EFFECTS OF RECREATION AND ENVIRONMENT UPON THE EROSION OF MOUNTAIN FOOTPATHS IN THE LAKE DISTRICT NATIONAL PARK

Rosalind Anne Coleman

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Department of Geography
University of Sheffield

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SUMMARY OF THESIS

Increasing numbers of walkers in mountain areas have led to concern about the deterioration of footpaths through the erosion of vegetation and soil.

Sites were established to monitor path erosion by repeated measurements of cross sections. Results demonstrated that although many sites were stable over a two year period, some deteriorated rapidly. Erosion by human agency and surface water run off proved equally effective under favourable conditions. Comparisons of air photographs (1947-72) suggested that footpath erosion was not a new phenomenon, but also reinforced the trends measnred over the two years.

A survey was made to examine relationships between footpath morphology and environmental/recreation site conditions. Results suggested that in the variation of path width, of the extent of bare soil and the depth of gullying, much could be accounted for by corresponding variation in the path gradient and the degree of recreation pressure. The altitude, and certain vegetation and soil types proved relevant, but of less importance.

Among the paths surveyed, the extremes of erosion measured were localised, but occurred on most paths. Signs of active processes were observed on about one third of the sites, and appeared on most paths with a slope of more than 17 degrees.

Experimental work on a purposely created path demonstrated the efficacy of trampling as an erosive agent, especially in combination with wet weather and waterlogged soil.

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INTRODUCTION

There is no doubt that recreation in hill and mountain areas has increased throughout the period since 1945 (Griffin, 1971; Bayfield, 1973; Hookway, 1975), not only in peak holiday periods but also in the winter months (Griffin, 1972; Davison, 1975; Lake District Special Planning Board, 1975).

The 1950's and 1960's saw growth in education visits, with the opening of outdoor pursuits and field study centres (Bayfield, 1973 (a)). The media, especially television, have played their part in popularising and publicising hill walking, as have inumerable guides and pamphlets published by various organisations such as the National Park Authorities and the Ramblers' Association.

The Lake District has been popular with visitors for over a century, with fell walking becoming a fashionable pursuit by the turn of the century, for example as described in Wordsworth's "Guide to the Lakes", published in 1906. Even as early as 1945, the comment had been made that there was no longer solitude on the popular routes and summits (Lake District Special Planning Board, 1975). Now, at the end of the 1970's, the ever increasing pressure of walkers is a cause of concern to certain members of the Lake District Planning Board and to the National Trust, a major landowner in the area.

There is little sign of any lessening of demand. About half the visitors staying in the Lake District, and over 90% of day visitors, come several times a year (Lake District Special Planning Board, 1975). It is not surprising therefore that the impact of hill walkers is beginning to cause concern in certain areas. On popular routes, paths have been well defined for many years, but it appears that in some places there is progressive deterioration, with serious loss of vegetation and soil.

It may be that pressure upon some hill paths is, or may become, so great that some management policy will be needed. Yet this prospect is fraught with difficulties. Footpath maintenance is not underwritten by grant aid; most work is done by unskilled volunteers supervised by Park Wardens; not all "mountain lovers" appreciate the efforts made nor agree with the necessity for action in the first place (Roberts, 1973).

Amongst the immediate problems of the National Park Authority, the long term future of footpaths is, perhaps, of low priority. Moreover, information is scanty (Bayfield, 1978). Recreation research is relatively young and scattered over many aspects and areas.

It is the aim of this thesis to add something to the body of recreation research and to knowledge of the Lake District mountain footpaths in particular.

CHAPTER ONE

FOOTPATH EROSION: SOME RELEVANT QUESTIONS AND THE DERIVATION OF THE RESEARCH

1.1 FOOTPATH EROSION: INITIAL QUESTIONS

Given the situation described in the introduction - of expanding use of the countryside - and given the sometimes, emotive reaction of the conservationist, the role of scientific research is possibly

(1) to identify a problem,

(2) to discover and separate the causes of the problem,

(3) to quantify the relationships and rates of change within the system, and

(4) to present, to those responsible, a clear exposition of the consequences of alternative management strategies.

For the case of mountain footpaths, the following questions can be asked:

Q1. Is footpath erosion a problem?

Q2. What are its main causes?

Q3. What are the implications for management?

These questions can be expanded to give sets of more specific questions for which answers can be sought from existing information. Only then is it possible to see where further information is required.

Definition of this problem is difficult because it is not an absolute quantity which is being defined, but only one that is relative to other factors, such as economic factors, transitory viewpoints or state of awareness. The question always arises as to whom something is a problem. An attempt to answer this and to define possible problems is made below in the statement of the subsidiary questions arising from Q1 above. However, even these beg such questions as the definition of "excessive" or "widespread".

Identification of causes and relationships involved in footpath erosion requires some knowledge of the complex situation which arises in a system in which its many factors act upon each other as well as upon the footpath. A simplified representation of the system is given in figure 1.1 and is used as a basis for the questions raised as subsidiaries to Q2.

If some knowledge of the system can be obtained, then there is an opportunity to answer the sort of questions that are relevent to management plans for conservation, recreation expansion and other changes. These are suggested in the subsidiary questions to Q3.

Q1.1 Are present amounts of footpath erosion

(a) visually intrusive

(b) dangerous underfoot

(c) harmful to agriculture or nature conservation?

Q1.2 Is excessive footpath erosion at present a widespread phenomenon?

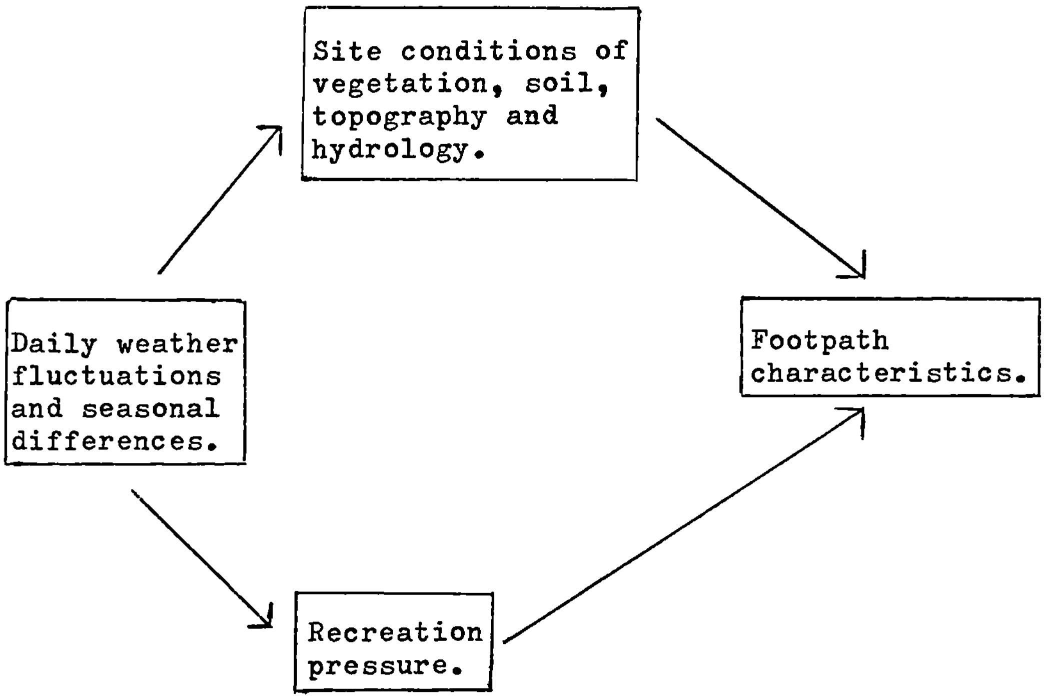
Q1.3 What are current rates of footpath erosion?

Q2.1 What are the main site conditions which are likely to result in serious erosion?

Q2.2 How do numbers of people affect the amount of erosion?

Q2.3 What is the relative importance of numbers of people and of site conditions?

FIGURE 1.1 A simplified model of the factors operating in a footpath system



Q2.4 How are all these factors modified by differences in season or in weather?

Q3.1 Is it possible to predict the course on a path, if its site conditions are known?

Q3.2 Will increasing the numbers of users by a certain amount increase the erosion in the same proportion?

Q3.3 Is some eventual equilibrium reached, albeit after a large amount of degradation?

In the next section, the available evidence for answering these questions is examined, within the context of recreation in general and the Lake District in particular.

1.2 DISCUSSION OF QUESTIONS RAISED IN SECTION 1.1

Q1.1 (a) Are footpaths visually intrusive

Perception of visual intrusion can be gauged at two levels, that of professional planners and academics, trained to understand and be aware of such problems, and that of individuals, possibly informed through the media, but otherwise reacting instinctively.

Visual intrusiveness has been mentioned generally (Speight, 1973; Hanson, 1974) and specifically in relation to the Lake District by the Lake District Special Planning Board (1975, 1977), in connection with the National Trust (Anon, 1975; Barrow et al, 1973), in the Westmorland Gazette (1976, 1978), in climbing journals (Talkaround, 1969; Griffin, 1970), and by Barkham (1971). Barkham writes about the "linear scars of footpaths"; although he admits that the "deleterious visual impact of these scars" is a subjective judgement, he notes that the recent increase in walking for recreation has caused "spectacular degradation".

In 1969, the Countryside Commission sponsored the Upland Management Scheme, a small part of which was devoted to rehabilitation of degraded fell paths. The scheme was continued and expanded from 1972, in association with the National Park Authority, but as yet, the work has been on lowland paths, with the exception of some repairs to a lower section of the Striding Edge path (Helvellyn) and a small roadside section of one Cat Bells path (Derwentwater), (Countryside Commission, 1974, 1976). In both the introduction to the National Park draft plan and the plan itself the Planning Board makes it clear that the visual impact of erosion scars is not acceptable, but the impression given is that the impact is small in comparison with other results of recreation pressure, such as camping sites, car parks and ltter (Lake District Special Planning Board, 1975, 1977).

The National Trust, an important landowner in the Park, became sufficiently worried about footpath erosion spreading over the fellsides in Langdale to embark upon an ambitious and expensive programme of reconstruction. This work is as yet in its early stages, but apparantly results are encouraging enough for it to be continued (N. Allison, Chief Warden, pers. comm.). Similar work has been completed at Tarn Hows, jointly sponsored and organised by the National Trust and the Countryside Commission (Barrow et al, 1973; Brotherton et al, 1978).

It is pertinent to ask whether the "general public" perceive any visual detraction, but this is a neglected area of recreation studies. Barkham (1971) reports the results of a student field exercise in Langdale, during which a questionnaire study included some questions about paths. However, from the results, it would appear that the questions were not designed to establish perception of erosion on paths, but rather, preferred walking surfaces. Preliminary investigations of public attitudes to footpaths in the Lake District, however, give support to the argument that walkers are both aware of, and influenced by, footpath erosion (Section 1.3).

Q1.1 (b) Are eroded footpaths dangerous underfoot?

Little evidence exists for or against the proposition that eroded paths might become dangerously loose. The Westmorland Gazette (1975) reported that some walkers had almost been hit by falling boulders loosened from the badly eroded section on Striding Edge (Helvellyn), and the Planning Board (1977) declared that certain routes had become unsafe, but these were all on rock rather than the open fellside.

The Mountain Accident Association keeps no statistical record of the number of accidents occurring on badly eroded sections of footpaths. It is possible that eroded paths contribute to exhaustion and minor injuries, because walkers slip on the loosened surfaces, and stones have been knocked downhill onto walkers below (J. Wyatt, Head Warden L.D. Planning Board, pers. comm.).

Q1.1 (c) Are footpaths harmful to argiculture or nature conservation?

Speight (1973) regards soil erosion induced by recreation as ecologically important because of the thousands of years needed to develop soil. Also the products of erosion can bury and kill vegetation, a factor noted by Bayfield (1974). However, Speight does note that the localised nature of paths limits their ecological importance. The same viewpoint is held by the Nature Conservancy: "Only rarely are important species endangered, and in the Lake District path erosion is of little importance" (Regional Officer, North West, pers. comm.).

Although Barkham describes the danger of gullying in paths after heavy rain, and the deposition of material down the lower slopes, (1971), this is minimal compared with the "natural" erosion seen around gullies and stream heads. The Countryside Commission report on the Upland Management Experiment (1976) suggests that the impact of fell path erosion on farming is limited to a few places where it has made shepherding more difficult. That the effect is minimal is implicit in a report on the problems caused to sheep farmers in the Lake District by recreation, which does not mention erosion (Guardian, 1977).

Q1.2 Is excessive footpath erosion a widespread phenomenon?

Since "widespread" and "excessive" are subjective terms, there can be no absolute answer to this question; definitions will vary from person to person, according to his or her experience, both of paths in other walking areas and of Lake District paths in the past.

Erosion has been noted as widespread on many popular paths (Talkaround in Climber and Rambler, 1969). In the magazine of the Ramblers Association, the view was expressed that erosion is still a localised problem, although difficult and costly to deal with where it occurs (Anon. Rucksack, 1975 (a)). This view is similar to that expressed by the Friends of the Lake District, a local conservation organisation, who consider that the problem should not be exaggerated. The Friends are critical of many attempts to solve the problem: "the remedy is worse than the disease" (Anon., Friends of the Lake District, 1975 (b)).

The opinions expressed are obviously subjective because no information has been gathered to give an unprejudiced basis for knowing (a) what proportion of paths are very wide - assuming this can be defined - or (b) how fast footpaths are increasing in width or depth. An exercise of this nature was attempted by Willis (1976), mapped path width categories, path roughness, and damage categories for the approaches to Snowdon's summit, North Wales. Nothing comparable exists for the Lake District. In the Introduction to the National Park Draft Plan (1975), the Planning Board suggests that since, in some places, erosion is a problem, "the extent of the problem needs to be gauged and appropriate action undertaken.....".

Q1.3 What are current rates of footpath erosion?

Current rates of footpath erosion are almost an entirely unknown quantity. A distinction must be made between old and new paths, because it follows that the introduction of a new walking path will result in an immediate effect on the vegetation and soil, but that, given time, a stable path may be created. It is all too easy in this relatively "conservation conscious" era to be overconcerned with soil and vegetation erosion in the early stages of the establishment of a footpath.

Rates of erosion as a consequence of recreation have been investigated and reported by only a few authors. Speight (1973) found that only 7% of his bibliography of 186 entries included any figures for recreational use, and even fewer mentioned rates of change. Hawkes (1973) measured changes in bare areas and footpath density on Ilkley Moor, using air photographs; Burton (1974) measured vegetation changes at Cannock Chase, using quadrat surveys; Willard and Marr (1970) and Schofield (1967) looked at the effects of people walking on tundra and sand dune vegetation, respectively, measuring changes in amounts of bare soil over a short period. Bayfield (1973) and Burden (1969) measured changes on footpaths - in the Cairngorms and on a Surrey nature trail - but in each case the usefulness was limited: in the Cairngorms the measured path was new, and on the nature trail it was a special occasion. Only Streeter (1975) presents any data for changes on a well established path as the result of "normal" recreation use, and Streeter's measurements are for chalk bedrock on Box Hill, Surrey.

Q2.1 <u>What are the main site conditions likely to result in serious erosion?</u>

The term "site conditions" covers a wide range of characteristics of vegetation, soil, topography and hydrology. The most thoroughly investigated of these is vegetation. Numerous references could be made to the work of ecologists who have studied the interaction of trampling and vegetation, investigating species tolerance, productivity and relative resistance; for example, Bates (1938), Bayfield (1971), Liddle (1973), Leney (1974), and Rees and Tivy (1978). Fewer studies have been made of soils although there is a large amount of agricultural literature on compaction effects, notably Barnes et al (1965).

Soil erosion has been studied predominantly within the field of agricultural soils: for example, Zingg (1940), Wischmeier (1959, 1960, 1976), Meyer and Wischmeier (1969), Chepil and Woodruff (1963), Woodruff and Siddoway (1965), Elwell and Stocking (1973), David and Beer (1975), and Morgan (1977). Geomorphological studies are fewer; examples are De Ploey and Savat (1968), Slay maker (1972), Yair and Klein (1973) and Harvey (1974). Few studies of soil erosion can be found in the recreation and ecology literature; the work of Ceizlinski and Wagar (1970) is one example.

The literature available does indicate that the characteristics of a site will affect its susceptibility, or otherwise, to erosion. This will be discussed in greater detail in chapter two.

Q2.2 How do numbers of people affect rates of erosion?

The effect of recreation pressure on the intensity of erosion is difficult to measure because so many factors affect the result; for example, the seasonal growth of vegetation. Nearly all the data available on recreation and its effect upon vegetation are based on the results of experimental work, in which either trampling simulation or actual trampling has been applied to plots of ground or plants in pots. A series of controlled experiments was carried out by Liddle (1973) on sand dune vegetation. From these he deduced a regression model with sets of coefficients for summer and winter, from which the amount of vegetation remaining, for given numbers of passages by walkers, can be predicted. Bayfield (1971) carried out trampling experiments by walking and also by mechanical simulation. He found that there was a relationship between the damage to a Calluna - Trichophorum community on Cairngorm, and the number of walking passages. His mechanical foot experiments, similar to those of Wagar (1964), showed a similar effect.

However, although experiments such as those described are useful, particularly perhaps in testing the relative resistance of different plant species to trampling, they are rather divorced from the reality of well established footpaths. Footpaths develop gradually, so that the development of resistant species in place of the original vegetation may occur. Simulated or real trampling on hitherto unused plots may be unrealistic, especially since some experiments have used plants grown from seed in pots. In the Lake District, much of the path vegetation is a mixture of grass species, usually Agrostics, Festuca spp., regardless of the vegetation of surrounding areas. Comparative studies of different paths are rare. The work of Gardner (1976) and Willis (1976), both on Snowdon paths, appear to be the only attempts to relate erosion to path use, and the recreation counts are limited in the number of days sampled.

Q2.3 What is the relative importance of numbers of people and site conditions?

Not surprisingly, in view of the limited number of recreation studies, the effects of different factors have scarcely begun to be evaluated. The "site specific" nature of most investigations, such as those already mentioned, precludes comparisons with other sites; the lack of comparative data is deplored by Bayfield (1973 (a)) and Speight (1973). There is a need for studies with sufficient numbers and variety of sites for comparisons to be possible between both recreation and site condition factors (Bayfield, 1973 (a), 1978)

Q2.4 How are factors affected by differences in weather/season?

It has been suggested by many writers that wet ground makes the vegetation more susceptible to damage. Burton (1974) applied an arbitrary factor of "2 times" to calculations of visitor pressure for days when the ground was wet. Liddle (1973) found from his experimental plots that winter damage was approximately twice that in summer from the same number of passages. On the other hand, Bayfield (1971), from a snow trampling experiment, observed that even a few centimetres of snow had an appreciable cushioning effect.

The effects of daily weather conditions and seasons upon moisture levels in the soil, upon growing conditions for plants, and upon snow and ice amounts, are relevent to path erosion amounts. However the magnitude of these effects in comparison with those of recreation pressure amounts and different site conditions is little known.

Summary and Conclusions to Section 1.2

It seemed that the existing knowledge of the effects of recreation upon "natural" landscapes pointed the way towards further work. Although the reaction of many vegetation species to trampling is quite well known, the overall effect on established paths in different environmental conditions is little known. The desirable situation, in which the state of a path can be predicted from its site conditions, age and recreation pressure, is far away.

For the Lake District paths in particular, there appeared to be a number of potentially useful areas of study. It appeared desirable to be able to identify environmental site characteristics which produce paths particularly susceptible to erosion. Furthermore, it seemed important that the relative effects of site characteristics and recreation pressure should be known, since such knowledge must be a pre-requisite of efficient path management. Some assessment of rates of erosion of footpaths was considered to be necessary, not only as an attempt to fill a sizeable gap in the knowledge of the paths, but also to see whether, or which, paths were stable in relation to the numbers of people using them. It was thought that such measurements might be the only way to distinguish sites which were very wide but at the same time stable. It was also thought that by measuring the rates of erosion of footpaths, it might be possible to identify the relative effects of "natural" erosion forces and trampling.

Thus it was hoped that the research might directly contribute partial answers to questions 1.2, 1.3 and 2.1, and that implications might be drawn for questions 3.1 - 3.3. In no way was it intended to make value judgements upon what did or did not constitute a footpath erosion problem, but only to present existing facts as a basis for such judgements, should the need arise.

Since any small scale project can scarcely hope to embrace the whole of a potentially large problem, it was intended from the start to limit the area being studied to one or two parts of the Lake District. Thus, to use the results for other parts of the National Park would be an extrapolation. However, given that the areas chosen were not atypical, there would always be the possibility that extrapolation might be reasonable on logical if not statistical grounds.

1.3 FOOTPATH EROSION AS A VISUAL INTRUSION: REACTION OF WALKERS

In the discussion of Q1.1 (a), mention was made of the views of various organisations and informed individuals on the subject of footpath erosion. However, it was noticeable that little is known of the extent of awareness of the general public. Yet the practical importance of footpath erosion is intrinsically tied up with public perception.

An opportunity presented itself for some simple questionnaire work during the period of the Spring Bank Holiday, 1978, when four fine days were suitable for asking walkers to pause for a short time and express their opinions.

The real aim of the questionnaire was to see whether or not walkers were aware of any problem of footpath erosion. This precluded the use of the words "footpath erosion" early in the questions. It was decided to ask the "open-ended" question, "What do you think of footpaths up the mountains in the Lake District?", with the aim of seeing what footpath characteristics dominated the thoughts of walkers, and whether erosion was mentioned voluntarily. The complete questionnaire is given in figure 1.2, from which it can be seen that certain information was noted and several supplementary questions

FIGURE 1.2 Questionnaire used in the footpath survey on Helvellyn

HELVELLYN FOOTPATH SURVEY   Questionnaire No. _____

Date [ ]   Time [ ]   Location [ ]

Equipment [ ]   Group size [ ]   Family group [ ]

1. IS THIS THE FIRST TIME YOU HAVE BEEN WALKING IN THE LAKE DISTRICT?

YES ⟶ GO TO 4

NO ⟶ CONTINUE

2. WHEN DID YOU FIRST COME AND WALK HERE?

[ ] PRE-WAR
[ ] POST-WAR - PRE-1960
[ ] 1960 - 1970

} → GO TO 3A

POST - 1970 ⟶ GO TO 3B

3A. HOW MANY TIMES HAVE YOU VISITED THE LAKE DISTRICT FOR WALKING?

ANS [ ]
? [ ]

3B HOW OFTEN DO YOU VISIT THE LAKE DISTRICT FOR WALKING?

1 PER YEAR [ ]
EVERY 2-3 YEARS [ ]
LESS FREQUENTLY [ ]

4. DO YOU WALK IN OTHER HILL AREAS?

YES [ ]
NO [ ]
? [ ]

5. WHAT DO YOU THINK OF FOOTPATHS UP THE MOUNTAINS IN THE LAKE DISTRICT?

F. EROSION COMMENT FIRST [ ]
ANTI. CONSERVATION MEASURES [ ]
MENTION F. EROSION [ ]

GOOD [ ]
EASY TO FOLLOW [ ]
ROUGH/STONY [ ]
? [ ]

6. DO YOU THINK THE PATH IS GETTING WORN AWAY AT ALL

YES [ ]
NO [ ]
? [ ]

MENTION WATER/RAIN [ ]
RECREATION PRESSURE [ ]
? [ ]

7. DO YOU KNOW SOME PEOPLE THINK THAT FOOTPATH EROSION IS BECOMING A PROBLEM IN CERTAIN AREAS?

YES [ ]
NO [ ]
? [ ]

MENTION WATER/RAIN [ ]
RECREATION PRESSURE [ ]
? [ ]

were asked, partly to increase the length of the questionnaire so that walkers would consider it worthwhile to stop, and partly to elicit further information that might affect answers to the main question.

The questionnaires were split between the Wythburn path on Helvellyn and the Causey Pike path,* because it was thought that walkers on the latter path would be more experienced. This proved to be true, but the differences were less than expected. Table 1.1 shows that, in terms of equipment, knowledge of both the Lake District and other hill areas, the Causey Pike walkers were slightly more experienced, but in fact the majority of all the hill walkers were well equiped and experienced; there were few casual tourists.

In all, 81 groups were interviewed - none refused - asking one person only to answer the questions. The interviews were carried out half way up each path, in such a position that the walkers would have to come through areas of substantial footpath erosion whether they were going up or down.

The main points of interest, in terms of path user perception of erosion, are summarised in table 1.2. When asked what he or she thought of the paths, several types of answer were invisaged, as can be seen from the questionnaire; in fact the answers were very stereotyped. About half the respondents replied "good", but footpath erosion was mentioned first, unprovoked, by nearly a quarter; just over a third mentioned footpath erosion as one of their answers to this question.

