	0	0	0	0	0	0	0
Mod.	1	1	1	1	1	1	1	1	1	1
Poor	3	3	3	3	3	3	3	3	3	3
Nil	6	6	6	6	6	6	6	6	6	6
Eroded area Stream crossing Steep section										
FINAL SCORE										

5. LANDMARKS

6. NOTES

Table I Data sheet utilised by the Natal Parks Board for the footpath survey conducted in 1989.

Appendix II

Date	% sand	% silt	% clay	% organic	mean (ϕ)	skewness	sorting
19/10/93	88.9	8.7	2.4	0.4	3.18	-0.53	1.22
20/10/93	18.2	41.8	40	0	4.38	-0.43	0.62
21/10/93	70.0	25.7	4.3	0	3.5	-0.42	1.29
26/10/93	77.5	3.8	18.7	0.2	3.07	-0.1	1.22
11/11/93	60.8	26.5	12.8	0	3.62	-0.27	1.18
18/11/93	48.3	45.0	5.7	0.1	3.9	-0.43	1.05
19/11/93	50.0	48.6	1.4	0.2	3.93	-0.22	0.85
26/11/93	71.1	23.4	5.6	0	3.47	-0.11	1.02
28/11/93	32.7	65.1	2.2	0	4.11	-0.39	0.77
29/11/93	58.0	39.5	2.5	0	3.76	-0.37	1.15
mean	**57.5**	**32.8**	**9.6**	**0.1**	**3.69**	**-0.33**	**1.04**
tread	86.2	13.6	0.6	0	1.2	0.06	2.92

Table II.a Runoff plot 1 sediment and tread particle size distribution characteristics.

Date	% sand	% silt	% clay	% organic	mean (ϕ)	skewness	sorting
19/10/93	70.0	26.9	3.1	0.2	3.72	0.09	0.66
20/10/93	17.2	35.7	45.3	0	4.06	-0.31	0.27
21/10/93	56.4	39.3	4.3	0	3.77	-0.21	0.93
26/10/93	85.6	5.3	9.1	0	3	-0.13	1.08
11/11/93	80.4	16.7	2.9	0.1	3.26	-0.04	0.85
18/11/93	52.4	41.1	6.6	0.2	4.17	-1.14	0.95
19/11/93	-	-	-	-	-	-	-
26/11/93	38.0	57.9	4.2	0	3.85	-0.55	1.06
28/11/93	36.1	56.3	7.6	0	4.04	-0.55	0.94
29/11/93	59.2	38.8	2.0	0	3.69	-0.31	1.13
mean	**55.0**	**35.3**	**9.5**	**0.1**	**3.73**	**-0.35**	**0.87**
tread	88.9	10.9	0.2	0	2.95	-0.54	1.04

Table II.b Runoff plot 2 sediment and tread particle size distribution characteristics.

Date	% sand	% silt	% clay	% organic	mean (ϕ)	skewness	sorting
19/10/93	77.7	18.7	3.5	0.3	3.18	-0.52	1.17
20/10/93	32.9	59.9	7.2	0	4.15	-0.40	0.18
21/10/93	48.9	44.1	7.0	0.1	3.94	-0.24	0.97
26/10/93	52.2	37.4	10.4	0	3.92	-0.15	0.88
11/11/93	77.7	20.9	1.5	0	3.50	-0.10	0.80
18/11/93	35.9	54.3	9.8	0.1	4.18	-0.32	0.75
19/11/93	77.4	22.4	0.2	0.1	3.51	-0.38	1.20
26/11/93	75.1	21.5	3.4	0	3.47	-0.17	0.89
28/11/93	32.2	65.3	2.5	0	4.13	-0.47	0.88
29/11/93	65.9	30.7	3.4	0	3.68	-0.16	0.90
mean	**57.6**	**37.5**	**4.9**	**0.1**	**3.77**	**-0.29**	**0.86**
tread	89.3	10.5	0.2	0	3.00	-0.44	1.49

Table II.c Runoff plot 3 sediment and tread particle size distribution characteristics.