Approximately two thirds, when asked, thought that the path they had just traversed was wearing away; nearly three quarters of the total sample, and 91% of the Causey Pike sample, had read, or seen on television, reports of footpath erosion as a problem in certain areas. About a quarter of

*see figure 3.1, page 60

TABLE 1.1 Experience of fell walkers as elicited from questionnaires.

	PERCENTAGES OF INTERVIEWED WALKERS	
	Wythburn	Causey Pike
Equipped with boots and rucksack	78	86
Walked in the Lake District before 1971	78	96
Walked in other hill areas	75	82

TABLE 1.2 Fell Walkers' opinions of the characteristics of Lake District footpaths, as elicited from questionnaires

	PERCENTAGE OF INTERVIEWED WALKERS		
	Wythburn	Causey Pike	Total
Mentioned path erosion first in aswer to question 5*	24	23	23
Other answers to question 5			
(a) good	47	55	48
(b) easy to follow	17	23	19
(c) rough and stony	12	0	19
Mentioned path erosion at all in answer to question 5	34	46	37
Think path is wearing away	68	68	68
Have heard of footpath erosion as a problem	67	91	73
Possible causes			
(a) recreation	32	9	26
(b) water	12	5	9

*Question 5: "What do you think of footpaths up the mountains in the Lake District?"

the total sample volunteered recreation as a cause of the problem and a much smaller proportion, 9%, volunteered water as a cause.

The simple conclusion to be drawn from this is that the general public is quite well informed and aware of footpath erosion as a problem, whether or not it really is so. Moreover, it ranks quite high as a noteworthy path characteristic.

1.4 SUMMARY

Available evidence suggests that there is some perception of footpath erosion as a possible problem in the Lake District mountains. Research to identify rates of erosion and the main factors affecting footpath development would seem to be a useful adjunct to successful management in the National Park.

CHAPTER TWO

FACTORS IN THE FOOTPATH SYSTEM

From figure 1.1 it was seen that three main groups of factors affect the morphology of a path: the environmental site conditions, recreation pressure and daily and seasonal fluctuations of the weather which modify the effect of the first two groups. Since the weather fluctuations may be considered to be the same for all paths, it is the environmental and recreational differences which are of interest when studying the morphological differences between paths at different sites.

Footpath morphology is a general term, embracing many aspects of a path. These include the spatial extent of a path, the amount of damaged vegetation, the amount of bare ground and gullying into the soil and regolith. These characteristics are produced by the interaction of the forces acting on the paths and the resistance of the materials, organic and inorganic, of which the path is made. Moreover the path itself interacts with these forces and may modify their effect as it develops. A general model can be stated as

$$\left.\begin{array}{l}\text{RECREATION}\\ \text{GEOMORPHOLOGICAL}\end{array}\right\}\text{FORCES} + \left.\begin{array}{l}\text{VEGETATION}\\ \text{SOIL}\\ \text{REGOLITH}\end{array}\right\}\text{RESISTANCE} \Rightarrow \begin{array}{l}\text{FOOTPATH}\\ \text{MORPHOLOGY}\end{array}$$

However, this is highly simplified. Many variables within the system interact to reinforce or counteract each other; some only start to be relevent once, or if, a certain stage or threshold of development is reached. To disentangle the system is difficult, but an attempt is made below to indicate some of the most important factors and show how they relate to each other and to path development. This is done within the broad framework of the simplified model above; that is, the effect of the different forces are considered, with the factors affecting them; the resistance of path materials is considered, again with the relevent factors. Only then is it possible to suggest which factors are the most important and which variables might be measured to represent them.

2.1 RECREATION PRESSURE FORCES

The exact force exerted by trampling on any part of a path is obviously incalculable, for practical reasons, except under controlled experimental conditions. The weight of the walker, the type of footwear, even the gait of the individual all influence the detailed force distribution on the ground. The manner of action of trampling forces varies, since particles may be pushed, rolled and dragged along the path. Also earth and stones cling to the boots and shoes of walkers and so may be transported along the path.

In the absence of control, most research workers have assumed that these factors can be averaged and so they have counted numbers of users. Where this has been done, however crude the estimate, it has usually been demonstrated that path morphology is related to intensity of use, but not necessarily in a linear fashion (Bayfield, 1973 (b); Liddle, 1973; Dale and Weaver, 1974; Boorman and Fuller, 1977)

Barkham (1971) noted, during some experimental trampling, that walking downhill was more damaging than walking uphill. This is clearly demonstrated by Harper et al (1961, 1967), who measured forces exerted by individuals walking up and down a force platform set at different angles. On some mountain paths, it is possible that a strong "up" or "down" bias in use might be significant (Gardner, 1976).

The effect of slope is to alter not only the static components of weight upon the ground, but also the impact, which is related to the momentum generated during the downward passage of the foot. The force plate experiments of Harper et al show that the maximum force exerted is greater on a slope than on level ground. This force can be resolved into two components: a compacting force normal to the surface, and a shear force parallel to the surface in a downward direction - even uphill walking produces a maximum shear force downhill. Both the compacting and the shear force are relevent to path wear, because the compacting force bruises the vegetation and both compacts and vibrates the soil, whilst the shear force drags the surface, scraping soil and vegetation or pushing it downhill. The force plate experiments, for angles of 0,10,15 and 20 degrees, show that the shear force increases with slope at a more rapid rate than does the compacting force. To these direct forces can be added a considerable torque caused by the twisting action of the foot.

Quinn (1977) carried out similar force plate experiments, but for a greater range of slope angles, 5 - 35 degrees. His results, when graphed, show a clear and apparantly linear relationship between slope and the maximum shear force exerted downhill, with force increasing with slope. In contrast, the compacting force normal to the surface increases slightly up to 10 degrees, but then decreases rather irregularly. Moreover, both sets of experiments deomonstrate that there is no clear impact by the foot, but rather a complex series of impacts over time, as the weight is transferred from one part of the foot to the other. The effect of slope is clearly crucial for measuring recreation force, but complex.

On most footpaths, recreation pressure is not concentrated in a single line, but spread out over an area. The behaviour of walkers, that is, the way in which they are distributed across a path when totals are averaged out over a period of time, depends on many factors. Bayfield (1973 (b)) investigated distributions of trampled wires, proportional to the number of walkers, on a developing path at Cairngorm, and showed that there were large differences in the way people walked on different path sites, depending upon the location of obstacles, wet and rough sections. He found, not surprisingly, that walkers tended to avoid badly eroded sections, but that they were constrained to keep to the path if adjacent terrain was very rough. Similar observations were made by Barkham (1971) and Gardner (1977); the latter observed 75% of walkers avoiding eroded sections by using the vegetation at the side.

Monitoring the distribution of walkers across large numbers of path sites is very time consuming, especially as personal experience suggests that the distributions vary with the weather/seasons. In dry conditions, paths become very hard underneath, with a layer of loose stones on top, which can make walking extremely hazardous; hence the vegetation at the side is preferred. In wet conditions, the reverse is true because modern rubber soled boots give a poor grip on wet vegetation; then, wet or damp stones and earth often provide an easier and safer surface. It also appears that the presence of large numbers of people, such as at a Bank Holiday, gives confidence to walkers, so that they are more likely to walk off the path.

It is reasonable to suppose that frequency patterns of recreation use might be as important in assessing recreation pressure as total numbers. Little data exist to confirm or deny this. Ceizlinski and Wagar (1970) investigated the effects of different frequencies experimentally, but found little difference. Liddle (1973) found that the effect of frequency was far outweighed by that of intensity. In any case, other than in controlled experiments, or continuous monitoring, the value of such a variable is hard to obtain.

Summary

The main factors affecting recreation pressure forces are:

(1) the numbers of people using the path

(2) the slope of the ground, which modifies the effect of (1)

(3) the distribution of walkers across the path, which dictates the intensity of the force per unit area.

2.2 GEOMORPHOLOGICAL FORCES

If the vegetation on a path is trampled so much that it dies, then the dead material, roots and organic layer become crushed and finely comminuted so that they are easily removed by wind and water (Burden, 1969; Willard and Marr, 1970), thus exposing the soil and regolith underneath. In practice it is these unconsolidated layers that are particularly vulnerable to erosion subsequent to vegetation removal, because bedrock takes a long time to weather into erodible particles. From the appearance of the vegetation at sites where bedrock is exposed in the path, most bedrock sites are relatively stable unless the rock is too steep for easy walking. In the discussion below, "soil" will be used as a general term to include any unconsolidated deposits below the surface.

The erosion of the soil can occur directly by recreation forces, or by the various geomorphological processes, or by a combination of both. Erosion can be thought of as the product of two sets of processes: detachment and transport, illustrated in figure 2.1. The factors affecting each will be considered separately.

2.2.1 Detachment

(a) Detachment by trampling.

This has already been considered in the previous section, but it becomes relevent to geomorphological processes when material is detached by trampling, and then transported by geomorphological forces.

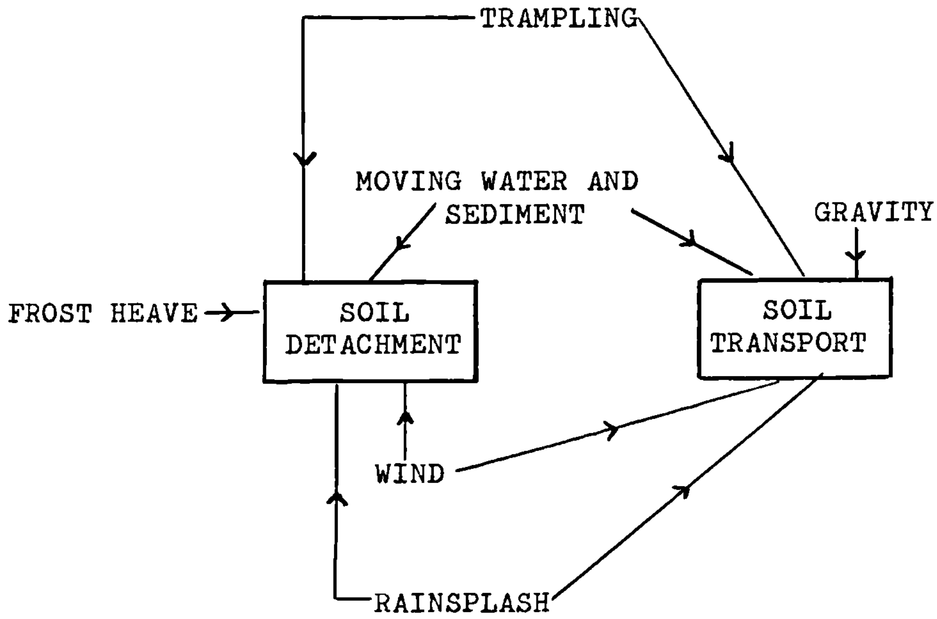
(b) Detachment by rainsplash

This is known to be important, (Smith and Wischmeier, 1957; Hudson, 1971; Foster and Meyer, 1975; Morgan, 1977). Variation of the amount of detachment between different sites is not easily measurable for a large number of sites; it is likely to depend upon the amount of fine particles of soil exposed to rain bearing winds. The efficacy of the process in initiating soil motion depends on the slope of the soil surface and the distance from the nearest transporting agent, such as a streamlet of water.

(c) Detachment by wind

Wind detachment is most likely to be effective on the exposed ridge tops, but must also operate elsewhere. Wind blown particles of grades up to sand size have been reported from Eastern England (Wilkinson et al, 1965; Radley and Sims, 1967) and on the south coast (Young, 1969). However, in the Lake District, it is movement of organic matter - vegetation

FIGURE 2.1 Soil erosion on footpaths as the product of detachment and transport



and peat fragments - which is most evident, mostly on ridges, where fierce cross winds can blow, and upon which the thin soils found there quickly dry out.

(d) Detachment by frost heave

Frost heave in the form of pipkrakes is almost ubiquitous on Lake District paths which have lost their vegetation cover. It is associated with diurnal freeze-thaw (Outcalt, 1969), where ground cooling causes needles of ice to grow out normal to the surface, with small stones and soil aggregates on the end (French, 1976). Ice needles several centimetres long can be seen frequently in the winter (Plate 1). The repeated growth and collapse of ice needles accumlates mounds of sediment, at the sides of paths particularly, which are conspicuous in spring and which form easily eroded deposits for the first heavy rain. To a more limited extent, frost heave operates on the path surfaces as well as the sides, which can act as preparation for erosion by running water or trampling, but on a popular path, trampling can counteract the frost loosening. The operation of needle ice is dependent upon oscillation of the temperature about the freezing point, upon availability of moisture and upon soil texture. It also operates most effectively on paths which have incised surfaces and hence well developed "banks". Thus, some path sites may be more susceptible to this form of detachment than others.

(e) Detachment by running water.

Detachment and transport by running water, possibly aided by a considerable sediment load at times, is one of the most destructive agents of footpath erosion (Snowdonia National Park Officer, pers. comm.). The evidence of sheets of stones deposited down hillsides (Plate 2) supports the idea that water detachment and transport of large stones is possible under certain circumstances. Even quite small trickles of

PLATE 1 Needle ice (piprakes) in the side of a footpath (car keys indicate scale)

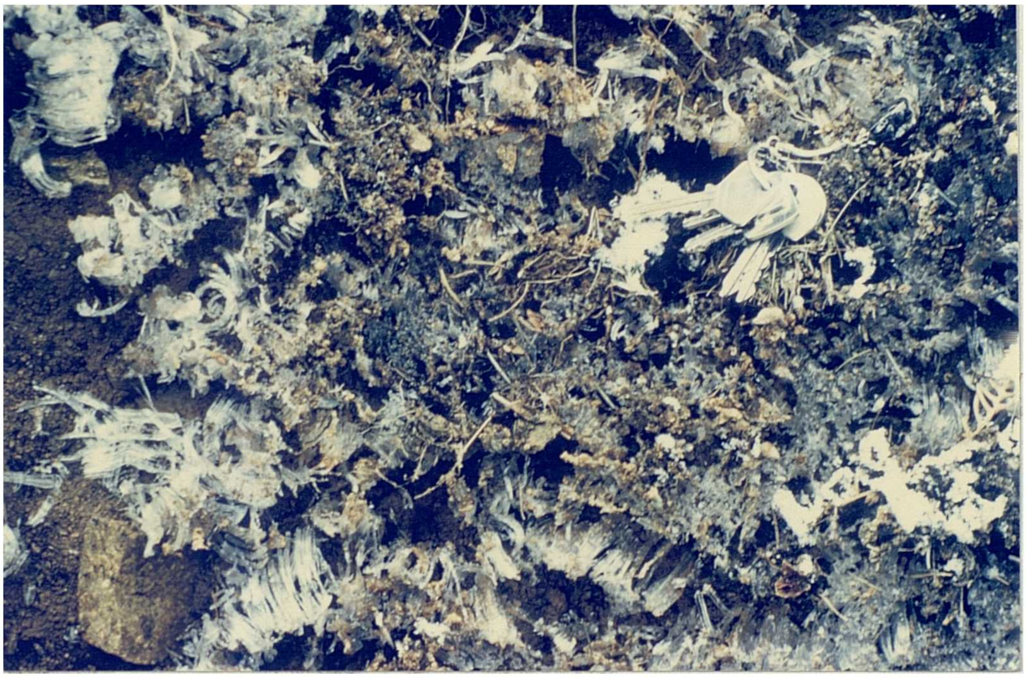


PLATE 2 Stones from footpath erosion,
deposited down the hillside

water have been observed to move stones of a few centimetres in length, by undermining the fine materials supporting them.

Conventional anaysis of fluid erosion shows that detachment occurs if either the fluid drag force or the lift force is greater than the resistance of friction and weight (Carson, 1971). These forces are dependent upon the depth of flow of the fluid, the velocity distribution and the amount of turbulence. On most footpaths, water is collected and channeled, because the path surface is generally lower than the surrounding area. Moreover, the rough stony surfaces of some paths may concentrate water and scour, locally. Very large stones can act almost as bare rock surfaces to impede infiltration; this has been observed on scree slopes by Yair and Lavee (1976). In addition to acting as collecting "gutters" for water flowing down the hillsides, or through the surface layers of adjacent slopes on the uphill side of the path, the compacted nature of most paths makes infiltration rates very small indeed. Thus as some sites the volume of water running down the path may be sufficient to initiate motion of particles. However, as already mentioned, small flows can initiate motion of larger particles than would be expected by conventional fluid analysis - drag and lift - forces because of the undercutting of material supporting them (De Ploey et al, 1975, 1976). Variation in the amount of run off generated at different path sites is an extremely complicated function of many factors, governing infiltration rates, catchment, path shape and actual rainfall amounts. More will be written about this in 2.2.2 (c) below.

2.2.2 TRANSPORT

(a) Gravity

Particles which have been detached by one of the processes mentioned above, whether or not they are subsequently transported by water or wind, are subject to the force of gravity, which may modify any subsequent motion. Thus, particles may fall, roll or slide at a rate which, apart from the frictional properties of the particle and the surfaces, largely depends upon the weight component downslope. To a certain extent this is a simplification, since the shape and density of particles may decide whether they roll or slide, but generally, the gravitational component, which depends on the slope and the particle weight, is of great importance in determining how far particles will move if detached. For example, particles detached by rainsplash travel downslope in proportions - compared with upslope movement - and for distances which increase with slope, because the gravitational component increases with slope and the horizontal distance decreases with slope (De Ploey and Savat, 1968; Slaymaker, (1972).

(b) Wind

Wind as a transporting force, as in the case of its initiating detachment, is of importance for certain particle sizes and densities. However, it is difficult to establish the differences in the force of the wind between one site and another. The force is a function of the wind speed and turbulence (Chepil and Woodruff, 1963), but both can be modified by slope angle and position (Chepil, Siddoway and Armbrust, 1964). These authors suggest that the tops of knolls are particularly vulnerable to wind erosion, because of the compression of the layers of air flow imposed by a knoll; this increases the gradient of the wind and so also its erosivity. Wind speed and turbulence will be affected by the local topography, but also by meteorological conditions. Rodda (1962) employed an exposure index for mountaineous terrain in connection with rainfall amounts, but the situation was simplified by the fact that most rainfall came from a west-southwesterly direction. For wind exposure, the situation is more complex. The strongest winds in the Lake District are westerly, but these are usually associated with rainfall and so would be less likely to cause wind erosion of soil. The variation in wind direction throughout the year probably ensures that all sites situated at the top of slopes and ridges will be subject to a certain amount of wind erosion at some time. However, it should be noted that most footpaths are incised to a greater or lesser extent below the level of the surrounding vegetation. Thus, it is quite likely that the path surfaces are protected from wind erosion at many sites. In addition, most paths from which the vegetation has been eroded are quickly veneered by particles of gravel size or larger, sizes which are too large to be removed by wind.

(c) Moving water and sediment

It is clear that on many paths sufficient water is available to transport quite large amounts of material when meteorological conditions produce a situation with considerable surface run off. Surface run off on footpaths is usual, for all but the lightest rain, but the quantity produced is seldom sufficient for gullies to be incised to any great depth. Deep gullying was observed to have occurred only about three or four times during the two years of monitoring sites, and then not always at the same sites. Small amounts of sediment transport are occurring frequently, however. Trampling is an important agent in this, because it disturbs the soil and either puts it into suspension in the water or enables it to be entrained by the water itself. Differences between sites in the amount and concentration of water run off are very great, depending upon the infiltration characteristics of the site, the catchment for run off, the shape of the path cross-section - which may or may not concentrate run off - and the input of rainfall to the site.

Fluid transport of sediment can take place in different ways: in suspension within the fluid, by saltation, and by rolling or sliding along the surface. In each case, the force exerted by the fluid is a function of more than one factor: not only the quantity of water is important, which affects the depth of flow and its velocity, but also the amount of turbulence and the weight of the water - the slope component. However, these relationships are not simple; the slope affects the depth of water and the velocity, decreasing the former and increasing the latter as it increases, but sediment transport increases with depth and velocity and so the effect of slope is not straightforward. The force available for sediment transport is also a function of path shape, which, if incised, tends to concentrate the available run off, increase the velocity and so cause further incision.

Surface roughness plays a part in water concentration and infiltration (Yair and Klein, 1973; Yair and Lavee, 1976). It also affects the turbulence of water flow (Foster and Meyer, 1975; Francis, 1975). On footpaths, surface roughness is usually a function of particle size, although vegetation and microrelief also may be relevant.

Summary

The main factors affecting the geomorphological forces are

(1) the exposure of the site to frost heave,

(2) the exposure of the site to wind,

(3) the volume of water run off, the way in which it is concentrated - or otherwise - and the velocity/turbulence patterns within the flow,

(4) the gravity-slope component, which modifies the above, and also modifies any transport resulting from trampling initiated detachment of particles.

2.3 VEGETATION RESISTANCE

The resistance of vegetation to trampling is well documented, but mostly in terms of observed phenomena rather than causative processes.

One usual effect of trampling seems to be a reduction in species variety (La Page, 1967; Liddle, 1973; Goldsmith et al, 1970; Roberts, 1974; Willis, 1976), but on footpaths, this is not of much ecological significance because the area involved is so small. In the Lake District, the fellside vegetation is already poor in terms of species diversity because of the wet climate, acidic rock types and the sheep's selective grazing (Dewdeney, Taylor and Wardhaugh, 1959; Ratcliffe, 1960; Pearsall and Pennington, 1973; Bocock and Adamson, 1976).

Another effect of trampling is a reduction in vegetation productivity (Bayfield, 1971; Bell and Bliss, 1973; Allcock, 1974; Leney, 1974; Grime and Hunt, 1975). Liddle (1975 (b)) found a relationship between primary productivity and amounts of trampling, using data gathered from many sources. However, as pointed out by Huxley (1970), there are few species which can withstand a long period of heavy trampling pressure.

Observations and experiments by many research workers suggest that the type of plant is important. Those plants which produce buds and shoots at ground level are less vulnerable than those producing this growth well above the ground (Bates, 1938; Davies, 1938; La Page, 1967; Gimmingham, 1972; Beeching, 1975). Some research results include named species as being particularly vulnerable or resistant. In general, most grasses and some sedges seem to tolerate trampling more than do the woody heath species. Moderate trampling can even encourage grass tillering (Bayfield, 1971; Liddle, 1973; Allcock, 1974; Goldsmith, 1974). Tussocky forms are particularly resistant because their upper parts cushion the lower shoots and the roots (Liddle, 1973).

The following species are found on the Lake District fells and have been listed by one or more authors as being resistant to trampling: Nardus stricta, Agrostis spp, Fesuca spp, Deschampsia spp, Juncus squarrosus (Willard and Marr, 1970; Barkham, 1971; Liddle, 1973; Burton, 1974; Leney, 1974; Beeching, 1975; Willis, 1976).

In contrast to the grasses, most of the heath species seem vulnerable, because their perennating buds are at the tip of the shoots and there are only a few reserve buds at the base of the stem, (Gimmingham, 1972; Willis, 1973). Calluna vulgaris, Vaccinium spp and other similar species have been found to be vulnerable by Burton, Leney, Beeching and Boorman and Fuller (1977). Another susceptible species is Pteridium aquilinum (Barkham, Burton). Pteridium stores food in and reproduces itself from rhizomes, but if the fronds are crushed, the means of rhizome repletion is destroyed and eventually the plant ceases to appear (Smith, 1977).

Any type of vegetation is less resistant when conditions are unfavourable for growth. It has been noted that trampling is more damaging in the winter (Liddle, 1973), although not necessarily so with a snow cover which is deep enough to cushion the force (Bayfield, 1971). On the other hand, where snow has lain for a long time, it produces saturated soil and rank vegetation when it melts. Even without snow, vegetation in the early spring is susceptible; Slater and Agnew (1977) observed that 63% of the annual surface damage to a Calluna - Sphagnum community was done at Easter by 40% of the annual visitor total.

The variation in climatic conditions for growth between sites is not easily measured, because mountain topography can create microclimates differing widely in cloudiness, windiness, rainfall and snowfall - and hence in moisture and temperature regimes - even over short distances (Barry and Van Wie, 1974). Mountain climates are harsh, especially on exposed ridge tops, where temperature extremes, drought and wind abrasion make vegetative growth more difficult than further down the slopes (Oliver, 1964) and susceptible to natural erosion (Billings, 1974); also seedling establishment is slow and many species reproduce viviparously. Thus, regeneration of bare areas can be slow, particularly if the top soil has been eroded to leave a layer of boulders, and if water runs down the path frequently, washing away fine particles and seeds.

When the mean temperature is near the limit for growth, small variations due to local topography have a greater effect than similar variations at a higher temperature (Hunter and Grant, 1971). Thus, sites at high altitudes are vulnerable in the periods of the year which are marginal to growth, autumn and spring. On the other hand, in summer, more moisture is retained at high altitudes, so that low altitudes may be disadvantaged. Even in the Lake District fells, where average annual rainfall is greater than 2500mm on the high fells, drought is not uncommon on the steep slopes with their shallow soils and their rapid run off (Manley, 1973).

Another factor of vegetation resistance which is affected by altitude is snow cover, although aspect and distance from the west coast are also relevent. In the valleys of the Lake District, any snow cover is short lived, 12 days per annum on average, but this figure rises to over 100 days above 800m (Manley) and snow deposits can remain until May or June in favourable localities.

It has been shown that many climatic variables are closely related to altitude (Taylor, 1976) and that these in turn affect vegetation growth. Hunter and Grant (1971) assessed the impact of climate on the growth of Lolium perenne at sites in east Scotland between 166 and 720m. They found that wind exposure, soil temperature, soil moisture and vegetation development all were proportional to altitude. Ceizlinski and Wagar (1970), in simulated trampling experiments, found that both aspect and altitude were significant for vegetation resistance. However, one of the problems in using climatic variables is that since the climate influences soil formation and hence indirectly vegetation, natural species type changes with altitude and confuses the apparantly simple relationships found by Hunter and Grant, who were using the same species throughout their experiments.

Another factor lowering vegetation resistance appears to be the occasional presence of high levels of moisture in the soil. This reduces its stength so that plant roots are more easily disturbed or dragged out, or the leaves embedded. Moreover, trampling smears mud over the leaves, which reduces photosynthesis, and a slipping foot can tear long scars in the turf.

Growing conditions are not only a function of climate. Soil is important - in terms of nutrient supply, aeration, moisture retention and rooting depth. In the Lake District, soil type is closely related to altitude (Pearsall and Pennington, 1973). This is partly because the distribution of materials from glacial and periglacial processes is such that deep accumulations of well drained deposits are found mainly on the lower slopes, in contrast thin mantles over bedrock, higher up the mountains. To this can be added the colder, wetter climate of the higher altitudes, which inhibits the action of soil fauna so that an acid mor humus builds up, which rapidly leaches the underlying mineral soil if free drainage obtains. The potential productivity of these mor soils is low compared with the mull soils of lower altitudes (Pearsall and Pennington).

Whatever the original soil, the effect of trampling is generally to alter soil aeration, moisture and temperature regimes because compaction occurs, and so the nutrient cycle and root development are altered (Barnes et al, 1971; Chappel et al, 1971; Leney, 1974; Liddle and Greig-Smith, 1975). Not all soils change by the same amount and in some cases trampling may even create a more favourable condition for vegetation growth.

<u>Summary</u>

The main factors affecting the vegetation resistance are

(1) vegetation type - its life form

(2) vegetation productivity - depending on its climatic and pedological environment.

2.4 SOIL AND REGOLITH RESISTANCE

2.4.1 Resistance to Geomorphological Forces

Factors affecting the resistance of unconsolidated deposits to erosion are complex because

(i) under different conditions and for the operation of different processes, the same factor might not be relevant;

(ii) erodibility may be most dependent upon the amount of disturbance of the surface trampling;

(iii) erodibility factors may be partly time dependent; for example, soil erosion may proceed until such time as the surface is sealed by rainsplash, or the readily eroded paricles are removed (Young and Mutchler, 1969; Yair and Klein, 1973; D'Souza and Morgan, 1976).

Excluding the effect of internal friction and cohesion in a deposit, resistance to movement is a function of particle size, but it is clear from the available literature that such an over-simplified view is inadequate. It is also clear from the literature that the identification of the soil characteristics which make up its erodibility is difficult.

The susceptibility of soils to erosion is so important to agriculturalists, that it is not surprising that much of the literature on soil erosion is found in this field. Geomorphologists have apparantly been less interested, apart from work in fluvial geomorphology on the erosion of river banks. With this preponderance of research in lowland areas, any application of the conclusions to mountain soils may be an unrealistic extrapolation, particularly as so many of the results are based on empiricism rather than theory.

Clearly, no one index of susceptibility satisfies the complex interation of processes operating in a natural situation. Many authors suggest that particle size factors are important, and various indices have been derived from these, reviewed by Bryan (1968) and summarised by Hudson (1971). Wischmeier et al (1971) derived an index depending on the five soil properties: particle size proportions of silt and sand, organic matter, soil structure, and profile permeability index. Bryan, in an experimental study of some Peak District soils, found some relationship between soil erodibility and soil properties. He found that brown earths were less erodible than podsols, A horizons less than B horizons, and that erosion decreased with particle size from sandy loam to clay loam. Bryan suggested that the explanation of this lay in the proportion of clay and organic matter, because this affected aggregate stability, which variable he later demonstrated to be an efficient predictor of erosion (1971, 1974), as long as the proportion of water stable aggregates in the soil was significant. In a poorly aggregated soil, Bryan found that texture was of greater relevance.

In the Lake District, many of the mountain soils are developed under mor humus, and most are highly leached so that the amount of colloidal material - organic matter and clay - present in the top soil is small. This means that the proportion of water-stable aggregates will be low (Baver, 1966). Also, one of the effects of trampling is to reduce aggregate stability (Chappel et al, 1971). Furthermore, footpaths are subjected to cycles of frost heave in winter, and Bryan (1971) demonstrated how frost action reduced aggregate stability. Thus, there is reason to believe that the erodibility of Lake District footpath soils might be related to soil texture.

Little data exist for the erosion of stony soils. Yair and Klein (1973), investigating gravel and stone sized sediment on plots at slopes of 14-26 degrees, found that only fine material became entrained. Harvey collected sediment from two gullies in the Howgill Fells, Cumbria, at slopes of 35-55 degrees (1974). Some of the processes he described may be operating on Lake District footpaths. The material being eroded is similar - drift and solifluction deposits with many large boulders and stones - but the slopes are steeper. Harvey found that

(1) erosion by water was dependent on the strngth and infiltration of the materials, which in turn he found dependent upon previous precipitation and frost;

(2) erosion by mud flows followed prolonged low intensity rainfall, heavy snowfall and melt, and thawing of needle ice; this would suggest a stong seasonal effect in the suitability of meteorological conditions to erosion - such conditions as mentioned by Harvey are to be expected during most winters in the Lake District;

(3) erosion by stones and boulder fall followed their loosening by ice.

In the Howgill Fells, mud flows were caused by water absorption by the soil to a level beyond the plastic and liquid limits of the material. It is possible that similar processes operate on some paths in the Lake District, but the appearance of newly eroded sites suggests that water erosion is more usual; channels are clearly incised, with meandering form andrectangular cross-sections, from those of small dimensions in fine materials to those in large gullies in bedded screes. Thus, it seems resonable to suppose that the relative erodibility of sites will depend mainly on both the particle size distribution of the fine earth fraction and that of the stones and boulders.

The discussion so far, of the resistance of the soils to erosion, has centred around water erosion. Susceptibility of soils to frost erosion by the action of piprakes also appears to be related to particle size (Yong and Warkentin, 1975). Corte (1971) found that silty soils favoured the growth of needle ice, given that sufficient moisture was present. Lake District soils in winter usually have a high moisture content because precipitation is plentiful and evaporation rates are low.

Resistance of soils to wind erosion is as complex as resistance to water erosion; both follow similar principles of fluid erosion. Resistance to motion varies with the size of particles. Bagnold (1954) suggests that particles of a size less than 0.03 mm, when once settled were found to be difficult for wind to move. Chepil and Woodruff (1963) suggest that few particles of a size greater than 0.5mm are moved by wind and even smaller ones may not move if they are sheltered by large particles. Surface roughness is also relevent, but, although an uneven surface increases turbulence which favours erosion, the roughness reduces wind velocity and thus inhibits erosion (Chepil, 1945).

Generally, smooth surfaces are more erodible (Chepil and Woodruff, 1963). Lake District footpaths vary considerably in their surface roughness, depending on whether the surface is vegetated, partly vegetated or on the size of the surface particles. Another relevant factor to a soil's resistance is its moisture content, since wind erosion is associated with dry soils (Woodruff and Siddoway, 1965).

For both wind and water erosion, increasing size of particles above silt sizes is associated with decreasing amounts of erosion. Within the lower soil horizons, especially where the underlying deposits are of bedded screes and other similar formations, the proportion of large stones and boulders increases, and these coarse materials are often embedded in highly compacted clay and silty material. Hence resistance to erosion may increase, but at the same time, such horizons often mark the effective boundary between permeable and almost impermeable materials and so tend to gather more throughflow, which in turn increases the run off force and, for large flows, probably counteracts the greater resistance of these layers.

2.4.2 Resistance to Trampling Forces

The extent to which materials move underfoot depends upon friction and the cohesion of the materials. The stress exerted by trampling is resisted according to the sheer strength, which can be expressed approximately as

$$s = c + (\sigma' + u) \tan\phi$$

where s = shear strength

c = cohesion

σ' = effective normal stress

u = pore water pressure

ϕ = angle of internal friction

(Carson and Kirkby, 1972)

Cohesion is increased by the presence of colloidal sized particles - clay and organic matter. The normal stress is the force pushing the particles together and depends on the normal component of the trampling force. The pore water pressure depends upon the amount of moisture present and on pore space characteristics. For completely dry soils or coarse materials, it is zero; up to a critical level it increases with moisture, but then, if the soil becomes too wet it becomes negative and tends, therefore, to push the particles apart. The angle of internal friction - $\tan\phi$ is the coefficient of friction - depends on various particle characteristics since it describes how readily particles slide past each other. Hence, particle size, sorting of sizes, shape and surface friction are all important.

Thus to compare path sites for their resistance to trampling forces, it seems once again relevent to consider particle size distribution. Also geological differences may be significant; for example, many of the Skiddaw Slate particles are smooth, and slaty particles may slide or roll quite differently from the more spherical volcanics. The slates are also highly jointed in general, softer and more susceptible to weathering (Hollingworth, 1954).

Highest moisture content - and so pore water pressures which may assist ready deformity of the trampled materials - is associated with saturation accompanying the spring or winter melting of snow. This may be because maximum infiltration of water occurs under a snow cover. Thus, paths which are deeply incised and can hold drifted snow, especially on north and east facing slopes at high altitudes, are more susceptible to plastic or liquid flow when trampled. Some seepage areas are also susceptible.

The presence of boulders, already mentioned as affecting the behaviour of walkers, should be noted again, in the context of resistance, because, particularly at low slope angles where erosion tends to be less, boulders can absorb much walking pressure. Often in such situations, the vegetation is preserved around their edges so that erosion is generally reduced. On the other hand, on steep slopes, the reverse is true and the loosening of boulders can be accompanied by considerable disturbance if they bounce and roll far downhill.

Summary

The main factors affecting the resistance of soil and regolith are

(1) particle size - of fine earth fraction,

(2) stoniness - proportion and size of stones and boulders,

(3) shear strength.

2.5 THE INTERACTION OF THE FACTORS

Although the factors affecting footpath erosion have been presented so far in a fairly simple way, in reality the system is complex because there is much interaction among them. Some indication of this interaction can be gained from figure 2.2, which sets out the main path erosion factors.

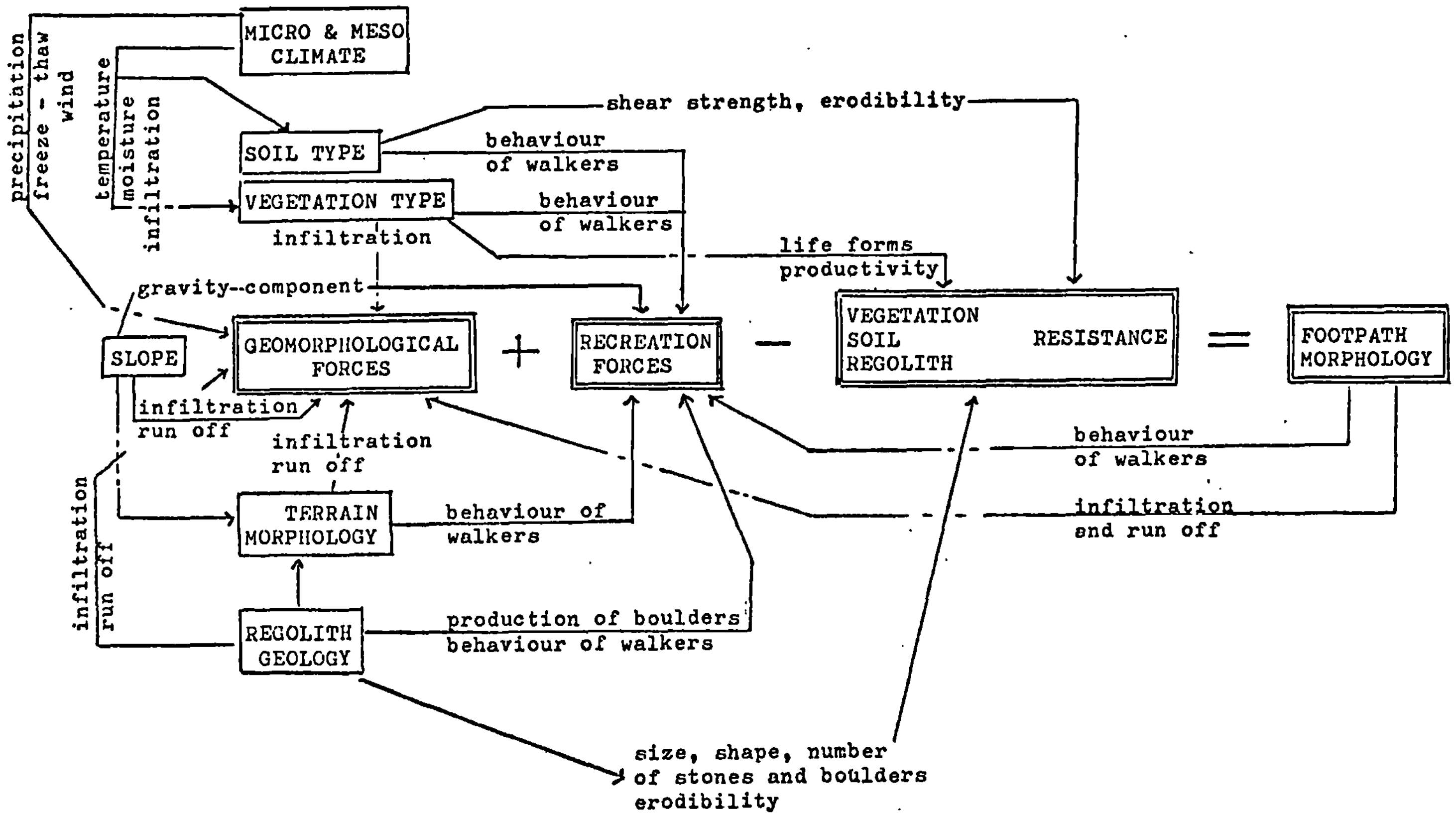
One of the effects of these interactions is that some factors may influence both the erosive force and the resistance to erosion, which may make the analysis of morphological data difficult to interpret. Another effect is that some factors may coexist so closely that their separate influences cannot be assessed. To cite examples, soil type may affect erosive force, through its water infiltration and run off properties, and also resistance, through its shear strngth and erodibility. The close association between soil, vegetation type and altitude is another problem. In the Lake District both soil and vegetation tend to be altitudinally zoned (Pearsall and Pennington, 1973).

2.6. SUMMARY OF THE MAIN FACTORS

Recreation Force

1. Number of people using path.
2. Distribution of people across path area - reaction to site.

FIGURE 2.2 The interaction of forces in footpath erosion and the influence of environmental site conditions.



Geomorphological Forces

3. Exposure of the site to meteorological conditions favouring frost heave and strong winds.

4. Volume of water run off .

5. Distribution of water flow patterns within the path cross-section .

Vegetation Resistance

6. Vegetation type - its life forms, methods of reproduction and growth .

7. Vegetation productivity - reactions to climatic and pedological environment .

Soil and Regolith Resistance

8. Textural characteristics - particle size distribution of the fine earth fraction, stoniness, size and type of stones and/or boulders .

9. Shear strength.

Gravity component

10. Slope angle - modifying many of the factors listed above.

Path Morphology

11. Cross-sectional form of the path, itself a product of the forces listed, but in turn affecting the way in which they operate, in particular, modifying the distribution of people, water run off.

CHAPTER THREE

RESEARCH AIMS, STRUCTURE AND SAMPLING DESIGN

3.1 RESEARCH AIMS

In order to attempt to answer some of the questions outlined in the first chapter, the research was divided initially into two sections. The first section was to consist of a programme of path monitoring to assess the rates of change of a range of footpath site types. To this was to be added some information on the existing amount of footpath erosion on several paths, with a range of site types, so that some indication of the state of the footpaths and the amount of change might be given. The second section comprised a morphological survey, of a wide range of different sites, with the aim of identifying possible relationships between path morphology and site conditions by inductive reasoning from existing associations. In the event, there was a certain amount of overlap between the sections, since the effect of different site factors on erosion amounts could be seen to be operating in the changes measured during the monitoring programme.

During the progress of the research, it became evident that only limited information could be obtained about the relative effects of the erosion agents, because of the lack of control over the relevant factors. Thus a small scale experimental project was set up, to try to evaluate some relative effects of trampling and meteorological conditions upon the amount of soil loss from a specially created footpath.

3.1.1 Path monitoring

This was carried out at two levels of detail, in order to try to achieve two different aims.

(a) Measurements were made at a small number of sites, such that the detail and accuracy of measurement were sufficient for changes over a period of days or weeks to be visible in the data. It was hoped that such measurements would enable the effects of heavy recreation pressure, for example at a Bank Holiday, and severe rainstorms to be isolated. Because of the difficulty encountered in trying to make accurate measurements, at frequent intervals, the number of sites monitored was small, but it was sufficient to indicate the probable pattern at other sites.

(b) At a much larger number of sites, less detailed measurements were made, to establish changes at a larger scale than those in (a), and to enable monitoring to be carried out over a greater range of site types than was possible with the more detailed measurements. These sites were measured twice a year, in March and September, in order to divide the measurements between the season of highest recreation pressure, summer, and that of highest rainfall and run off, winter.

One of the problems in making short term measurements of change, is that it is difficult to separate long term trends from short term fluctuations. In an effort to solve this problem, air photographs were used to examine the sites over a period of about twenty years. The sites that were chosen and the techniques with which they were measured are discussed in detail in chapter four.

3.1.2 Morphological survey

This was carried out over a series of 25 paths, for which recreation pressure was different, the paths ranging from those which were little used to those which were very popular at all times of the year. A large number of sites was investigated, to try to cover the range of ecological and geomorphological conditions found in the area. The first task in the morphological survey was to identify the most relevant factors in the footpath system and choose measurable variables which were representative of those factors. The subsequent fieldwork was carried out in three phases, increasing the level of detail in the investigation at each phase.

3.2 VARIABLES CHOSEN FOR MEASUREMENT IN THE MORPHOLOGICAL SURVEY

For many of the factors listed in section 2.6, it is not easy to collect, from a large number of sites, data which exactly represent the factors. Some of the factors, for example, wind, exposure, water run off, vary in time depending upon synoptic and/or antecedent conditions. Other factors, such as recreation pressure, are impossible to define exactly, since past as well as present use is relevant. Inevitably, the use of surrogates becomes a necessity, to enable the large number of sites needed to cover the range of environments to be investigated.

In the discussion below, the main factors listed in section 2.6 are reconsidered within the context of the way that they can be measured or the surrogates that might be chosen for them. (The number of the factor, as listed in section 2.6 is given in brackets in each case).

3.2.1 Recreation force

Number of people (1)

Preliminary fieldwork suggested that an estimate of recreation pressure could be obtained from measurements of the width of uneroded paths (see section 5.3 in chapter 5). However, estimates were eventually obtained of total numbers of users for a sample of days over a range of paths (section 5.4). The limitations of such counts are discussed in chapter 5, but notwithstanding these, it was found that the estimates were a reasonable approximation to recreation pressure.

Distribution of people (2)

It was not practicable to monitor the distribution of people across all the paths and so it was necessary to consider the factors which caused variation in these distributions among paths. Observation, and subsequently the preliminary work on path widths (section 5.3), suggested that the angle across the path produces a degree of restriction which increases as the angle increases, presumably because sideways walking on a steep slope is difficult. Certain path properties such as permanent wetness and large boulders on the surface, tend to cause an increase in width as walkers spread out to find ways around the obstacles. Distributions are also affected by the surface roughness, usually the product of erosion, since walkers find some eroded surfaces uncomfortable and slippery. Other properties such as vegetation height, steep drops and wide open grassy slopes, can restrict walkers or encourage them to spread out.

The variables, angle of cross slope, presence of permanent wetness and boulders were all used. In addition, an attempt was made to estimate the "potential width for path development" as a measure of the degree of restriction caused by the type of site characteristics mentioned above.

3.2.2 Geomorphological Forces

Site potential for frost heave and wind (3)

Because it was not possible to measure these directly, it had to be assumed that the variables, altitude and aspect, which have already been mentioned as being related to climate, would suffice. This meant that the more detailed effects of individual shelter or exposure effects would be lost. However there seemed no easy way of avoiding this. Although various exposure indices exist, they depend upon knowing the direction of the prevailing winds. In the mountain area being studied, wind patterns are extremely complex, because they relate to the interaction of the regional wind with the alignment of valleys, through which funneling can occur, and at the head of which convergence of air can cause strong currents, depending on the speed and direction of the regional wind. However, it was thought that the major ridges between the valleys, along which several of the paths are found, would be more exposed than the valleys and main slopes, and so this was another variable used, as a presence-absence effect.

Volume of water run off (4)

This is an extremely complex factor because it depends on many other factors. Water run off is the product of the water flowing over the surface of the ground, throughflow within the vegetation, litter and soil horizons and contributions from sections of path immediately above the site being studied. The amount of overland flow and throughflow is dependent upon the input of precipitation and the infiltration characteristics of the site. The amount of that flow which is trapped within a path section depends on the depth to which the path is incised below the surrounding ground surface, but also on the alignment of the path, since those paths travelling across slopes can act as effective "gutters". Contributions from path sections above depend upon the relationship of these sections to the site being considered; water and sediment is sometimes channeled into the path sections below, sometimes diverted down the adjacent hillside. Another factor which may be relevant is the "catchment" characteristics of the site - whether there is a large area contributing; whether the shape of the slope is concave (water convergence), convex (water divergence) or straight (normal).

Whether the input of rainfall to different slopes and sites is significant is difficult to establish. Rainfall data in mountains is not easily obtainable because there are large errors in using rain gauges due to the effect of wind (Rodda, 1967). The limited data available suggest a correlation of rainfall with altitude (Taylor, 1976) which may be modified by aspect and valley convergence.

Since it was not possible to measure the infiltration rates for each site, surrogates had to be found from more easily measurable soil, vegetation and topographic properties. Water runs off most quickly if infiltration rates are so low that surface run off can occur. This more likely to occur where soils are thin, where bedrock is near the surface, if there is an impermeable horizon near the surface, such as an iron pan in a podsol, and where the slopes are steep. Surface run off also occurs on areas adjacent to footpaths where trampling has been sufficient to cause soil compaction and where often the vegetation is short grass, itself a product of trampling.

Throughflow rates are governed by vegetation, litter and soil infiltration and diffusion rates. These in turn are a function of the complex structure of root channels, pore spaces, and all the other connecting spaces found within the various horizons. Rates are also influenced by the slope of the surfaces, which determines the strength of gravitational pressure. However, although soil structure and texture, and the effect of slope are theoretically important (Kirkby, 1969), other factors may predominate. Arnett (1974) found that throughflow variations were unrelated to slope angle, slope length, surface roughness or soil texture, but were partly explained by permeability contrasts between horizons, and by root or rhizome penetration channels.

Where there is overland flow, and as already intimated, footpaths produce run off readily, the volume of water ought to increase downslope because an increment of water transported from up the path is added to any "in situ" input at each succesive position. Thus it might be expected that the bottom of a path section might experience greater erosion than the top. Work demonstrating the effect of slope length on the erosion of low angle agricultural soils has been done by Zingg (1940), Smith and Wischmeier (1957), Young and Mutchler (1969), and Meyer et al (1975). However, Lam (1977) found no relationship between erosion and run off length on badlands in Hong Kong, and De Ploey et al (1976) have suggested that run off on natural slopes is complex, with many discontinuities in the flow. Preliminary work on a number of sites on the Lake District where the path length was thought to be of sufficient length for this erosion effect to be possible, demonstrated that erosion amounts were not related to distance down the path.