Date	% sand	% silt	% clay	% organic	mean (ϕ)	skewness	sorting
19/10/93	78.4	20.2	1.4	0.4	3.52	-0.03	0.75
20/10/93	16.6	67.6	15.8	0	4.40	-0.17	0.51
21/10/93	70.5	27.1	2.4	0.1	3.63	-0.05	0.86
26/10/93	63.8	30.8	5.4	0.2	3.70	-0.11	0.92
11/11/93	68.6	30.1	1.3	0.1	3.63	-0.02	0.84
18/11/93	63.6	34.8	1.5	0.2	3.73	-0.03	0.86
19/11/93	-	-	-	-	-	-	-
26/11/93	68.3	27.4	4.4	0	3.63	-0.03	0.84
28/11/93	39.7	52.1	8.2	0	3.93	-0.41	1.01
29/11/93	66.0	31.1	2.9	0	3.75	-0.05	0.75
mean	**59.5**	**35.7**	**4.8**	**0.1**	**3.77**	**-0.1**	**0.82**
tread	90.2	9.7	0.1	0	3.00	-0.38	1.54

Table II.d Runoff plot 4 sediment and tread particle size distribution characteristics.

Date	% sand	% silt	% clay	% organic	mean (ϕ)	skewness	sorting
19/10/93	88.2	10.8	1.0	0	3.32	-0.31	0.76
20/10/93	39.5	46.1	14.4	0	4.03	-0.46	0.92
21/10/93	82.2	16.4	1.4	0	3.47	-0.16	0.70
26/10/93	65.0	31.6	3.4	0	3.68	-0.10	0.90
11/11/93	82.0	16.5	2.5	0.2	3.53	-0.11	0.64
18/11/93	55.1	43.3	1.6	0.1	3.82	-0.03	0.87
19/11/93	-	-	-	-	-	-	-
26/11/93	51.5	40.1	8.4	0	3.82	0.04	0.80
28/11/93	60.1	36.9	2.9	0	3.63	-0.14	1.04
29/11/93	64.7	33.2	2.1	0	3.70	-0.10	0.89
mean	**65.4**	**30.5**	**4.2**	**0**	**3.70**	**-0.15**	**0.84**
tread	87.0	12.8	0.2	0	3.10	-0.41	1.06

Table II.e Runoff plot 5 sediment and tread particle size distribution characteristics.

Date	% sand	% silt	% clay	% organic	mean (ϕ)	skewness	sorting
19/10/93	92.1	7.0	0.9	0.2	3.17	-0.26	0.80
20/10/93	28.5	61.8	10.1	0	4.17	-0.54	0.86
21/10/93	89.3	9.7	1.0	0.1	3.37	-0.37	0.81
26/10/93	41.3	47.0	11.7	0	3.70	-0.14	0.96
11/11/93	85.1	11.5	3.3	0	3.52	0.01	0.57
18/11/93	56.5	39.8	3.7	0.1	3.84	-0.13	0.75
19/11/93	-	-	-	-	-	-	-
26/11/93	51.5	40.1	8.4	0	3.93	-0.18	0.89
28/11/93	57.1	37.0	5.9	0	3.82	-0.25	1.03
29/11/93	65.9	31.1	1.0	0	3.72	-0.05	0.88
mean	**63.0**	**31.7**	**5.1**	**0**	**3.69**	**-0.21**	**0.84**
tread	84.3	15.4	0.3	0	3.22	-0.36	1.07

Table II.f Runoff plot 6 sediment and tread particle size distribution characteristics.

Appendix III

Index	A (mm)	I_{60} (mm.hr^{-1})	I_{60}^2 (mm.hr^{-1})^2	E (J.m^{-2}mm^{-1})	AI_{60} (mm^{2}hr^{-1})	EI_{60} (J.m^{-2}hr^{-1})	$EI_{60}A$ (J.mm.m^{-2}hr^{-1})
19/10/93	22*	no data available					
20/10/93	5*	no data available					
21/10/93	5*	no data available					
26/10/93	7*	no data available					
11/11/93	3*	no data available					
18/11/93	7	7	49	11	49	77	539
26/11/93	6	4	16	-	96	-	-
28/11/93	5	3	9	-	15	-	-
29/11/93	5	2	4	-	10	-	-
03/12/93	12	2	4	-	24	-	-
08/12/93	10	9	81	16	90	141	1409
10/12/93	7	2	4	-	14	-	-
14/12/93	5	3	9	-	9	-	-
15/12/93	19	4	16	-	16	-	-
16/12/93	6	5	25	4	25	22	130
22/12/93	12	5	15	4	25	22	259
27/12/93	15	8	64	14	64	111	1666
29/12/93	5	3	9	-	9	-	-
30/12/93	21	8	64	28	64	222	4664
01/01/94	6	3	9	-	9	-	-

Table 1 Indices for rainfall events during the runoff plots monitoring period

(* data from rainfall guage obtained during periods of failure of the automated weather station)