Some experimental data suggest that slope curvature and roughness affect the amount of run off (Zingg, 1940; Smith and Wischmeier, 1957; Young and Mutchler, 1969; Soons, 1971; Monteith, 1974; De souza and Morgan, 1976). Yet Lam (1977) found no such relationships. Yair and Klein (1973) working on stony mountain soils, found slope relationships which were the opposite to that which they had expected, which they thought was caused by the differences in materials found on slopes of different angles. Yair and Lavee (1976) found a complex slope and roughness effect. One explanation for the disparity among results may be that on real, as opposed to experimental, slopes, some of the factors tend to occur in fixed combinations, such as coarse materials and high slope angles. Also, as pointed out by Toy (1977), low intensity rainfall may have more opportunity for infiltration on a long slope, compared with high intensity rainfall, which may produce cumulative run off downslope.

Clearly, the amount of run off at a site is difficult to estimate from static site characteristics. The variables chosen included vegetation and soil type, soil depth and texture, slope curvature, estimates of the size of the area of hillside contributing to overland flow and/or throughflow, and estimates of the contribution of path sections above.

Water flow within path cross section (5)

This could only be estimated from the measured cross section. The contrast between one path and another is mainly in the extent to which gullying occurs, since it is this which causes water to flow inwards to the lowest point as well as down the footpath. Concentration of the water in this way increases its erosive potential.

3.2.3 Vegetation Resistance

Vegetation type and productivity (6 and 7)

The dominant species making up the site community were recorded, but vegetation productivity was unknown. However it could be assumed that for any one species, its productivity could be related to its soil and climatic environment. Thus variables such as soil depth, altitude, aspect and position on or off one of the main ridges, variables already being measured for reasons above, might indicate levels of vegetation productivity.

3.2.4 Soil and regolith resistance

Textural characteristics (8)

These were measured during the third phase of the sampling. The variables included were particle size, stoniness, size of the larger particles on the path surface, organic content of the soil, moisture content, depth and type of the organic horizon and soil depth. Soil type, which appeared to be related to many of these variables, was recorded at all stages, as was the geology.

Shear strength (9)

Measurement of shear strength in stony soils is difficult. To obtain a representative result, for any laboratory test, a large undisturbed sample is needed. For a field test, the only practical solution in the type of area being studied is some form of portable penetrometer. Attempts were made to obtain representative penetrometer readings, but the soils were so stony that it was thought that the results were probably meaningless. Readings were too closely related to the incidence of stones at the point at which the penetrometer was inserted.

3.2.5 Other factors

Gravity component (10)

Slope angle was measured at each site. This variable was treated as the slope of the site rather than the path surface, which was, at times, irregular.

Path morphology (11)

Variables selected for describing the morphology of the paths were the width of the path - as visible on the ground, including trampled vegetation and bare ground -, the amount of bare ground, the depth of gullying and a category of erosion. The latter variable was an attempt to identify paths which were undergoing erosion, according to various criteria (see section 6.1.4), and identify them as eroding independently from identifying them as having a certain amount of erosion. In addition to the path morphology at the site, that of sites immediately above and below was used as a variable to express the possible interaction of adjacent sites; for example, it was thought that a badly eroded site might affect sites below with deposition of eroded material; gullied sites might migrate backwards by headward erosion - this was observed at one of the sites being monitored for rates of change.

The details of measurements and estimated categories are given in the relevent sections for the different phases of sampling.

3.3 SAMPLING CONSTRAINTS AND SAMPLING DESIGN

3.3.1 Definition of the sampling area

The Lake District National Park comprises an area of about 2000 km^2, of which about 45% consists of land higher than 250m OD. Of this, probably about half - that is, an area of 400-500 km^2 - represents the popular walking and climbing area. Thus, in a limited study such as this, some selective sampling was necessary.

It was thought desirable to investigate paths (i) on the two main geological types, namely the Skiddaw Slates and the Borrowdale Volcanic series (Hollingworth, 1954); (ii) with a wide range of recreational pressure. A further criterion was accessibility, since economy of the time spent travelling and climbing to sites would mean that a greater number could be visited.

Using these criteria, the most suitable area seemed to be that centred on the Helvellyn range, and north west of the Newland valley (Figure 3.1). The area includes both the slates, in Newlands, and the volcanics, Helvellyn. Both areas are popular with walkers and have been visited for the purpose of fell walking for over a century. However, the Newlands valley does not compare with Helvellyn in popularity. Quoted by Baddeley's guide as the mountain possibly more ascended than any other in the Lake District (Baddeley, 1935), Helvellyn has maintained its attraction up to the present day (Wainwright, 1957), no doubt as a result of its accessibility. Within the Skiddaw slates area, it was thought that only Skiddaw itself, and possibly Cat Bells, adjacent to Derwentwater, approached Helvellyn in popularity and so these were eventually included in the sampling area (Figure 3.2).

3.3.2 <u>Sampling constraints</u>

Having defined the area of study, certain additional criteria were chosen to define the type of path being studied. These were as follows.

FIGURE 3.1 Location of the study areas

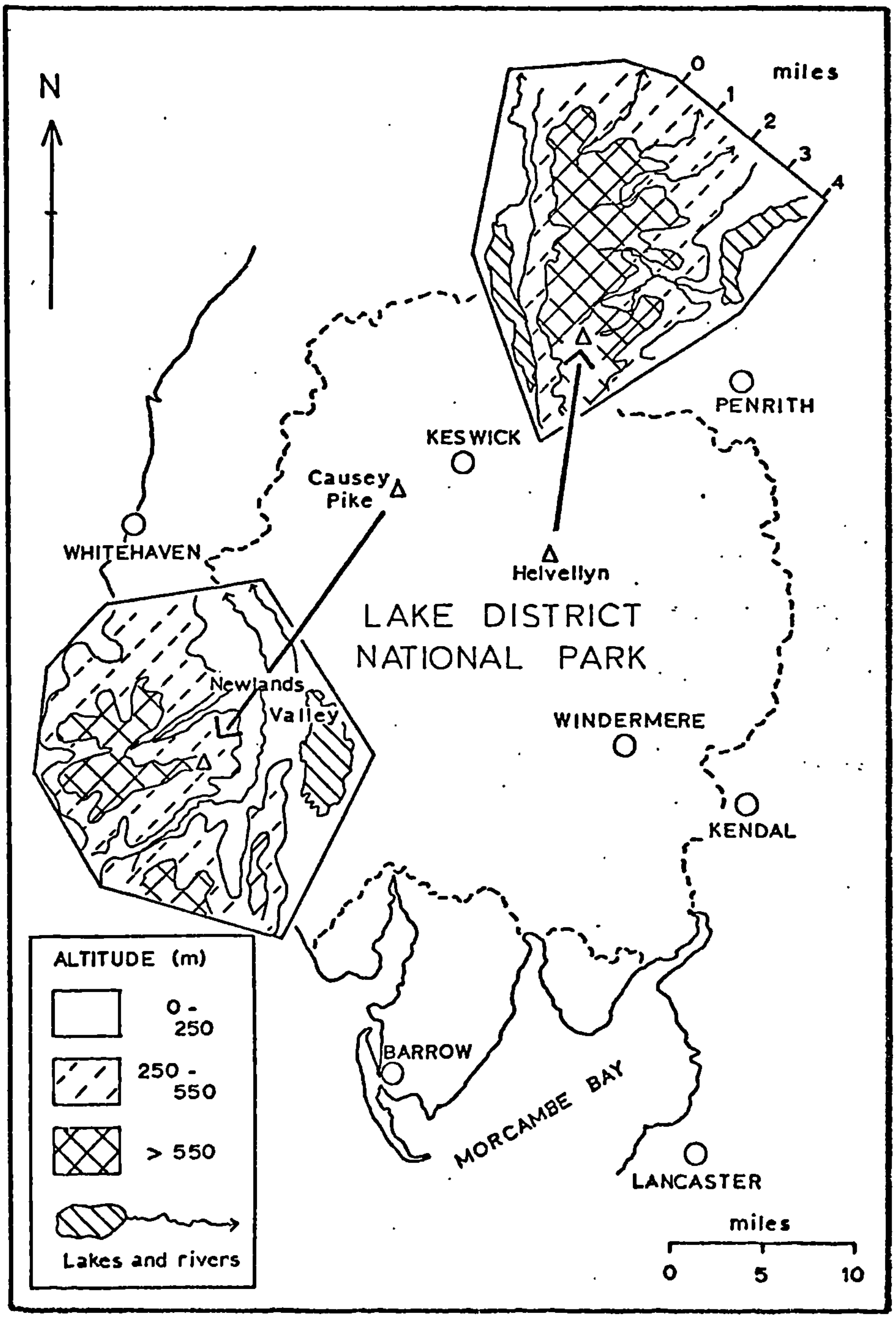
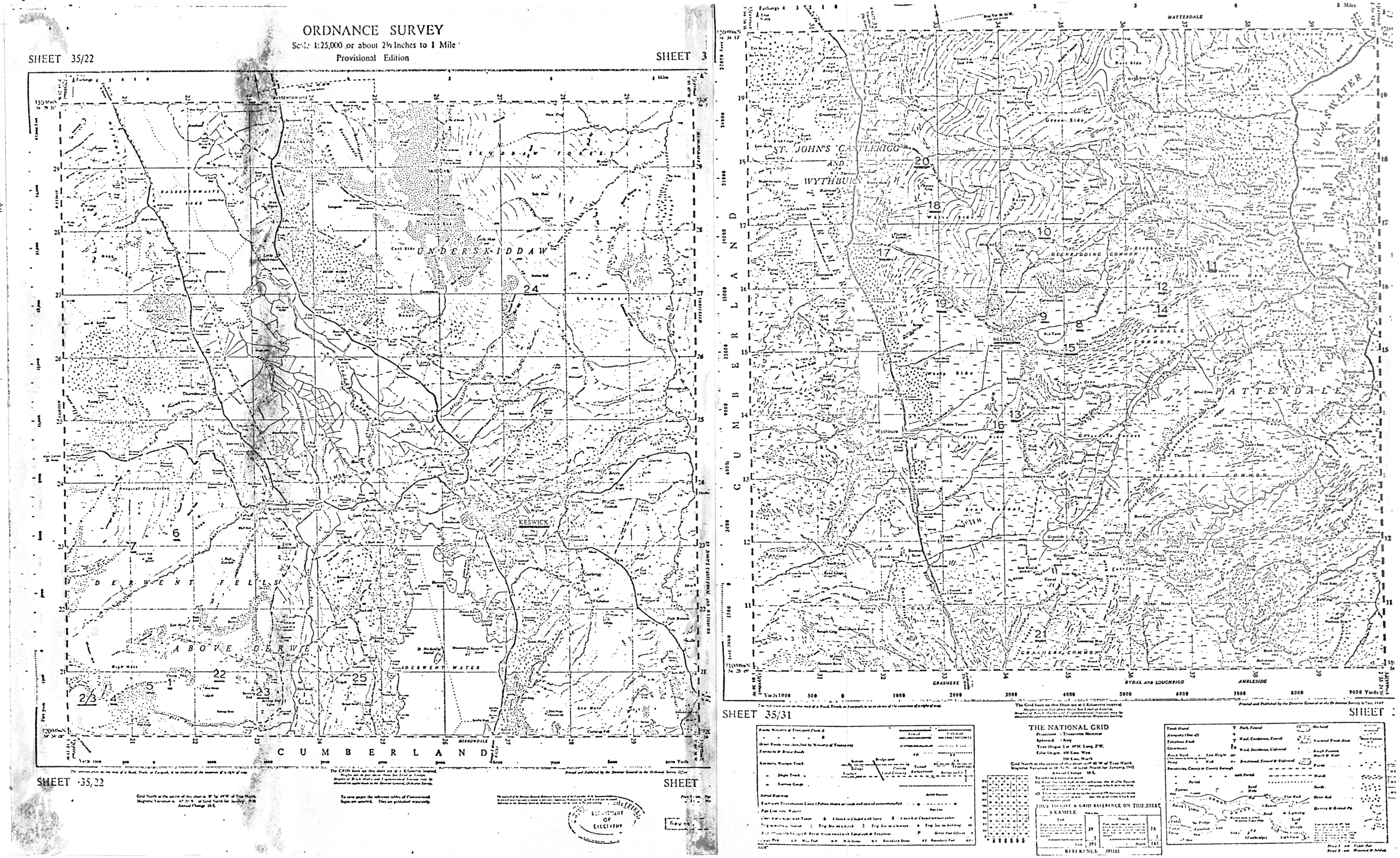


FIGURE 3.2 Location of the sampled paths

1. Causey Ridge
2. Sail A
3. Sail B
4. Scar Crags A
5. Scar Crags B
6. Grisedale Pike A
7. Grisedale Pike B
8. Red Tarn
9. Swirral Edge
10. Kepple Cove
11. Mires Beck A
12. Mires Beck B
13. Dollywagon Pike
14. Striding Edge A
15. Striding Edge B
16. Wythburn
17. Helvellyn Gill
18. White Stones
19. Browncove Crag
20. Fisher Gill
21. Tongue Gill
22. Causey Pike
23. Rowling End
24. Skiddaw
25. Cat Bells



(i) Paths should be naturally worn tracks up the mountainside, and used primarily for recreation. This excluded all constructed paths and roads, such as those to old mines, and also excluded farm tracks. In the event, this criterion was hardly used since, once beyond the valley road, most paths led directly into open country. The only path along which sheep were known to be shepherded regularly was that on the lower slopes of Causey Pike; it was observed that in practice, although the shepherd and his dogs used the path, the sheep moved along many parallel tracks of their own through the heather. On the whole, most shepherding seems to avoid the loose, stony footpaths.

(ii) Paths should be of similar age, in order that differences between paths should reflect levels of use rather than the stage of development. Obviously, the age of a path and its history of use can rarely be established. Even the existance of a path on a map, or otherwise, is not a reliable guide. For example, the main path up Causey Pike, which shows clearly on air photographs taken in 1947, is not recorded on either the Bartholemew, nor the Ordance Survey one inch to the mile maps published until the 1970's. A combination of sources was used to verify that a path had been used at least throughout the post-war period, and where possible, before that. The sources used were maps, air photographs (although complete cover was not obtained), and guide books. The paths and the sources are listed in table 3.1. Most of the paths in the area appear in most of the sources, and all are obviously old, well established paths. However, what can never be established is the way in which relative use among the paths has changed.

(iii) Paths should have sufficient length to permit the measurement of a variety of site characteristics, whilst retaining recreation pressure. Thus, the joining of two or more paths was taken to divide paths into different sections - labelled A and B in path names (Table 3.1). If any one path section was very short, especially if the terrain was homogeneous with respect to the variables being studied, that section was excluded. Thus the actual summit ridge of Helvellyn, for example, was not included.

3.3.3 Sampling Design for the morphological survey

The number of site variables which might be relevent to the erosion state of a footpath is high. Moreover, some are more easily identifiable or measurable than others. From the start it was realised that a crucial variable, recreation pressure, could never be more than an estimate, since the form of a path is the product of past as well as present use. It was also realised that comprehensive measurement of many soil properties would not be feasible at a large number of sites.

Thus a sampling design was chosen to accommodate these problems. Since one of the criteria of section 3.3.2 provided for site variability within each path, a series of sites on each path would obviously provide some information on relationships between path form and site variables for that path. Although an estimate for recreation pressure was eventually established, initially this could not be assumed; thus sufficient sites had to be chosen on a path to validate some sort of multivariate analysis. It was thought desirable to have at least twenty sites on a path, in case analysis had to be carried out entirely on a path by path basis.

In an attempt to establish some general "footpath - site" relationships, before embarking on more detailed soil

TABLE 3.1 List of paths satisfying criteria for inclusion in the sampling - see figure 3.2 for path location.

PATH	GEOLOGY	SOURCE OF INFORMATION (listed below)						PHASE OF SAMPLING
		1	2	3	4	5	6	
Grisedale Pike A	Skiddaw	x	x	x	x	x	N	2
Grisedale Pike B	Slates	x	x	x	x	x	N	2
Causey Pike				x			A	1
Rowling End		x	x	x	x	x	A	1
Scar Crags A		x	x	x	x	x	A	2
Scar Crags B		x	x	x	x	x	A	2
Sail A		x	x	x	x	x	A	2
Sail B		x	x	x	x	x	A	2
Cat Bells		x	x	x	x	x	A	1
Skiddaw		x	x	x	x	x	A	1
Causey Ridge		x	x	x	x	x	A	2
Fisher Gill	Borrowdale	x	x	x	x	x	B	1
White Stones	Volcanics	x		x	x	x	B	1
Helvellyn Gill			x	x	x	x	B	1
Brown Cove Crag		x	x	x	x	x	B	1
Wythburn		x	x	x	x	x	B	1,2
Tongue Gill		x	x	x	x	x	B	1
Dollywagon Pike		x	x	x	x	x	B	1,2
Mires Beck A				x	x	x	N	2
Mires Beck B				x	x	x	N	2
Swirral Edge			x	x	x	x	N	2
Striding Edge A			x	x	x	x	N	1,2
Striding Edge B			x	x	x	x	N	2
Red Tarn		x	x	x	x		N	1,2
Kepple Cove			x	x	x	x	N	1,2

<u>Source of information</u>

1. Stanfords Guide, 1860
2. Ward Lock Guide, 1935 (16th Edition)
3. Wainwright Guides, 1955, 1962, 1964
4. O,S. 1" map, 1966
5. Bartholemew 1" map, 1954
6. Air photographs, A - 1947
   B - 1953
   N - no cover obtained

Note: the last column of the table indicates in which phase the path was sampled, see section 3.3.3

and regolith examination, a multi-phase sampling scheme was adopted. Eventually, three phases of sampling were used and at each the amount of detail in the site measurements was increased. The surveys were preceded by some preliminary work to decide upon certain details of some of the techniques used.

From the eligible paths listed in table 3.1., half were chosen at random for the first phase of measurement. Subsequently, the paths Skiddaw and Striding Edge were added to the list, purposely, because they were thought to be the most popular paths on each lithology. For the second phase, all remaining paths were used; also some of the first phase paths were re-sampled to include the variables added at the second phase. Time prevented all of the paths being "upgraded" to the second phase. During the third phase, an attempt was made to control the variation of certain variables by the method of sampling, so that the effect of site soil and regolith characteristics could be studied in more detail.

Within each path, homogeneous sections were identified in the field. This was done subjectively and so is subject to the limitation that one person's view of uniformity is not necessarily the same as that of another person. The degree of homogeneity is to a certain extent a question of scale, but also depends upon the characteristics being considered. In this study, a section of path was considered to be homogeneous if path morphology, terrain, vegetation and surface materials were only variable to the extent of minor fluctuations (Plate 3). Although, as a definition, this may appear vauge, in practice, not only do paths fall clearly into separate sections as they climb across different parts of the hillside, but also the transition zone between one section and the next is seldom more than a few metres.

PLATE 3 A series of "homogeneous" path sections on Causey Pike

Most path sections identified were greater than 20m long.

In sampling within each path, two conflicting criteria have to be reconciled. On one hand, to allow enough data for some multivariate analysis, at least twenty sites is desirable, and more, if the variation in site types allows, will lessen the chances of reaching false conclusions due to local coincidences of site variables. On the other hand, to sample too closely along a path can result in spatial correlation effects which may have a deleterious effect upon some forms of analysis. Preliminary sampling on sections of path with uniform vegetation type, soil type and similar aspect, showed that, for changes in path morphology as a result of different slope conditions, spatial autocorrelation was present if the sampling interval was 10m, present for some characteristics at 20m, but not present at all at 30m. If this were to be representative of most paths, it seemed advisable to sample not more than once out of each of the homogeneous strata already mentioned, unless a stratum was of considerable length, say of the order of 100m.

Ideally, having stratified each path into homogeneous sections, the selection of these for sampling would have been on the basis of the range of variables in the area; so that a suitable number of strata would have been allocated for each variable being studied, to encompass the range of that variable. However, in practice this was not possible. One of the reasons was that not all variables are visible on the surface, for example, soil type. Another was that it was known from the start that every combination of variables did not exist in the area, for example, certain vegetation types were closely linked with geology, not as a cause and effect, but as a result of land use. Furthermore, to guarantee enough sites on a path, for some paths it was necessary to sample all the strata. Thus, the selection of sites was made on the basis of one per stratum, randomly selected, but excluding any transition zone between two strata. If a homogeneous length of path existed of 100m or more, then sites were selected on the basis of one per 50m. This method, therefore, occasionally over-sampled path sections. However, there was no means of knowing in advance that all the site variables were as uniform as those used to identify the strata, and the sampling interval seemed satisfactory for obtaining the desired number of sites. Almost without exception, long uniform stretches of path were found on Helvellyn, where the paths were in any case much longer than those up from the Newlands valley, because Helvellyn is larger in area and higher in altitude. The sampling method is summarised below.

(i) Paths were identified as having uniform recreation pressure ,

(ii) paths were stratified into homogeneous strata,

(iii) within each stratum, a site was selected randomly.

3.3.4 Sampling design for path monitoring

(a) Detailed measurements

The details of this are given in Chapter Four; thus, at this point comments are limited to a statement of the sites chosen. Five sites were used. Two were situated on Helvellyn, on the popular Wythburn path, one being an established track - visible on the 1953 air photographs - and the other a recently initiated short cut. Thus it was hoped to be able to compare the rates of change of small path sections at a different stage of development. Another old track was chosen as the site for a third set of measurements, on the Causey Pike path (Figure 3.2), which was a site of similar characteristics to those on Helvellyn, but on Skiddaw Slates, and with lower recreation pressure. The remaining two sites were situated at the northernmost point of the Cat Bells path (Figure 3.2), on Hawes End. The reason for wanting to monitor the Hawse End path was that its lower section had been closed to walkers in the spring of 1973, but a new path was being worn on adjacent ground, by walkers ignoring the official path around the corner of the closed eroded section. A site was chosen on both the closed section and the new path; thus it was hoped to be able to see whether the old path started to recover and how fast the new path became worn.

(b) Large scale measurements

Two paths were chosen for these sites. By limiting the measurements to two paths, rather than distributing the sites throughout the sampling area, it was possible to compare changes under different site conditions, for constant recreation pressure. By choosing two paths rather than one, it was hoped to be able to distinguish the effect of different amounts of recreation pressure. The paths chosen were again the Wythburn and Causey Pike paths, because both were long and varied with respect to site conditions. On each path, sites were selected on the basis of their existing state, and were chosen so that some sites were apparently in the process of erosion and deterioration, and some were apparently stable. Initially, 40 sites were chosen, but more were added at a later date to make the measurements more representative. Details of this are given in Chapter Four.

Since the rare opportunity of measuring the development of a new path in this area presented itself, in the form of the new Hawse End path, five sites were chosen to compare differences in site conditions, and to compare with the sites on established paths.

To reinforce or correct any conclusions drawn from these measurements, which were over only a short time period, all the sites were identified on air photographs, which covered a much longer time period, from 1947 for Causey Pike and from 1953 for the Wythburn path.

CHAPTER FOUR

FOOTPATH MONITORING

Foothpath monitoring to investigate rates of erosion was carried out at two levels of detail, as already mentioned in chapter three. Changes in the chosen path sites were identified from measurements of transects across the paths between fixed points. The detailed measurements were carried out using a rigid bar; the other measurements were made from taut cord.

4.1 CORD TRANSECTS

4.1.1 Sampling

Three paths were used for monitoring. The Wythburn path up Helvellyn was chosen as an example of a popular route, very accessible and used in winter as well as the main holiday season. The Causey Pike path (Newlands Valley) presented a contrast as a less well known route, not so accessible and, it was thought, with few visitors in the off-peak season. A third path was chosen because, by chance, a section of the north ridge route up Cat Bells (Derwentwater) had been closed by the National Park Wardens in 1973. A new path was in the process of development at a short distance away and so this was monitored until it, too, was closed by the Wardens in the spring of 1978. A new path in such a well established area is uncommon; it afforded an unusual opportunity to follow the erosion of a path from an early stage.

The sample of sites was chosen purposely to provide examples of paths some of which appeared to be stable and some of which were eroding; the number of sites was limited mainly by the time required for their measurement, but also by the range of site types available on the paths.

(a) Wythburn Path

Initially, eight sites were chosen, of which three appeared to be stable and five eroding. Of the latter, two were apparently in the process of rapid erosion. Thus, categories of possible erosion rates were indicated: little or no erosion, moderate erosion and rapid erosion, named categories A, B, C respectively. The original intention was to choose three transect lines within each of the eight sites, to be a representative as possible of the whole site, so that wherever possible a transect should cross the main areas of erosion, transport and deposition of the eroded material. However, this design was not rigidly adhered to, since

(1) stable sites would not be expected to have areas of erosion and deposition, although they might act as transporting surfaces for material derived from elsewhere;

(2) at some eroding sites, material was deposited in a scatter of stones, washed far down the hillside.

Subsequently, more transects were added to some of the sites to confirm, or otherwise, the results being obtained, bringing the final total to thirty transects, ten in each erosion category, A, B and C.

(b) Causey Pike Path

This path is shorter tha Wythburn and less varied.

Seven suitable sites were found and, with the transects added at the later stage, a total of twenty seven were measured, nine in each category.

(c) Hawse End Path

The new path developing at Hawse End, the north ridge of Cat Bells, was relatively short, about 250 metres; only five transects were established, two in category A, two in category B and one in category C.

Thus, sixty two transects were established in all, but not all of these survived through the whole period of monitoring. The measurements were taken in the spring and the autumn, thus dividing the year approximately into the season of maximum recreation force and that of maximum geomorphological force. The sites established are listed in table 4.1.

4.1.2 Method of measurement

(a) Fixed points.

One of the problems of establishing fixed points in a popular recreation area is to leave markers that can be found again, but not accidentally by visitors or sheep. Three different methods were used.

(1) wooden stakes were hammered in, in suitably inconspicuous positions, behind vegetation; nails were placed in each post to locate the measuring cord.

(2) markers were positioned in the ground, then hidden by stone cairns.

(3) markers were used, as in (2), at which a pole was erected vertically at the time of measurement.

Experience showed that techniques (1) and (3) were more accurate than (2) providing that the cord was high enough to clear the irregularities in the ground, but not so high as

TABLE 4.1 Transects established for monitoring by cord technique, 1976-8.

PATH	SITE	TRANSECTS	DESCRIPTION OF SITE	VEGETATION	SLOPE (degrees)
WYTHBURN	1	1.1-1.3	multiple tracks and short cuts	Pteridium	20-24
	2	2.1-2.3	stony track with steep cross slope	Nardus	16-19
	3	3.1-3.3	path along top of convex "fan" and cutting through zig-zags	Nardus	23-24
	4	4.1-4.3	short cut routes up knoll, through zig-zags	Agrostis-Festuca	30-32
	5	5.1-5.2	original path very gullied and rough, and alternatives	Agrostis-Festuca Vaccinium	20-27
	6	6	stable grassy track	Agrostis-Festuca Nardus	2-3
	7	7.1-7.2	stable track, good stony surface	Nardus	10-16
	8	8.1-8.2	short cut through old zig-zags	Nardus	21-23
CAUSEY PIKE	1	1.1-1.3	steep cross slope, much water seepage after rain	Calluna	13-16
	2	2.1-2.3	multiple tracks and eroded gully	Calluna	19-27
	3	3.1-3.3	widespread over grass, small gully	Vaccinium	20-22
	4	4.1-4.3	steep cross slope parallel tracks	Calluna	18-19
	5	5.1-5.3	very bouldery and gullied	Calluna	25-26
	6	6	stable, well vegetated	Nardus-Juncus	13
	7	7.1-7.2	stable, easy grass and earth surface	Calluna	10-11
HAWSE END	1		stable, grassy	Pteridium	19
	2		bifurcated, stepped	Pteridium	22
	3		steps well developed	Pteridium	30
	4		steep cross slope stone surface	Pteridium	18
	5		steps, some collapsed and initial stage of gullying	Pteridium	32

to create large errors of measuring from the cord to the ground. Method (3) created less visual intrusion than method (1), but it was subject to the error of locating the pole vertically and was also more time consuming.

(b) Transects.

A transect across the path was obtained by stretching a nylon cord, marked at ten centimetre intervals, between the fixed points. The transects established at a later stage were measured from a steel tape, but it was not thought that this improved the accuracy of recording changes significantly. Constancy of tension was obtained at a transect by noting the initial cord position at each of the fixed points and subsequently maintaining the cord in the same position.

A rigid metre rule, with a small spirit level attached, was used to record the vertical distance of the path surface from the cord - the vertical distance was chosen as it could be establsihed more accurately than the shortest (perpendicular) distance. At the point of measurement on the cord, the rule was placed at right angles to the cord, thus, theoretically, defining a unique point on the path. Measurements were taken at 10cm intervals across the path, at 20cm intervals across neighbouring vegetation, at any change of surface type - for example a soil-vegetation boundary - and at any relevant topographic feature.

Thus for each transect it was possible to obtain measurements of bare ground width, damaged vegetation width, average depth of the eroded surface and an estimate of the area of the cross-section. In addition, the total width of the path was estimated, identifying the path limits from changes in vegetation character such as the length of grass and absence of species intolerant of trampling (see section 6.1.1). Vegetation damaged by trampling, that is, with surface leaves bruised and smeared with soil, and patches of bare soil or exposed roots, proved to be an unreliable variable. Vegetation, apparently badly damaged at one time, showed considerable powers of recovery later (see plates 4 (a) and (b) and section 6.1.1).

(c) Accuracy

The original reason for establishing fixed points was to monitor changes in path width, not only the overall width, but also the width of bare ground and damaged vegetation. The technique seemed likely to be adequate for such large scale measurements. During the process of making the first measurements, the vertical profiles of the transects were recorded, and the possibility of repeated measurements of these profiles was considered.

A suitable site was chosen to test the accuracy of repeated measurements at the one transect. Since many of these transects were quite long - many eroding paths are 10m or more in width - and complex, with alternating grass and earth, one such site was chosen, site 5 on Hawse End. The transect was approximately 11m long between two wooden stakes; the path surface was a mixture of grass and earth, and "stepped" in places; also, the vertical distances being measured varied between a few centimetres and about half a metre. Thus the site was typical of most of those at which transects were taken and there was no reason to suppose that levels of accuracy would not be comparable elsewhere. Measurements were taken twice, then the cord was removed, replaced and measurements taken twice again. This was repeated six months later when the bracken (Pteridium) had died down and presented a more easily measured surface at the sides of the path. Since the profile of eroded and

PLATE 4(a) Vegetation erosion (April 1977) ......

PLATE 4(b) ..... and recovery (September 1977)

damaged parts had ulimately to be related to the "fixed" profile of the relatively untouched vegetation sections, the success of the method was judged by its ability to reproduce reasonably consistent values of the average difference between the "eroded" and "non-eroded" surfaces.

Errors arise from two sources: from positioning the cord and from judging the vertical position of the rule. In spite of taking care, it was found that the cord position did vary slightly, possibly being deflected a little by tall vegetation, Pteridium at this site, and/or by small differences in fastening it around the marker points. This can be seen in the variation in the average depths, table 4.2, among different cord positions, especially in the September measurements. Large errors between individual points on the transects may arise if the boundaries between vegetated and eroded surfaces are ambiguous or change in depth abruptly downslope, since, then, a slight error in placing the rule or cord may result in the measurement of a considerably different position.

Some individual measurements vary by a few centimetres, hence the usefulness of the average, in which some of the errors will be self cancelling. The results show that at this site, the difference between vegetated and eroded surface is, on average, reasonably consistent - there was apparantly a small amount of soil erosion during the winter. The sum of lengths of bare ground is also reasonably consistent, almost surprisingly so in view of the alternating grass and eroded earth, frequently stepped, at this site.

It seemed that changes in the average depth of the eroded surfaces of the order of centimetres, and changes in the length of bare ground of the order of ten/twenty centimetres might be accepted as more than the probable

TABLE 4.2 Accuracy of the fixed cord transects: repeated measurements at site 5, Hawse End

		AVERAGE DEPTHS (cm)			
		D_E	D_V	D_D	L_B
SEPT 1976					
Cord 1st	Transect 1	36.4	25.7	10.6	183
position	Transect 2	36.1	25.8	10.3	184
Cord 2nd	Transect 1	41.7	31.8	9.9	187
position	Transect 2	42.0	31.6	10.4	190
APRIL 1977					
Cord 1st	Transect 1	37.4	25.2	12.2	192
position	Transect 2	37.4	25.0	12.4	190
Cord 2nd	Transect 1	38.4	25.9	12.5	193
position	Transect 2	38.7	26.5	12.2	194

D_E Average distance of eroded surfaces below cord

D_V Average distance of vegetated surfaces below cord.

D_D Average depth of eroded surfaces below the depth defined by the vegetated surfaces.

L_B Length of transect with bare ground.

level of error at most transect sites. Such a level of accuracy is acceptable for sites measured only at six monthly intervals. Also, it is sites which are eroding frequently and rapidly that are most likely to be of concern in footpath conservation; these sites were expected to become evident at this level of accuracy.

4.1.3 Results

Of the forty-three sites established and measured in March, 1976, three were abandoned because the markers at each end of the transect disappeared, thus rendering the exact re-establishment of the sites impossible. One way in which markers could be lost was through the unintentional disturbance of the ground by walkers; sheep also appeared to turn over stones, and, after heavy winter rain, debris could bury a site, making location of the fixed points difficult, even with the aid of photographs. In this respect, the wooden stakes were highly advantageous and, although untreated wood was used, most of the posts remained firm and un-rotted from November, 1975, when they were first inserted, until the last measurements in April, 1978.

At one site, one marker disappeared, but the line of the transect was re-established using the remaining marker and the known compass bearing of the line.

The depth changes measured were vertical. These were converted into surface lowering figures, normal to the surface, by multiplying the vertical depths by the cosine of the angle of the path surface, measured at the site.

The results are given in tables 4.3 - 4.5. Changes in the width of bare ground, Δ BG, and in the average depth of the path, Δ D, were calculated from the measurements. Changes in the area of the eroded cross-section, ΔA, were estimated from the plotted profiles, as also were noticeable changes, such as the collapse of a section of turf, the incision of a gully or a large increase in the amount of damaged vegetation. Not all the changes recorded in tables 4.3 - 4.5 are necessarily greater than probable levels of accuracy in the measurements. Changes are probably significant if (a) increase in the length of bare ground is greater than or equal to 20cm, (b) increase in the average depth is greater than or equal to 2cm, or (c) the profile has undergone a noticeable change. Using these criteria, it appears that the number of profiles with a significant change is high, varying from 31% to 67%, depending on the path and the season (Table 4.6)

However, such figures may be misleading if the changes are no more than short term fluctuations. This is particularly noticeable at site 1 on the Wythburn path, where heavy rain tends to wash down the incised path, clearing out loose stones, which are subsequently replaced with others kicked down from further up the path.

The occurrence of unusually high rainfall, October 1977, and consequent gullying in some apparently fairly stable paths, for example site 2.2 at Wythburn, demonstrated that occasional "catastrophic" events might have far reaching effects upon path development.

Much of the erosion recorded on the Hawse End path may be a consequence of instability at new sites which have not had sufficient time to come to any sort of equilibrium with the amount of recreation pressure.

4.1.4 Discussion

Net changes over the two year period present a more reliable guide to long term trends, but even these need to be

TABLE 4.3 Changes measured at the cord transects, Wythburn, 1976-8

SITE	C	March 1976 - Sept. 1976				Sept. 1976 - April 1977				April 1977 - Sept. 1977				Sept. 1977 - April 1978			
		ΔBG	ΔA	ΔD	P	ΔBG	ΔA	ΔD	P	ΔBG	ΔA	ΔD	P	ΔBG	ΔA	ΔD	P
1.1	B	0	-270	-0.9		0	50	0.2		20	-400	-1.2	*	60	1040	2.6	*
1.2	B	12	180	0.6	*	0	70	0.2		0	-60	-0.2	*	30	360	0.8	
1.3	C	60	170	0.8	*	10	60	0.2	*	0	30	0.1	*	0	1020	3.7	*
2.1	A	0	0	0.0		0	0	0.0		15	20	0.1	*	0	0	0.0	
2.1a	A									0	0	0.0		0	140	0.3	
2.2	A	0	190	0.6		36	30	0.1	*	0	-10	0.0		0	600	1.4	*
2.2a	A									0	240	0.8		0	0	0.0	
2.3	B	4	280	1.5		0	0	0.0		0	0	0.0		15	0	0.0	
2.3a										0	0	0.0		0	0	0.0	
2.3b										0	0	0.0		0	0	0.0	
3.1	A	0	0	0.0		0	0	0.0		0	0	0.0		0	0	0.0	
3.2	B	136	1120	1.7	*	30	1100	1.3	*	0	0	0.0		10	1800	2.3	*
3.3	B	28	260	0.5	*	0	0	0.0		60	1680	2.5	*	5	800	1.2	
4.1	B	0	90	0.3		Markers for fixed points lost											
4.2	C	4	280	1.8	*	0	0	0.0		0	0	0.0		0	-100	-0.6	*
4.3	C	16	590	1.4	*	44	2000	4.1	*	0	0	0.0		20	1200	2.4	*
4.3a	C									10	40	+0.0		0	850	2.8	*
5.1	C	10	60	0.7		0	400	4.0	*	40	480	3.4	*	100	1920	8.4	*
5.1a	C									20	400	5.0	*	20	1020	12.5	*
5.2	C	14	70	0.4		30	800	3.1	*	0	0	0.0		40	200	0.7	
5.3	C	0	490	1.7		0	800	2.9	*	30	720	2.3	*	20	400	1.2	*
5.3a	C									0	1510	2.8	*	130	3000	6.0	*
6.0	A	0	0	0.0		0	0	0.0		0	0	0.0		0	0	0.0	
6.0a	A									0	0	0.0		0	0	0.0	
7.1	A	0	0	0.0		10	200	0.5		0	0	0.0		10	300	0.8	
7.2	A	0	100	+0.0		0	0	0.0		0	0	0.0		0	0	0.0	
7.2a	A									0	0	0.0		0	0	0.0	
8.1	B	43	1290	1.3	*	0	80	0.1		10	680	0.7		0	1000	1.0	
8.1a	B									0	0	0.0		0	1060	2.1	
8.2	B	4	500	0.9		0	0	0.0		0	200	0.3		0	200	0.3	

C Category of erosion at site

P Noticeable profile change at site

ΔBG Increase in bare ground (cm)

ΔD Increase in average depth (cm)

ΔA Increase in area of cross-section (cm^2)

TABLE 4.4 Changes measured at the cord transects, Causey Pike, 1976-8

		March 1976 - Sept. 1976				Sept. 1976 - April 1977				April 1977 - Sept. 1977				Sept. 1977 - April 1978			
SITE	C	ΔBG	ΔA	ΔD	P	ΔBG	ΔA	ΔD	P	ΔBG	ΔA	ΔD	P	ΔBG	ΔA	ΔD	P
1.1	A	4	380	2.1		0	2100	5.5	*	0	-320	-1.8	*	0	400	2.2	*
1.2	C	0	-300	-1.4		0	1000	4.5	*	0	200	0.9	*	0	3300	15.0	*
1.2a	C									0	0	0.0		0	4900	21.3	*
1.2b	C									0	0	0.0		10	1600	7.3	*
1.3	C	40	2080	2.7	*	0	1400	1.8	*	20	-1800	-2.3	*	60	400	0.5	*
2.1	B	0	100	0.3		Markers for fixed points lost											
2.2	B	30	0	0.0		0	0	0.0		0	0	0.0		0	0	0.0	
2.2a	B									0	0	0.0		20	300	1.0	
2.2b	B									0	0	0.0		0	0	0.0	
2.3	C	0	-264	-1.1	*	0	1400	5.6	*	20	400	1.6	*	0	1100	4.1	*
3.1	B	0	0	0.0		0	500	5.0	*	20	300	3.0		30	700	4.7	*
3.2	B	65	1250	6.2		0	100	0.7		Markers for fixed points lost							
3.3	A	0	0	0.0		0	0	0.0		0	0	0.0		0	0	0.0	
4.1	A	0	120	+0.0		0	0	0.0		20	0	0.0		25	160	0.6	
4.2	B	30	-1600	-3.0	*	0	0	0.0		20	800	1.4	*	0	0	0.0	
4.2a	B									0	0	0.0		0	0	0.0	
4.3	B	10	300	0.8		0	0	0.0		30	500	1.2	*	10	400	1.0	*
5.1	C	0	-200	-0.2		0	400	0.4		0	160	0.2		0	-200	-0.2	
5.2	C	10	-1900	-1.9	*	0	0	0.0		0	0	0.0		20	500	0.5	
5.2a	C									20	3000	4.3	*	0	700	1.0	
5.3	C	40	-800	-1.3		0	1200	1.9		0	0	0.0		0	880	1.5	
6.0	A	0	0	0.0		0	0	0.0		30	80	0.5		20	0	0.0	
6.0a	A									0	0	0.0		10	0	0.0	
6.0b	A									0	0	0.0		100	0	0.0	*
7.1	A	0	0	0.0		20	0	0.0		5	0	0.0		10	0	0.0	
7.2	A	10	40	0.5		0	0	0.0		-5	0	0.0		50	100	2.0	*
7.2a	A									0	0	0.0		0	0	0.0	

C Category of erosion at site

P Noticeable profile change at site

ΔBG Increase in bare ground (cm)

ΔA Increase in area of cross-section (cm^2).

ΔD Increase in average depth (cm).

TABLE 4.5 Changes measured at cord transects, Hawse End 1976-8

		March 1976 - Sept. 1976				Sept. 1976 - April 1977				April 1977 Sept. 1977				Sept. 1977 - April 1978			
SITE	C	ΔBG	ΔA	ΔD	P	ΔBG	ΔA	ΔD	P	ΔBG	ΔA	ΔD	P	ΔBG	ΔA	ΔD	P
1	A	-30	0	0.0		50	0			5	80	0.0		0	0	0.0	
2	B	0	250	1.2		30	100	0.4		-35	280	1.3		20	100	0.4	
3	B	0	0	0.0		30	200	2.2	*	30	200	2.2		40	400	2.1	
4	A	-15	0	0.0		0	0	0.0		10	0	0.0		0	0	0.0	
5	C	6	300	1.9	*	10	200	1.2	*	55	200	0.9		20	680	4.9	*

C Category of erosion at site

P Noticeable changes of profile at site.

ΔBG Increase in bare ground (cm).

ΔD Increase in average depth (cm).

ΔA Increase in area of cross-section (cm^2).

TABLE 4.6 Percentage of transects with significant * changes from one measurement period to the next

PATH	March 1976 - Sept. 1976	Sept. 1976 - April 1977	April 1977 - Sept.1977	Sept. 1977 - April 1978
Wythburn	37	37	37	45
Causey Pike	39	31	50	67
Hawse End	40	60	60	60

* bare ground increase $\geqslant$ 20cm

average depth increase $\geqslant$ 2 cm

noticeable profile change

set in perspective by reference to a longer time period. The only method available for this was to compare the available air photographs of the paths, (see section 4.1.5).

The net changes over the two years for bare ground, average depth, area of cross-section and maximum depth, are given for the Wythburn and Causey Pike paths in tables 4.7 and 4.8. On the Wythburn path, 47% of the sites show an increase in the width of bare ground of 0.5m or more; 21% show an average increase in the depth of the eroded surface of 5cm or more; 37% show an increase in the maximum depth of 5cm or more and 42% show an increase in the area of cross-section of 1000 cm^2 or more. On the Causey Pike path, the corresponding values are 37%, 25%, 37% and 44%, and also, 19% of the sites indicate some significant deposition.

Were such rates of erosion to be representative of long term changes at these sites, then the future development of some footpaths would be alarmingly rapid. It is, perhaps, necessary to look more closely at some of these changes to see how they are occurring. A total of fifteen sites show an increase in the amount of bare ground of at least half a metre; of these increases, eleven were caused by erosion of vegetation either at the side of a rough path or as a short cut to avoid rough ground/miss out zig-zags - site 5.1 on Wythburn is a good example of this (plates 5 (a) and (b)). Three of the increases were caused by turf collapse after undermining of the soil, and only one increase occurred on a path with a good walking surface. In other words, these measured increases in the amount of bare ground on the paths are almost all consequent upon footpath widening, rather than an increase in the proportion of path width which is bare of vegetation.

Of the eight sites with average increases in depth of at

TABLE 4.7 Net changes recorded at the cord transects on the Wythburn path, 1976-8

SITE	ΔBG (cm)	ΔA_2 (cm^2)	ΔD (cm)	Δ MD (cm)
1.1	80	420	0.7	2
1.2	42	550	1.4	4
1.3	70	1280	4.8	10
2.1	15	20	0.1	0
2.2	36	810	2.1	4
2.3	19	280	1.5	8
3.1	0	0	0.0	0
3.2	176	4020	5.3	14
3.3	93	2740	4.2	14
4.2	4	180	1.2	8
4.3	80	3790	7.9	4
5.1	150	2860	16.5	24
5.2	84	1070	4.2	0
5.3	50	2410	8.1	8
6.0	0	0	0.0	0
7.1	20	500	1.3	0
7.2	0	100	+0.0	0
8.1	53	3050	3.1	4
8.2	4	900	1.5	0

Δ BG increase in bare ground

Δ A increase in area of cross-section

Δ D increase in average depth

Δ MD increase in maximum depth

TABLE 4.8 Net changes at the cord transects on the Causey Pike path, 1976-8

SITE	ΔBG (cm)	ΔA (cm^2)	ΔD (cm)	ΔMD (cm)
1.1	5	2560	8.0	27
1.2	0	4200	19.0	48
1.3	120	2080	2.7	28
2.2	30	0	0.0	2
2.3	20	2630	10.2	22
3.1	50	1500	12.7	22
3.3	0	0	0.0	0
4.1	45	280	0.6	-6
4.2	50	-800	-1.6	-4
4.3	50	1200	3.0	0
5.1	0	160	0.2	-6
5.2	30	-1400	-1.4	-25
5.3	40	1280	2.1	8
6.0	50	80	0.5	2
7.1	35	0	0.0	2
7.2	55	140	2.5	3

ΔBG increase in bare ground.

ΔA increase in area of cross-section

ΔD increase in average depth.

ΔMD increase in maximum depth.

PLATE 5(a) Path erosion on Helvellyn (Wythburn, site 5)

PLATE 5(b) Development of an alternative track at the same site least 5cm, only two are on newly eroding short cuts, thus, soil erosion is occurring on well established paths, and mainly on the Causey Pike path, the route with the lower recreation pressure. A similar pattern can be seen in the twelve sites with increases in the maximum depth of at least 5 cm; three sites are newly eroding short cuts, and of the remaining nine, six are on the Causey Pike route, the path not only with the most spectacular erosion, but also with the only significant deposition measured.

Many of the sites chosen for the sample were picked because they were thought to be eroding; so it is really necessary to examine these rates of erosion in the light of the original categories, which, it may be recalled were three: paths apparantly stable (A), with moderate erosion (B), and rapid erosion (C). Table 4.9 gives the average erosion amounts for the different paths and categories. It is, of course unjustified to generalise from this purposely drawn sample, but it is interesting that, although increases in the amount of bare ground are generally more on the popular Helvellyn path, soil erosion is greater on the Causey Pike path. Rates of erosion are low on most of the category A sites and in fact eight of the 12 sites categorised in this way showed no change in the two years of monitoring. Also, much of the high average value given to the Causey Pike sites in the A category can be attributed to catastrophic water erosion at site 1.1, without which the values would have been comparable with those of the Wythburn path. Over the whole path, the approximate length of both the Wythburn and Causey Pike routes in the B and C categories was estimated at just over half the total route. This does suggest that a significant proportion of each path may be changing to a greater or lesser extent.

The rates of erosion measured on both category B and C sites, whilst not necessarily valid for extrapolation, nevertheless indicate that at times changes can be rapid.

The pattern of erosion in table 4.9 suggests that geomorphological forces may be more important than recreation pressure in determining the amount of soil loss. Support for this can also be obtained from comparison of the winter and summer rates (Table 4.10). Winter, with greater rainfall, less evaporation and possibly frozen ground, provides more erosive run off than does the summer half of the year. This is even more striking when individual transects are examined (Tables 4.3 and 4.4). Site 1 on Causey Pike illustrates the erosive power of winter run off more spectacularly than any other site measured (Figure 4.1).

The amount of bare ground is influenced by the interaction of recreation and vegetation resistance, and this shows no clear seasonal influence in these data. The summer of 1976 was very dry and so the vegetation may have been under considerable stress, resulting in higher erosion than in 1977; however, this is speculative and there is no clear reason why the winter figures for 1977/8 should be so high, unless as a result of the wetter winter.

The new path developing at Hawes End had rates of erosion comparable with those on the two established paths. By the time monitoring was started, much of the initial conversion of grass into bare ground had been completed and further vegetation losses were mainly confined to the two steepest sites, sites 3 and 5 (Table 4.5). The amount of soil erosion from existing bare surfaces was strongly related to the slope of the site; the soil, vegetation type and run off characteristics were in any case fairly uniform. There was some indication that rates of erosion might be

TABLE 4.9 Average erosion at the cord transects on Wythburn and Causey Pike, for the three erosion categories, 1976-8

	CATEGORY	No. OF SITES	INCREASE IN BARE GROUND (cm)	INCREASE IN AVE. DEPTH (cm)	INCREASE IN MAX. DEPTH (cm)
WYTHBURN	A	6	12	0.6	1.0
	B	7	67	2.5	6.6
	C	6	73	6.6	9.0
CAUSEY PIKE	A	6	23.3	1.9	4.7
	B	4	45	3.7	5.0
	C	6	35	6.2	12.5

A little or no erosion

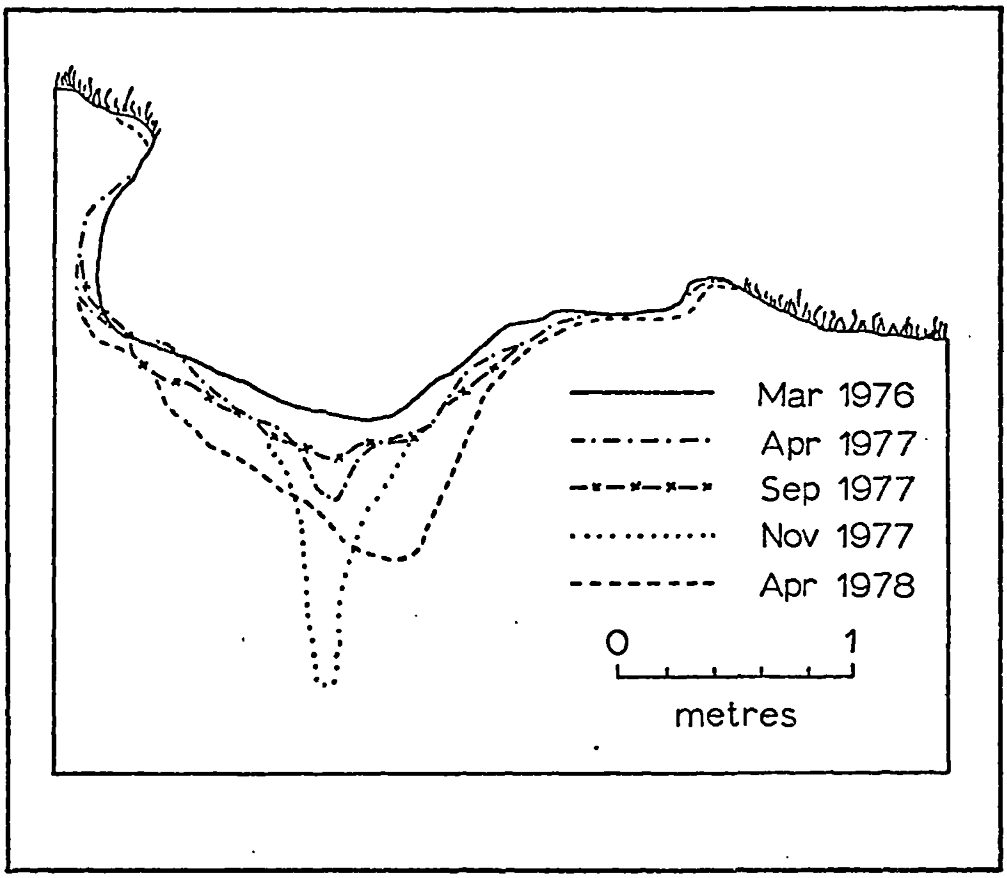
B moderate erosion

C rapid erosion

TABLE 4.10 Average erosion at the cord transects over the different summer and winter periods, 1976-8.

	SUMMER 1976	WINTER 1976/7	SUMMER 1977	WINTER 1977/8
WYTHBURN				
Increase in bare ground (cm)	17.9	8.4	10.8	16.3
Increase in ave. depth (cm)	0.7	0.9	0.4	1.4
CAUSEY PIKE				
Increase in bare ground (cm)	14.9	1.2	10.0	14.0
Increase in ave. depth (cm)	0.2	1.6	0.3	2.0
HAWSE END				
Increase in bare ground (cm)	-7.8	24.0	13.0	16.0
Increase in ave. depth (cm)	0.6	0.8	1.0	1.5

FIGURE 4.1 Gully erosion at site 1, Causey Pike



increasing on sites 3 and 5, both of which initially developed "steps" in the turf, which eventually collapsed, leading to the first stages of gully development (Plate 6).

The transects established in 1977, to add information at some of the sites, did corroborate the results from the original transects, as can be seen in Tables 4.3 and 4.4.

A brief description of the changes at each of the sites is given in Appendix 1.

The causes of the most severe gullying measured during the period can only be surmised. After heavy rain, most incised footpaths carry small streams, but clearly some gather more water than others. The most deeply gullied path is site 1 on Causey Pike, at which water appears to be concentrated at certain points within the main area of throughflow in the soil. These concentrations form springs at several locations at the side of this path site and feed water into the bottom of the path. Since the path runs across the lower part of a long slope, there is a considerable catchment for the water; also the podsolic soil under Calluna in combination with a steep slope - 25 degrees approximately - may favour rapid run off. Similar conditions of environmental factors occur elsewhere on the Causey Pike path, at sites 2 and 3, with springs obviously activated after periods of heavy rain, but the alignment of the path is less suited to capture the water, except at transect 2.3, which is deeply gullied. Another consideration in erosion is the material underlying the surface soil horizons. At all the sites on Causey Pike except sites 6 and 7, which are near the top of the slope, a considerable depth of unconsolidated deposits exists - slate fragments of varying sizes, but with few large boulders. At site 1, the depth of gullying is greater than one metre and there is still no

PLATE 6 Collapse of a turf step on the new path at Hawse End

sign of bedrock to halt or slow down the rate of incision. Thus, a plentiful supply of erodible material exists at these sites, so that, where there is sufficient run off to move the stones, gullying process will continue irrespective of the number of people walking up and down the path.

On the Wythburn path, similar factors operate at sites 1, 2, 3 and 8. Sites 4, 6 and 7 however, have bedrock near the surface. The latter two sites are in any case stable, but at site 4, bedrock has been reached at the top transect, 4.3, and so the downward incision has been limited. However, the bedrock sheds water very rapidly, and this path appears to be providing a channelled stream for the erosion of site 3 below. The causes of the rapid erosion at site 5 are slightly different. The new routes are eroding quickly in top soil, relatively fine material; the old path is losing material due to the collapse of its sides, partly due to undermining of the soil by frost and water, but also due to heavy trampling by walkers avoiding its extensively bouldery surface (Plates 5 (a) and (b)).

Changes in overall path width were noted at half the sites (Table 4.11). All but two of the fourteen increases in width occurred as a result of walkers trampling adjacent ground; the two exceptions were where width increased as a result of the collapse of the path side, bringing with it a portion of untrampled vegetation. All the Wythburn increases took place on paths across grass, and nearly all were associated with well established short cuts through long neglected zig-zags; moreover, most were accompanied by an increase in bare ground as a result of this new trampling.

Much of the path widening at the Causey Pike sites was through Calluna, at the side of paths which were rough underfoot. These routes appeared to be most popular with walkers when descending; the loose slaty path surfaces appear slippery when descending and to walk through the woody *Calluna* takes more effort when ascending.

TABLE 4.11 Changes in path width, 1976-8

	SITE	COMMENT	INCREASE IN PATH WIDTH (m)
Wythburn	3.2	A	5.0
	3.3	A	2.6
	4.2	A	3.0
	4.3	A	3.5
	5.1	A	1.3
	5.3	B	1.5
Causey Pike	1.1	B	0.3
	1.3	A	3.4
	2.2	A	2.7
	3.1	A	1.0
	4.1	A	0.5
	4.3	A	0.4
	5.2	A	4.1
	5.3	A	3.2

A Use of hitherto little trampled vegetation at the side of the path, or nearby

B Collapse of vegetated, and untrampled bank.

4.1.5 Comparison of air photographs

Air photographs of the Causey Pike area were obtained for the dates January 1947 and June 1957. For the Helvellyn area, the dates are April 1953 and October 1972. All but the 1972 photographs are at an approximate scale of 1:10 000; the 1972 scale is approximately 1:20 000. In 1947, a light covering of snow lay over the area, but on the whole this helped the identification of the path width because the snow collected in the depression; it is possible however that the widths would be overestimated if the snow drifted beyond the path confines. In 1972, the main problem was shadow, which, falling from high, north facing cliffs, obscured part of the footpath.

The identification of footpath development on an air photograph is limited to visible path width. Under some conditions, trampled grass can look very similar to bare ground and so these characteristics are not always distinguishable. On the other hand, lightly trampled vegetation does not always appear as a sufficient contrast to untrampled vegetation, in which case the bare ground may be all that can be distinguished. Very worn vegetation, particularly that with a peaty soil, shows up as dark patches and is particularly noticeable on the early Helvellyn photographs, where new routes are developing.

The width visible on a photograph will also be a function of the angle of the sun on the slope and may change with seasonal changes in the vegetation. Thus, the width identified on the photograph may bear only a little relationship to that which would be measured on the ground.

Errors must occur, not only as a result of wrong identification of the path area, but also through measurement and sampling. The identification of path area on a photograph could not be checked because no up to date photographs were available. Measurement and sampling errors were investigated, using the Helvellyn photographs.

Trials were made of measurements using a Hilger & Watts 5x print magnifier to estimate path width. This instrument measures to 1/10 mm, with interpolation to 1/20 mm. At a scale of 1:10 000, 1/20 mm represents 50 cm, which yields a rather imprecise value for path width, but greater accuracy would be irrelevant because the widths as defined on the photographs have no more precision.

Initially, about 1.5 km of path was randomly sampled in two ways:

(1) a sample of 50 transects and (2) three samples of 20 transects, each from three subsections of the path which had been identified as experiencing different amounts of erosion from fieldwork. The sampling error was estimated assuming that there was no spatial correlation of the differences between the transects, as they might be considered as random fluctuations about a mean value. However, as that assumption might not be valid, the sections were re-sampled twice to see whether comparable results were obtained and the re-sampling was done at different times with intervals of a day or so in order to eradicate any memory of the measured values. The procedure was carried out for both photographs and the results are given in table 4.12.

Sampling errors over a short section of path appear to be small enough to identify major changes in path width, the accuracy being dependent on the path's internal variability. The most eroded section, section 2, 1972, has a range for the mean width of 2.4m at the 95% probability level although the repeated sections demonstrate less variability.

TABLE 4.12 Comparisons of path widths: estimation of accuracy of measurements made from air photographs.

A. Statistical Estimates of Accuracy

	Mean width (metres)		Range of mean at 95% level of probability	
	1953	1972	1953	1972
50 points	2.4	4.1	2.0-2.7	3.4-4.7
Section 1	1.1	2.6	0.5-1.6	1.7-3.6
Section 2	3.0	6.4	2.3-3.7	5.2-7.6
Section 3	1.7	2.3	1.5-1.9	2.1-2.5

B. Estimation of accuracy from repeated sampling.

	Mean widths (metres) for repeated random selections					
	1953			1972		
	Run 1	Run 2	Run 3	Run 1	Run 2	Run 3
Section 1	1.1	1.0	1.1	2.6	3.5	3.3
Section 2	3.0	3.1	3.2	6.4	6.6	6.8
Section 3	1.7	1.6	1.7	2.3	2.6	2.3

When it is remembered that the accuracy of the measurement is about 0.5m and that identification of both the path extent and the scale conversion add further errors, it is only possible to have confidence in changes of considerable magnitude. Nevertheless, it is unlikely that all the errors will act in the same direction at each site on the path and so the use of the photographs to test the trends measured at the fixed cord transects seems reasonable.

Precise identification of the position of each cord transect on the air photographs was obviously not possible and so a small section of the path was taken and the width averaged. Table 4.13 gives the width estimates. The 1972 estimates of path width are missing from sites 2, 3 and 5 on the Wythburn path because the area is in shadow. Some problems arise in interpreting the comparisons of widths measured on the ground and on the photographs, since, as has already been pointed out, the measurements may not always be of the same features. For example, site 6 on the Wythburn path is well defined on the ground, but is indistinct on the photograph because it is grassy. Site 7 on the same path has similar characteristics: all that shows distinctly on the photograph is the area of bare ground, yet several metres of the path are clearly of lightly trampled grass when viewed in the field. Thus in some cases the measure from the photograph may be of bare ground, which could explain some large discrepancies; for example, Wythburn site 4 which has apparantly increased in width by about 6m from 1972 to 1976.

It is evident that the use of air photographs has some limitations, but clearly, if a path is becoming wider and the amount of bare ground is increasing, or if the number of routes at a site is proliferating, this should be visible

TABLE 4.12 Comparisons of path widths measured on air photographs and in the field at the cord transects. (All path widths expressed in metres).

A. WYTHBURN

SITE	AIR PHOTOGRAPHS		CORD TRANSECTS	
	1953	1972	1976	1978
1.1	indistinct	2.5	6.2	6.2
1.2	indistinct	2.5	7.9	7.9
1.3	3.8	4.7	8.0	8.0
2.1	1.0	1.0	2.0	2.0
2.2	1.9	shadow	5.2	5.2
2.3	1.2	shadow	3.5	3.5
3.1	not visible	shadow	3.1	3.1
3.2	1.5	shadow	10.9	15.9
3.3	1.5	shadow	12.0	14.6
4.1	2.9	4.7	6.7	-
4.2	2.9	6.2	12.2	15.2
4.3	2.9	5.2	12.0	15.5
5.1	not visible	shadow	2.8	4.1
5.2	not visible	shadow	5.6	5.6
5.3	2.4	shadow	4.3	5.8
6	indistinct	indistinct	2.1	2.1
7.1	1.9	2.4	6.0	6.0
7.2	1.4	1.9	5.8	5.8
8.1	not visible	5.2	12.5	12.5
8.2	not visible	4.7	7.6	7.6

B. CAUSEY PIKE

	1947	1957	1976	1978
1.1	1.2	1.4	2.2	2.5
1.2	1.2	1.4	2.9	2.9
1.3	1.2	1.4	7.0	10.4
2.1	1.8	4.3	4.5	-
2.2	not visible	0.7	5.3	8.0
2.3	1.8	2.9	3.6	3.6
3.1	indistinct	2.8	8.0	9.0
3.2	indistinct	2.3	6.0	-
3.3	indistinct	2.9	5.4	5.4
4.1	1.2	1.4	4.8	5.3
4.2	1.2	3.6	7.2	7.2
4.3	1.2	2.2	7.1	7.5
5.1	2.4	7.2	9.7	9.7
5.2	2.4	7.2	8.8	12.9
5.3	2.4	5.8	8.0	11.2
6	indistinct	1.4	3.2	3.2
7.1	1.8	2.2	2.5	2.5
7.2	1.8	2.2	3.0	3.0

on the photographs, providing that rates of change are sufficiently high. Thus the photographs were examined to see whether they confirmed the trends of widening or stability suggested by the transect measurements, not only in the light of the path widths, which as suggested above, might be misleading, but also in the way in which additional tracks might have formed.

(a) WYTHBURN

The sites showing the greatest rates of erosion over the two years are sites 3, 4 and 5. Unfortunately, sites 3 and 5 are in shadow on the 1972 photograph, thus any long term trends have to be deduced from the 1953 photograph. In 1953, site 3 appears to be fairly grassy, with the most dominant track being the original zig-zag; in 1976, although traces of the original path remain in the grass, the dominant track is an eroded path straight down the hill. Two of the tracks measured in 1976-8 at site 5 did not exist in 1953, although signs of path proliferation at the site can already be seen. Site 4 can be compared using both photographs. Between 1953 and 1972, the path width approximately doubled; moreover, an additional track formed; this had been followed by yet another by 1976, and one more started to erode between 1976 and 1978.

Thus, the photographs suggest that these sites are indeed becoming wider in such a way as to be more than a short term fluctuation and with no obvious sign of stabilising.

The most stable sites appeared to be sites 6 and 7 from the transect measurements. The photographs confirm this: there is no sign of path alternatives as at the unstable sites. The width of the path at site 7 as measured on the ground in 1976 does appear to be greater than that measured on the photographs, but, as already stated, this is likely to be because the photograph width does not include the area of lightly trampled grass that is evident in the field. The amount of bare ground measured in 1976 was 3.8 and 2.0 m at the two transects, which corresponds well with the 1972 photograph measurements of 2.4 and 1.9 m. The main path area at site 7 is bare of vegetation.

Most of the other changes measured at the transects were small. Site 8 is the only one of these at which marked changes have occurred during the period covered by the photographs, and this is due to the adoption of a more direct route than that of the original path. At present, no further short cuts are being made, but it is not possible to predict that now the path will be stable since there is evidence on the ground that lateral vegetation erosion is occurring - see comments for site 8 in Appendix 1.

(b) CAUSEY PIKE

On Causey Pike, the greatest amount of soil/regolith erosion was measured at site 1. However, this erosion, being in the form of gullying, shows less clearly on a photograph than that caused by vegetation trampling. The clearest indication of accelerated soil and regolith erosion on the photographs is an area of deposition of the eroded material on top of the vegetation. This can be seen on the slope below sites 4 and 5 on the 1957 photograph - the snow cover makes identification too uncertain in that of 1947 - but there are no signs of deposition below site 1. By 1976, there was some deposition, and, following two winters in which gullying was active, stones were deposited far down the hillside. It is possible that the very deep incision at site 1 is comparatively recent; alternatively, the gullying may be infrequent so that the vegetation can grow over the stones.

The sites showing the greatest amount of lateral erosion are sites 2 and 5. Both these sites also show changes on the photographs, one of the branches of site 2 not being visible on the 1947 photograph, and site 5 having visibly widened. The new branch of site 2, measured in the field as transect 2.2, is only just visible on the 1953 photograph, but by 1976 was measured on the ground as 5.3 m, increasing to 8.0 m by 1978. Since this path is developed in *Calluna*, trampling shows as a clear line and so the measured path increases over the years since 1947 are likely to be valid, unlike measurements in grass, which may be unreliable. The measurements for site 5, also *Calluna*, are equally likely to be reliable. Changes at site 4 are smaller than those at site 5, but are occurring in the same way and in the same vegetation, which suggests that the steady increase in this path's width from 1947 is also likely to be a real trend.

Apart from the gullying in site 1, the photographs appear to confirm the trends of erosion measured at the transects. They also confirm the stability of sites 6 and 7, which do not appear to have widened significantly, or undergone any other changes. Site 3, with a large area of trampled grass, is not defined with sufficient clarity to be able to establish its long term trend.

It seems fair to conclude that where there is sufficient recreation pressure to create new paths by the side of old, and where the path or site is such that short cuts and new ground are preferred to the original path and rough surfaces, a sequence of air photographs over a sufficient time period can be used to demonstrate long term trends in path evolution. Such demonstrations are essential to complement the more detailed measurments that can be taken at a series of sites, such as those made in this research.

It should be noted, however, that the photographs of these earlier years show that footpath erosion is not exclusively a problem of recent times. There are many sites, which, to present day observers - perhaps more conscious of conservation than those of twenty or thirty years ago - appear to have eroded very rapidly and recently. The view has been expressed by National Park Wardens and other interested persons that footpath erosion is a comparatively recent phenomenon. Yet it is possible to pick out paths which today are wide and eroded, and have been so for twenty years or more. Some examples are listed in table 4.14 and they include Browncove Crag, cited by at least one Warden as an example of one of the worst sites of path erosion. Clearly, aerial photography could be used to monitor footpath development throughout the whole of the National Park if no more than generalised levels of information were required. Figure 4.2 demonstrates the type of information that might be obtained.

4.1.6 Erosion amounts and rainfall totals

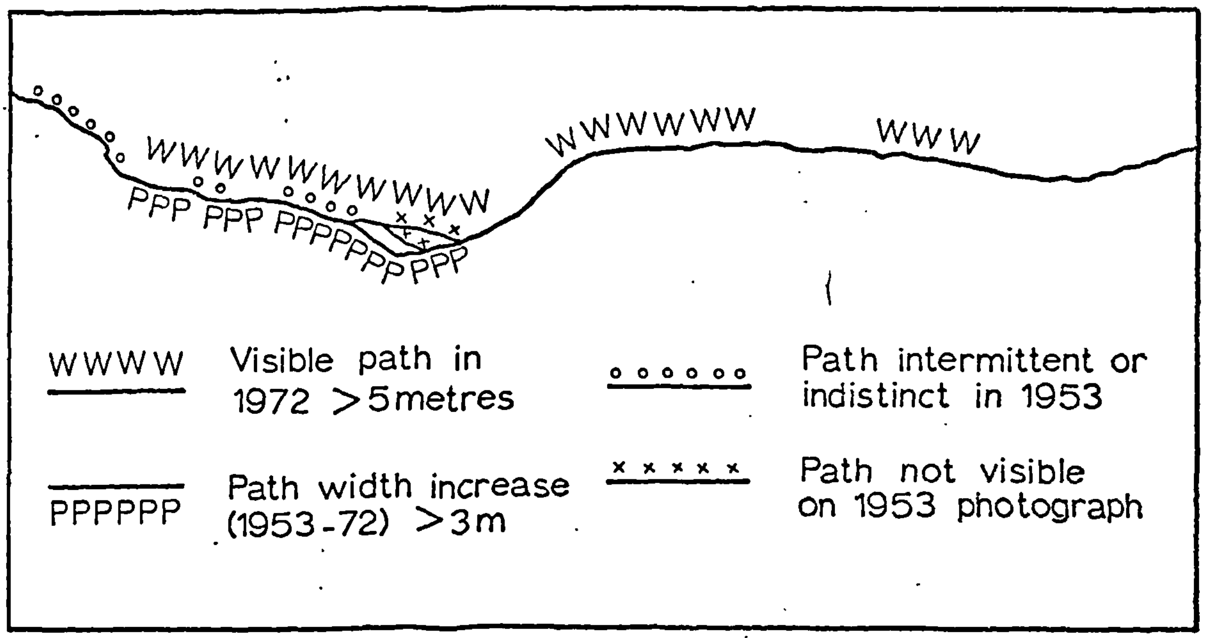
To conclude the investigation of erosion at the cord transects, amounts of soil erosion were compared with the rainfall totals for the period. The rainfall figures were obtained as monthly totals from the Keswick gauge since there exists no record for the exact locations. The monthly totals at Keswick, although collected from a site with many differences in situation, exposure and altitude from the transects, would reflect average differences from one six month period to the next.

Rainfall might affect footpath erosion in two ways. The amount of soil washed away is dependent upon rainfall

TABLE 4.14 Footpath erosion at selected sites: measurements taken from air photographs taken in 1947, 1953, 1957.

SITE	GRID REF.	DATE OF AIR PHOTOGRAPH	VISIBLE WIDTH (metres)	COMMENT
Browncove Crag	NY	1953	8.0	Multiple tracks
Wythburn	NY32851355	1953	9.0	short cut near forest
Sail	NY20352035	1947/57	6.0	multiple tracks
Scar Crags	NY20552050	1947/57	9.0	
Cat Bells (Manesty)	NY	1957	10.0	multiple tracks
Cat Bells (Newlands)	NY	1947/57	3.0	short cut through zig-zag
Rowling End	NY23102080	1957	7.0	multiple tracks (path indistinct in 1947)

FIGURE 4.2 Path changes over a long period: information obtained from air photographs



intensity, duration and frquency, and a wetter than average winter or summer might enhance erosion on unvegetated parts of the paths. Increases in bare ground may also be affected by rainfall, by the two extremes of drought, when the vegetation may become very stressed, and of saturation, when the soil may become so plastic that the whole mass of vegetation and soil is deformed by trampling, and mud may be smeared over the leaves. In either case, less trampling may be needed to cause the plant to die than at other times.

The rainfall totals (approximate) for each period of measurement are given in table 4.15, with the average increase in bare ground and depth of the unvegetated surfaces for the two paths. This table suggests that soil losses are related to rainfall totals, over the six monthly periods of measurement. Soil losses are also related to recreation pressure, since trampling can erode significant amounts of material, as will be seen in following sections. However, the wet winter of 1977/8 is reflected in the large average depth increases on both paths. The rainfall was particularly high in October - almost twice the monthly average in Keswick - and in March. About half the October total fell in a short time; 185 mm were recorded in 24 hours at Grasmere, south west of Helvellyn. This rain caused extensive gullying on many paths, including some not usually affected by erosion to any noticeable extent. In spring, material detached from the path surfaces by frost heave is vulnerable to water erosion. If the spring is dry, then much of this material is trampled back into the path. Thus, a wetter than average March may increase the amount of erosion.

The wet autumn and spring of 1977/8 may account for the increase in bare ground in that period, compared with the

TABLE 4.15 Comparison of average erosion amounts with approximate rainfall totals for the four measurement periods, 1976/8

	SUMMER 1976	WINTER 1976/7	SUMMER 1977	WINTER 1977/8
WYTHBURN				
Average increase in depth (cm)	0.7	0.9	0.4	1.4
Average increase in bare ground (cm)	17.9	8.4	10.8	16.3
CAUSEY PIKE				
Average increase in depth (cm)	0.2	1.6	0.3	2.0
Average increase in bare ground (cm)	14.9	1.2	10.0	14.0
Rainfall totals (mm)	498	778	596	1058
Average rainfall (1916-1950)*	633	843	633	843
No. of times monthly ave. exceeded	2	2	3	4

previous winter when the average increase was less; the dry summer of 1976 may account for the larger increase in bare ground then than in the following summer. The July and August rainfall was only 33% of the average and the vegetation visibly suffered from drought on many parts of the fells. However, this is merely speculative as the sample is too small to test any such hypotheses.

4.1.7 Conclusion

The cord transects were established to investigate rates of erosion on paths in a general way. Experience proved that these simple measurements were quite adequate for this. Paths which were changing rapidly - both lateral and vertical erosion - were easily identified. The technique was found to be highly suitable for measuring across wide paths, for which the bar transects described in the following section were inadequate; it was quick, inexpensive, and hence it was possible to monitor a larger number of sites.

The measurements showed that in certain places, erosion is proceding at a rate which, if maintained, will result in considerable widening of the paths within the next ten years or so, unless a natural feature such as a cliff should exist to limit development. They also showed that although path widening is proceding as a consequence of recreation, some paths are vulnerable to water gullying and the effects can be spectacular at a local scale.

4.2 BAR TRANSECTS

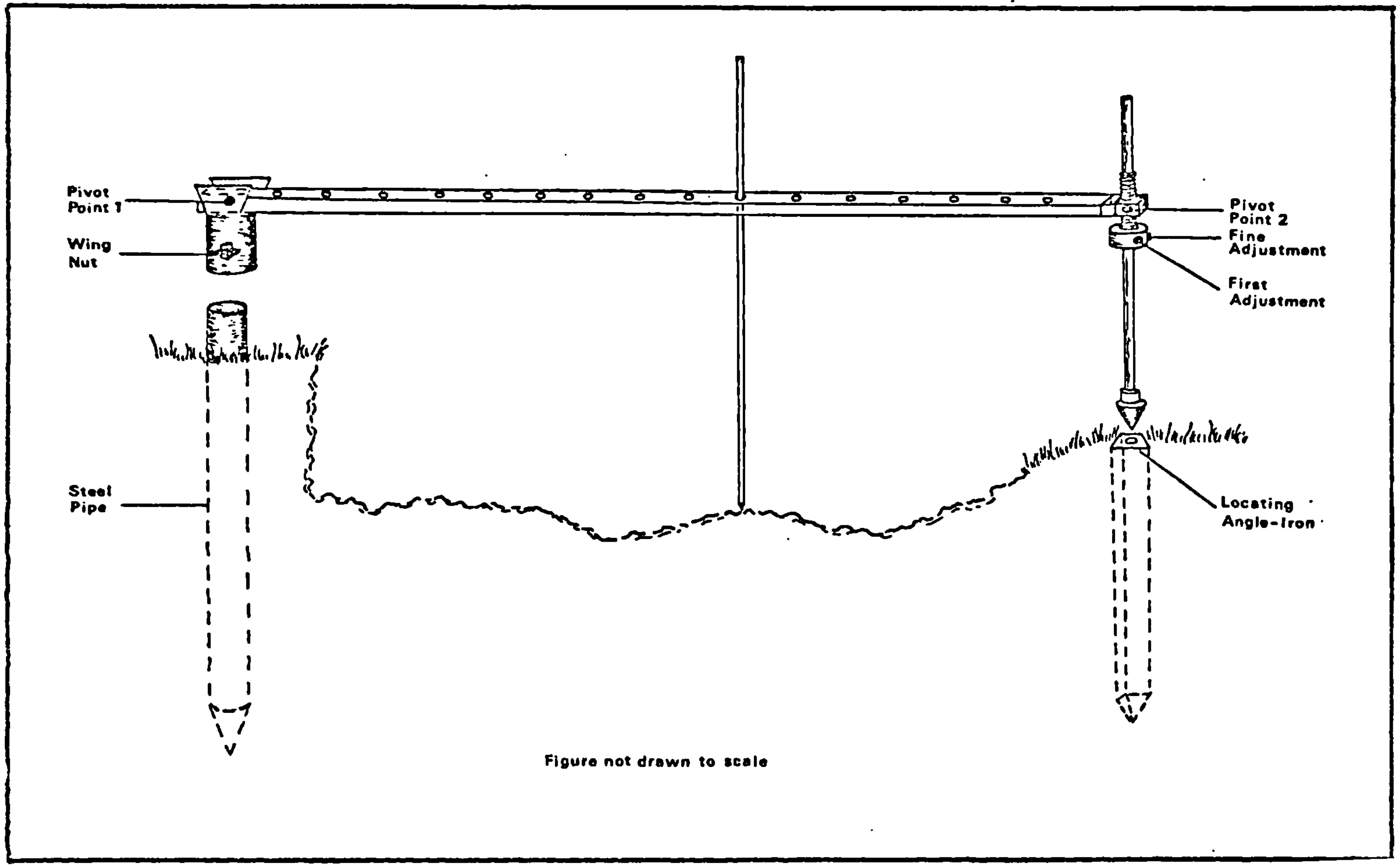
The cord transects were originally established to investigate lateral erosion. For detailed changes in depth on the paths, a technique more accurate than measurement from cord is required. The main purpose of establishing sites to measure details of depth changes was to investigate the seasonal effects of variation in recreation pressure and weather conditions.

4.2.1 Method of measurement

A technique was adopted similar to that described by Streeter (1975). A rigid bar, 2m long, with a square cross section, was placed horizontally between two fixed points. Depths to the path surface were measured using a metre long stainless steel rod, passing through holes drilled at 10 cm intervals in the bar (Figure 4.3). Measurements were made of the distance from the top of the bar to the top of the rod, the depth to the surface then being the difference between one metre and the measurement.

Three factors make the establishment of fixed points difficult: bedrock, to which a fixed post may be attached to give rigidity, may only occur many metres below layers of stony material; these layers are often highly compacted and bouldery; sites are seldom easily accessible for the use of drills and concrete. An attempt was made to overcome these problems by introducing flexibility of positioning into the measuring devices. A single piece of stainless steel pipe 6 cm in diameter was fitted with a wooden cone at one end to aid penetration into a previously augered hole of smaller diameter than the pipe. The whole was painted, then hammered in to a depth of 0.6-0.9 m depending on the site, in the hope that the depth would be sufficient to inhibit movement, and that the pipe would provide a fixed point. At the other side of the site, a piece of angle-iron bar of similar length was hammered in to provide a fixed point on the surface.

FIGURE 4.3 Bar apparatus used to measure detailed changes at monitored sites



The horizontal measurement bar was designed to be fitted on to the end of the pipe in such a way that it could pivot (pivot point 1 in figure 4.3) and so compensate for any tilt away from the vertical when the pipe was inserted into the ground. At the other end of the bar, a moveable rod, attached to a second pivot point, allowed both insertion into a hole in the angle iron and raising or lowering of the bar by a coarse first adjustment and then a fine screw (Figure 4.3). The exact replication of the bar position was obtained by a conical fitting at the end of the moveable rod and the use of a spirit level to ensure that the bar was horizontal.

Measurement error was tested at each site, by taking repeated measurements. Errors may arise from positioning the bar and inserting the rod through the holes. Each transect was measured six times, taking off and replacing the bar three times, and for each bar position, taking two sets of measurements. These repeated measurements were done in February 1976, when some of the points where the rod met the path were quite soft, so that the largest errors that would be likely would be experienced.

The errors calculated were the differences, for each point, between the depths measured (1) without replacement of the bar - the errors of placing the rod through the holes - and (2) with replacement of the bar - the errors of positioning both the rod and the bar. Three comparisons were available for each error calculation. The points were divided into three categories according to their likely susceptibility to error: points on grass, points on firm earth or stones, and points on soft earth or otherwise "difficult" surfaces - difficulties arise, for example, when the rod balances at different places when just catching an earth "bank" at the side of a path.

On the whole, differences were small. For the transects without replacement, the maximum difference recorded for grass and firm earth points was 3 mm, but many were zero or only 1 mm; the maximum for soft earth was 11 mm and for slipping on a bank 15 mm. For transects with bar replacement, the maximum difference for grass and firm earth was 4 mm; the maximum for soft earth was 13 mm and for slipping on a bank 23 mm. The average differences were much smaller, over all the paths, on grass, 0.5 mm for the rod and 1.2 mm for the rod and bar; on firm earth, 1.2 mm for the rod and 1.9 mm for the rod and bar, and on soft earth/difficult points, 2.3 and 6.2 mm respectively. The averages for each transect are given in table 4.16.

The accuracy levels were thought to be adequate for the intended purpose, that of measuring changes over short time intervals, such as a bank holiday. Most path surfaces include many loose stones which are in the process of being transported down the path; thus measurements to any greater level of accuracy would be spurious.

The main concern was whether or not the steel pipe would provide a fixed point throughout the necessary measurement period without being secured to bedrock. Using the expected errors for vegetated points, it was possible to estimate any movement of the pipes. It appeared that on all the sites, the pipe remained stable from its first insertion, in November 1975, until the following January, subsided by about three centimetres in the period February-March, then re-established, thereafter not apparantly changing position at all. However, in view of the possibility of movement, results were really only accurate relative to the "base levels" provided by the vegetated surfaces, except in the case of repeated transects over a short time period, such as

TABLE 4.16 Accuracy of the measurements at the bar transects: average differences between readings, (mm).

SITE	GRASS SITES		FIRM EARTH		SOFT EARTH/DIFFICULT SITES	
	A	B	A	B	A	B
Causey Pike	1.3	0.1	1.3	2.0	1.3	3.7
Hawse End (1)	0.0	1.0	1.4	1.5	2.3	6.3
Hawse End (2)	0.3	1.2	0.3	2.0	0.7	2.0
Wythburn (1)	0.7	1.3	1.7	2.7	3.3	10.0
Wythburn (2)	0.3	1.7	0.7	1.3	9.3	14.0
Total Average	0.5	1.2	1.2	1.9	2.3	6.2

A. No bar replacement

B. Bar replacement

a Bank Holiday or a major rainfall.

4.2.2 Location of sites

The limitations of this method are (1) carrying a cumbersome bar up a mountainside and (2) the restriction on bar length caused by weight and rigidity. Thus, all the sites were chosen to be easily accessible and had to have path sections with trampled width less than 2 m - sufficient distance had to be left on each side of the path for the fixed points to be secured and, preferably, hidden under longer vegetation.

Five sites were chosen, one of which was a double length site due to the fact that it was possible to secure the pipe in the centre and rotate the bar through 180 degrees to use each side of the fixed point. This was only possible because the path had been closed to walkers. The five sites are listed, with a brief description, in table 4.17. All are paths developed in *Pteridium* on an acid brown earth.

Two sites were chosen on the Wythburn (Helvellyn) path. The first was a well established site and the second a new development at the side of rough ground; thus, rates of erosion might be compared for different stages of development. A site was chosen on Causey Pike, on a well established part of the path, to contrast with the more popular Helvellyn route. At Hawse End, one site was chosen on the closed section of the path and one on the new path. There was therefore the possibility of comparing any recovery rates of the old path with erosion rates of the new.

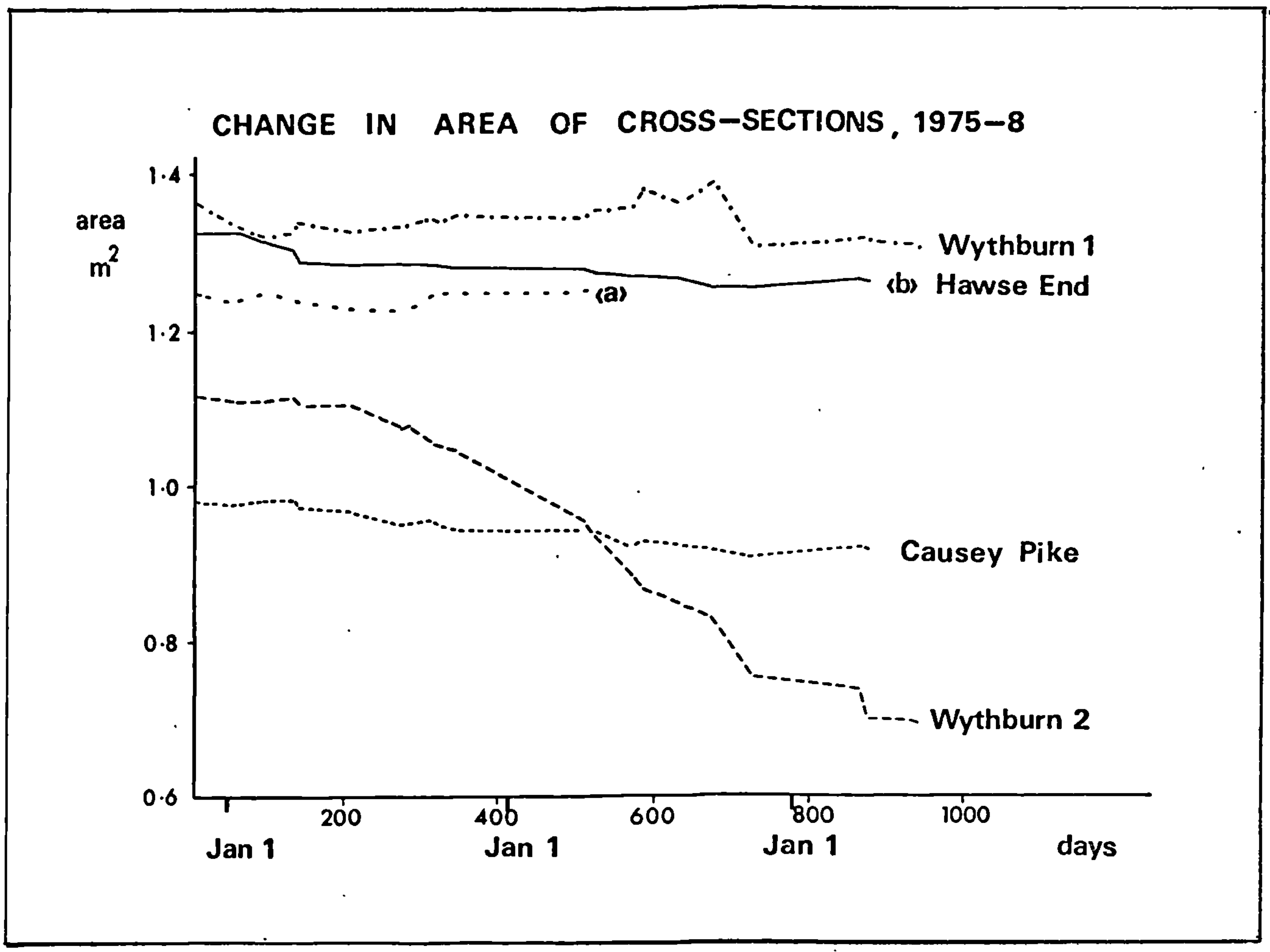
4.2.3 Results

The erosion amounts for each path are most simply summarised diagrammatically (Figure 4.4). However, in addition

TABLE 4.17 Sites chosen for the bar transects, November 1975-May 1978.

SITE	Causey Pike	Hawse End (1)	Hawse End (2)	Wythburn (1)	Wythburn (2)
GRID REF.	NY22702100	NY24762115	NY24742115	NY32801355	NY32901360
PATH SLOPE	28	30	25	17	24
CROSS SLOPE	4	3	18	18	22
GEOLOGY	S. Slate	S. Slate	S. Slate	B. Volcanics	B. Volcanics
DESCRIPTION	Section of main path, well established, path above and below is stable	Closed part of old path, above and below path is gullied	New path to replace closed part, most use is as upward route, path stable below, but eroding above	Well established path, bypassed by some walkers using short cut, many stones at site above and below.	New path developing by side of very bouldery section, no input of stones from above and easy removal of stones below.

FIGURE 4.4 Changes at the bar transects throughout the monitoring period - variation in area of cross sections ((a) Hawse End new path; (b) old path)



the main points are described below for each path in turn.

(a) Causey Pike

This long established path seems to be eroding slowly but steadily; the unvegetated surface was lowered at an average rate of about 1.4 cm a year over the two and a half years of measurement. There is some evidence that the rate of erosion increases at times of peak recreation, for example at Easter in both 1976 and 1977. However, there appears to be some accumulation of material on the surface during the summer of both years. To the casual observer, the path may appear unchanging, but the measurements show that this is not so. Every winter saw some undermining of the upslope bank in particular, mostly by the action of frost heave, which eventually culminated in collapse (Figure 4.5). This loosened the soil in the area near to the steel pipe so that it could no longer be relied upon, and measurements were terminated after March 1978.

(b) Hawse End (1)

The measurements at this site were curtailed in 1977 by repair work carried out by the National Park Upland Management Services (Countryside Commission, 1976). However, the measurements that were taken suggest that cycles of erosion and deposition were occurring, but without any well defined overall trend (Figure 4.6). There was certainly no evidence that the gully was becoming re-vegetated, apart from at its base several metres below the site, but there were signs that sheep were using the sides of the gully as shelters and causing erosion.

(c) Hawse End (2)

Surface lowering on the unvegetated parts of the new path averaged 3.7 cm a year, more than twice the rate on Causey Pike path. Erosion was apparantly fastest when heavy

FIGURE 4.5 Changes at the Causey Pike bar transect

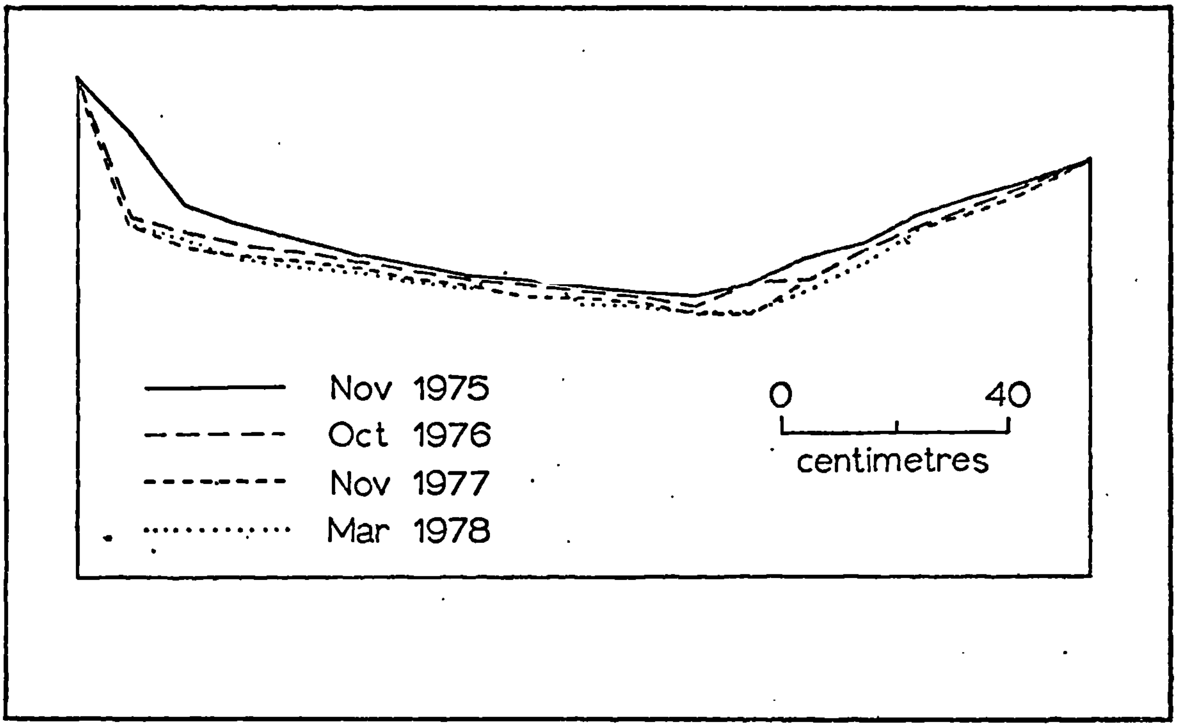
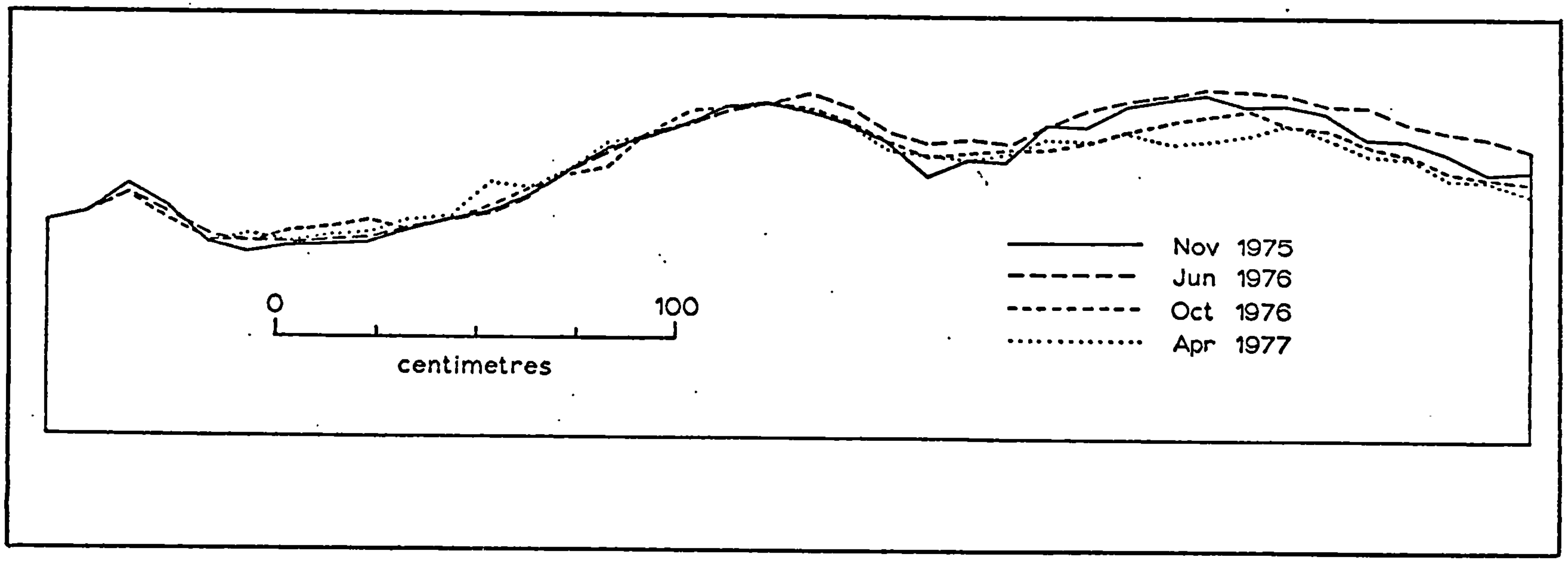


FIGURE 4.6 Changes at the Hawse End (1) bar transect



recreation pressure combined with fairly moist soil conditions, namely Easter and autumn in these years. This was to be expected because in the summer the path became hard and resistant; in the winter, fewer visitors used it and it was not sufficiently incised to channel much run off water (Figure 4.7). The path was closed to walkers by Easter 1978.

(d) Wythburn (1)

The cross-section profile at this site fluctuated over the measurement period because, during times of heavy recreation pressure, stones were kicked into and through the section from the section above. At times of very heavy rain and run off, the cross-section was "flushed out" exposing an "erosion surface" in compacted subsoil. At the start of the period, November 1975, a narrow path was being worn on the grass at the downslope side, by walkers avoiding the stones. In the summer of 1976, the bracken (Pteridium) grew tall, over hanging the path to such an extent that the route was avoided or not noticed (Plate 7 (a)). However, further erosion of the path side during the period from the autumn of 1976 to the spring of 1977 inhibited the growth of the bracken in the summer of 1977; the path, being more visible, was used more and there was a steady erosion of the grass and subsequently the top soil on the downslope side (Figure 4.8 and Plate 7 (b)). The average rate of surface lowering over the period was 1.9 cm per year, but this figure is perhaps misleading in view of the cyclical nature of erosion and deposition at this site. The average figure would probably have been negative in sign, that is deposition rather than erosion, had it not been for the heavy rain in October, 1977.

FIGURE 4.7 Changes at the Hawse End (2) bar transect

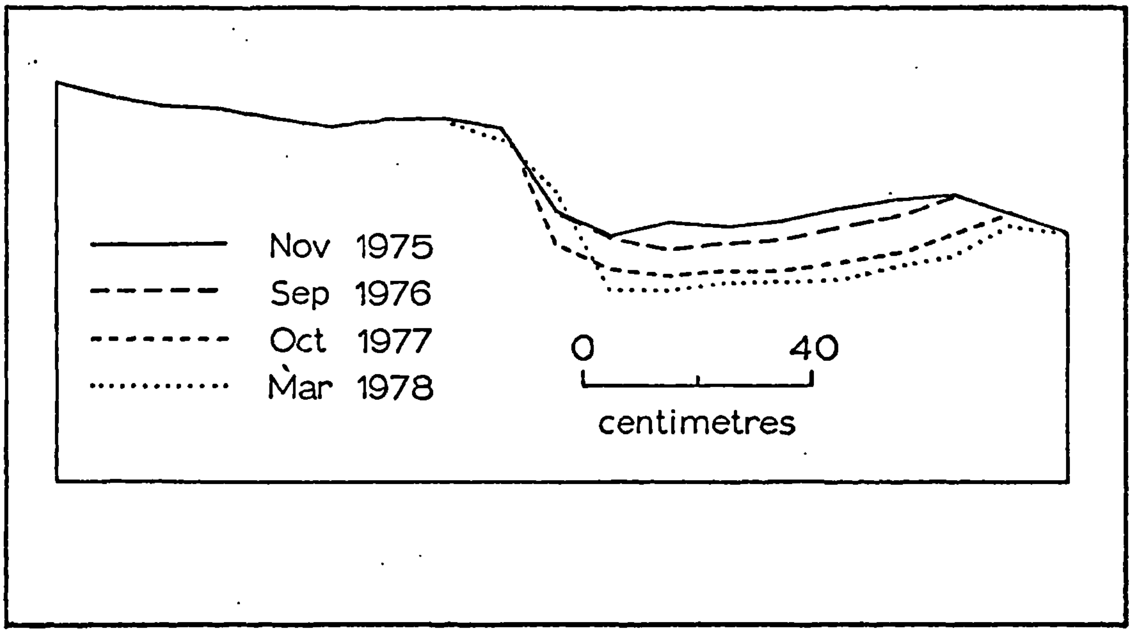
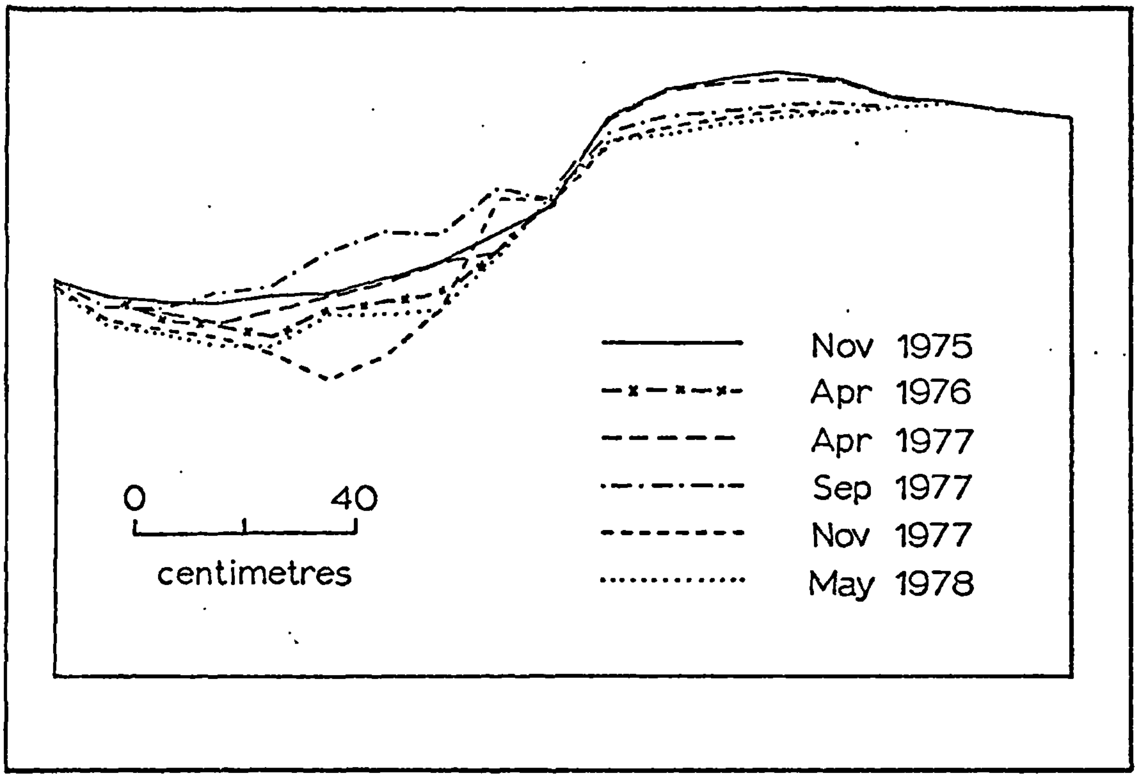


PLATE 7(a) Bracken overhanging the path at site 1, Wythburn, September, 1976

PLATE 7(b) Erosion at the side of the same path, April 1978

FIGURE 4.8 Changes at the Wythburn (1) bar transect



(e) Wythburn (2)

This site had a very high rate of erosion in comparison with the others. The ground was steep and not only was there little material entering the section from above, but also material was easily removed to below. Thus eroded material tended not to accumulate, but to be transported out of the section. The rate of erosion increased with time (Figure 4.4), mainly because a large portion of the downslope side of the path was eroded. The maximum depth of gullying appeared to stabilse toward the end of the monotoring period, with erosion of the sides of the path becoming more important than the erosion of the bottom (Figure 4.9). During the first year, summer erosion was much greater than winter erosion, and, being the summer of 1976, much of this must have been caused by walkers rather than water. However, during the winters of 1976 and 1977, particularly the latter, water run off also seemed to be effective. The effect of recreation is clearly marked, by the increase in erosion amounts over the Easter holiday period (Figure 4.4). Experiments with the aid of a group of students, walking up and down paths in this area, indicated that trampling moves stones a considerable distance, dependent on the slope (Table 4.18). Thus, on this path, conditions were ideal for erosion by trampling, the slope being 24 degrees. Over the monitoring period, the average rate of surface lowering was 9.9 cm a year.

4.2.4 Discussion

The bar transects were sensitive enough to detect changes caused by high values of the two main forces operating in the system: recreation pressure and water run off. Wythburn (2) demonstrates this most clearly, being the most unstable

FIGURE 4.9 Changes at the Wythburn (2) bar transect

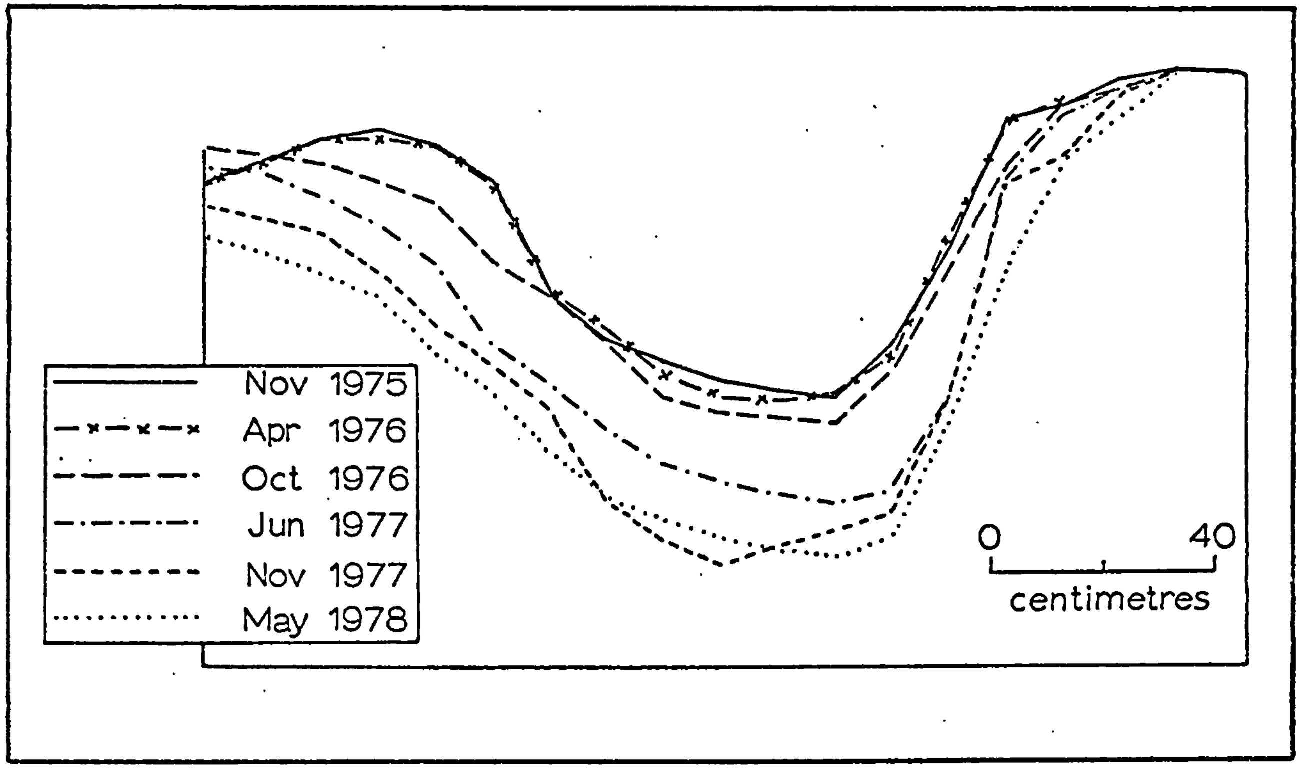


TABLE 4.18 Rates of movement of marked stones in trampling experiments on footpaths of different slope.

SLOPE (degrees)	AVERAGE DISTANCE* MOVED BY STONES ON PATH SURFACE PER 100 TRAMPLINGS (cm)		
	Walking Up	Walking Down	Average
9	1.2	3.8	2.5
14	14.2	20.4	17.5
22	26.1	45.7	35.9

* Average of six samples of 20 marked stones per sample.

site, but the other sites follow similar patterns (Figure 4.4): distinct erosion effects are visible in the profiles, following unusually heavy rain or peak recreation period - Easter being the heaviest of these.

The seasonal effect of differences in the geomorphological and recreation forces can be seen in table 4.19, which lists the changes in the cross-sectional area, the number of vegetated points and the number of bare ground points in the periods October to March and April to September. At Causey Pike and Wythburn (2), more soil erosion occurs in the summer than in the winter; Hawse End (2) is similar, apart from the first winter. These sites are not particularly effective at channelling run off and so the recreation pressure is the more effective force. At Wythburn (1), the reverse is true and winter run off removes many of the stones pushed into the path by walkers; at this site, the geomorphological forces of water are as effective as those of trampling. This site does channel water from the slope and path above and small streams are visible after most periods of rain.

Table 4.19 also shows that at these sites, most of the vegetation erosion occurs in winter. In most cases these figures represent the degradation of healthy grass to badly damaged grass and so, in some cases, reversals may occur and the grass may recover. This degradation is aided in winter by the wetness of the soil and the slow rate of vegetation growth. Bayfield (1979) experimented with vegetation responses to trampling and found little difference between winter and summer trampling when the vegetation was left to recover naturally. Wythburn (2) is an exception in that most of the vegetation disappeared in the summer; this path is mainly used in the summer and the

TABLE 4.19 Seasonal variations in the erosion at the bar transects 1975-8

A. EROSION OF CROSS-SECTION: AREA (m^2)

SITE	WINTER 1975-6	SUMMER 1976	WINTER 1976-7	SUMMER 1977	WINTER 1977-8
Causey Pike	0.0038	0.0309	0.0096	0.0261	-0.0007
Hawse End (2)	0.0217	0.0203	0.0068	0.0261	-0.0134
Wythburn (1)	0.0463	-0.0132	-0.0058	-0.0414	0.0690
Wythburn (2)	0.0023	0.0627	0.0969	0.1522	0.0526
TOTAL	0.0741	0.1007	0.1075	0.1630	0.1075

B. DECREASE IN NUMBER OF GRASS POINTS

Causey Pike	0	0	0	0	0
Hawse End (2)	3	0	2	0	4
Wythburn (1)	1	-1	2	2	2
Wythburn (2)	0	5	0	0	0
TOTAL	4	4	4	2	6

C. INCREASE IN NUMBER OF BARE GROUND POINTS

Causey Pike	0	0	0	0	0
Hawse End (2)	1	-1	5	-2	1
Wythburn (1)	1	1	3	-1	2
Wythburn (2)	1	5	0	2	-1
TOTAL	2	5	8	-1	2

loss of vegetation at one side was an expression of the wear and tear on a steep slope from walkers avoiding the stones in the path. The figures for increases in the number of points on bare ground generally represent the change from damaged vegetation to complete absence of vegetation. Bare ground appears to be created as much in the summer as in the winter at these sites.

These sites demonstrate how quickly some of the new paths are eroding. The Wythburn (2) path is typical of many short cuts and other path alternatives being worn in steep ground; it also indicates that recreation pressure can be as or even more effective than water as an erosive agent. The old Hawse End site showed little sign of re-vegetation, in spite of having been closed for five years by the end of the monitoring, until walls were constructed across the gully and some trees were planted. This site is near to the road. Further up in the high fells, rates of erosion comparable to those at Wythburn (2), with little hope of an equivalent rate of recovery of abandoned tracks, are causing steady increases in path extent wherever walkers form alternative tracks to straighten bends, cut zig-zags and avoid the rough surfaces they themselves have created.

4.2.5 Conclusion

The bar transects were designed to examine detailed recreation and rainfall effects, and to compare the differences in season with the state of the paths.

The results suggest that even well established paths which do not look as if they are changing very much may be steadily eroding, although not as rapidly as some new paths on steep ground. Erosion occurs both in winter and summer, depending on whether a path is vulnerable to water or to recreation pressure, or to both. Recreation pressure can be as powerful an agent of erosion as water, but its removal does not necessarily herald a rapid recovery of the path.

4.3 CONCLUSIONS

Both the bar and the cord transects indicate that footpath changes are rapid in some places. Two types of site can be distinguished as particularly vulnerable to erosion: Sites where large amounts of water run off are captured and channelled down the path, and sites where walkers are constantly rejecting old paths as too rough and creating new ones. Site 1 on Causey Pike exemplifies the first type; erosion there has been spectacular over the monitoring period and shows every sign of continuing, since each increment of erosion improves the water collecting properties of the incised channel. Other sites demonstrate similar properties - for example, site 3 on Causey Pike and site 2 on Helvellyn - but with a lesser degree of development. Sites 2, 4 and 5 on Causey Pike are of the second type, but erosion rates are not high because recreation pressure is not very great. Sites 3, 4, 5 and 8 on the Helvellyn path are also of the second type, and have higher rates of erosion than Causey Pike because of the greater recreation pressure.

Erosion at the bar transects showed that trampling could be as or even more effective than geomorphological forces in producing high rates of surface degradation at some sites. In particular, the comparison of a new short cut and its closed predecessor nearby suggested that natural path recovery on steep ground could not keep pace with the rate of new path erosion. The transects also indicated that as much path erosion can take place in summer as in winter, although not necessarily on the same type of site.

However, the rates of erosion measured are put into perspective by examining the paths as they appear on air photographs of twenty or thirty years ago. It is clear that many of the very eroded sites of the present day appear as wide, multi-tracked paths on the photographs. Thus, perhaps the phenomenon is not quite so new, and the rates of erosion not so great, as is sometimes thought. Direct comparison of old photographs and present day footpaths is not feasible because the same features are not necessarily identified on the photograph and the ground, but some comparisons can be made, and sites with a proliferation of routes can be identified. It is clear from general measurements made from the photographs for both the paths studied, that overall path extent has increased, but this is not to be taken as an indication that the paths are eroding in an unstable fashion. Long sections of both paths appear to be stable, with visible widths adapted to the number of path users. On the Helvellyn path, 60% of the total path length has no more than 3 m width of bare ground and was assessed as "non-eroding" using various geomorphological criteria (Chapter 6, section 6.1.4).

It can be suggested, therefore, that

1) extensive rapid footpath erosion is localised;
2) rapid footpath erosion is not necessarily a consequence of trampling: recreation and geomorphological forces can be equally destructive once the vegetation cover has disappeared;
3) new footpaths erode more quickly than the old ones can recover;
4) most vegetation erosion occurs during the summer half of the year, when recreation is most concentrated; some

soil erosion occurs in summer, but much results from erosive winter run off.

CHAPTER FIVE

ESTIMATION OF RECREATION PRESSURE

5.1 TECHNIQUES FOR MEASURING RECREATION PRESSURE

Even without the problem of path history, estimation of recreation pressure is difficult. There are three ways in which this can be attempted:

(1) continuous monitoring,

(2) sampled monitoring,

(3) adoption of surrogates.

5.1.1 Continuous monitoring methods

Automatic "people counting" devices have been well tested and documented, particularly by the Countryside Commission. Many methods involve either a mechanical or an electronic counter which records the pressure of the foot on a stile, or wooden step, or the pressure of a closing gate.
Although such methods suffer from various practical problems, they have been shown to work reasonably well if installed with care (Bayfield and Moyes, 1972; Coker and Coker, 1972).

They have been used with some success, for example, for recording people at Tarn Hows, Langdale (Brotherton et al, 1978). However, one essential is a gate or stile through or over which users have to pass.

An alternative device is that of a photoelectric cell, activated by the passage of a walker cutting off the light. Bayfield and Pickrell (1971) used such a counter on a nature trail, where it was possible for the counter to be built into a post at the side of the path. Although not completely accurate, reasonable agreement between that and a gate counter was obtained. However, changes in lighting can produce spurious counts and to make such a device weather proof is difficult (Easton, 1975).

5.1.2 Sampled monitoring

Time lapse photography has been used to record visitor movement in spatially restricted areas, for example, by Goldsmith et al (1970) at selected sites in the Isles of Scilly. Burton (1974) used air photography to record visitor distributions in Cannock Chase, but was only able to distinguish cars - pedestrian details of measurement had to be recorded by a group of observers spread over the area.

Goldsmith mapped a wider distribution than possible from photographs by asking visitors to fill in a questionnaire map. The response rate was good - less than 2% of those approached refused to complete it - although the accuracy of the questionnaire completion was not checked. Hopkins (1969) described a research technique used in the Forest Service (Utah) whereby a self registration method was developed for use at sites such as winter sports areas, camp grounds and picnic areas.

Many recreation studies have used direct observation counts as estimates of recreation pressure; for example, Burton (1974), Beeching (1975), Willis (1976). Sampled observations are often more feasible than continuous monitoring, but there is very wide variation in use of paths, depending on the time of year and weather conditions, not necessarily factors operating consistently among different paths. Some evidence for this variation in the Lake District mountains exists in the counts taken by the Brathay Exploration group (Gee, 1969).

A method for obtaining estimates of traffic from a sampled data series has been suggested by Duffey (1978), but the method, based on harmonic analysis techniques, requires a considerable amount of data for its operation.

5.1.3 Adoption of surrogates

Other criteria that may be used to estimate recreation use are availability of parking, presence of picnic sites, camp sites, youth hostels and public transport. However, although these and similar were used by Beeching (1975), who was interested in the numbers of people walking in the southern Pennines, their appropriateness for estimating numbers of walkers can be questioned, particularly as only a small percentage of holiday makers uses the mountains for walking - estimated as 10% in the Lake District (L.D. Special Planning Board Draft Plan, Section 10.1.3). Moreover many of these facilities are generally available at most access points and of course, these access points can serve more than one footpath.

There is some evidence to suggest that path widths reflect the amount of recreation pressure. Bayfield and Lloyd (1973) organised sampling of recreation pressure on the Pennine Way over four days in the summer at twenty access points. With a range of use between 5 and 40 people a day, measuring an index of path extent calculated from width and bare areas, they obtained a correlation of 0.69 between recreation use and the average index of extent. Considering that no standardisation of vegetation, soil nor topographic features was used, and that the number of sampling days was small, the results are encouraging for the use of path width as a surrogate for recreation pressure.

Gardner (1976) using a similar index on Snowdon paths, found that mean path extent was correlated with an index of annual use, in spite of the limited statistics available for the latter measure. Also, work on Ivinghoe Beacon has shown a clear relationship between path width and use rates, although complicated by other factors (Goldsmith, F.B., pers. comm.).

5.2 MEASUREMENT OF RECREATION PRESSURE IN THE LAKE DISTRICT

The only documented counts of recreation pressure in the Lake District are those of Brathay Exploration Group (Gee, 1969, 1972; Fishwick, 1974). In connection with a series of projects, a census of visitors was taken on the summit of Helvellyn, combined with some questionnaires on aspects of equipment, attitudes, access and sources of knowledge of the area. Counts were taken for

7 days	28 July - 3 August	1966
6 days	3 - 8 August	1967
2 days*	17 June, 19 August	1968
2 days*	6, 7 July	1969
6 days	6 - 15 April	1974

(* short days of 4 hour counts).

These counts were subdivided to give totals for all the main paths reaching Helvellyn summit, but, due to the fact that some of the paths branch lower down the mountain, the counts are not always applicable away from the summit. Nevertheless, they provide a base for testing the hypothesis that footpath width may be used as a surrogate for recreation pressure. This was tested in some preliminary fieldwork, because it was not known whether a satisfactory alternative would be found.

For assessing recreation pressure for this research, information was required for several different routes at the same time. The use of automatic counters proved impossible because

(1) for some paths access is completely open, with no stiles, gates nor other means of channeling walkers;

(2) for others, access is through farms, camping sites or picnic areas, where many people will pass other than those going up the mountains;

(3) in an area of heavy rainfall, maintenance of counters would be difficult; (for example, on one site where it was hoped to be able to install a counter, after rain the wooden step ran with water from a spring just above. On the same path, there were wooden steps which it was also thought might be used, but these collapsed due to subsidence of the ground, partly as a result of winter rains and partly as a result of forestry operations).

(4) beyond some access points, paths divide to serve two or more routes.

The possibility of obtaining sone assistance to carry out sample counts by observation was explored, since there are many education and field centres in the area. However, it proved impossible to find enough help to make the exercise worthewhile. Thus, another approach had to be considered.

From previous experience of fell walkers, it seemed likely that people using the paths would co-operate in a scheme to record themselves, without supervision. Goldsmith's experience of holiday makers in the Scilly Isles lent credence to the idea. People's willingness and ability to record themselves correctly was tested during preliminary work. This and the preliminary work to investigate path width as a surrogate is detailed in the next section.

5.3 PRELIMINARY WORK TO INVESTIGATE METHODS OF ESTIMATING RECREATION PRESSURE

5.3.1 Notice Board Recording

A series of notice boards were prepared with a hardboard backing to a sheet of carbon paper; the carbon paper was carbon side uppermost to a piece of tracing paper, the whole being encased in strong waterproof "see-through" film. Any pointed instrument could be used to make a mark on the tracing paper, and since pencils could break or be removed, the ends of knitting needles were used.

A brief note was appended to explain the research and to request path users to record the day, their group size, and tick the appropriate up and/or down columns (Plate 8). The noticeboards were then left at the beginnings of paths in suitable positions. For some paths there was a convenient stone wall, gate or stile; for those with open acess, small wooden supports were hammered into the hillside in a noticeable place and the boards placed against the supports. None of the boards was to be located near a road, partly to eliminate those people who walked a short way up and back, and partly to lessen the risk of vandalism.

PLATE 8 Example of a notice board, filled in at the Wythburn site

A more complicated method of recording was tried on the summit of Helvellyn. A map of the mountain with numbered and named routes was provided with the board and each group was requested to note the routes in addition to the information already mentioned. During the preliminary work, only the summit board and one board at the foot of the Wythburn path were used, since the aim was only to evaluate the technique. The results of the board counts were compared with observed counts taken during field measurements for testing the width surrogate (section 5.3.2).

Results

Boards were maintained from Saturday, 1 November until Sunday, 9 November (1975), on Helvellyn summit, renewing the recording sheet daily. This was a simple task because paths were being measured in the vicinity, but it was evident that, had this not been so, the time and effort needed for renewal would have made this impracticable. It also proved difficult to locate the boards so that every group saw them. For aesthetic reasons it was undesirable to place them at the summit cairn, and in any case, a stong wind would probably have damaged them, however well secured. The most practical location was the shelter, but this was preferentially situated for certain routes and it was also noticed that in sunny weather, some people avoided the crowds around it. Thus, although the summit board had the advantages that it recorded several routes at once, and that people seemed to take an interest - not only in recording their own routes, but comparing other paths - it was more practical to service boards at the foot of the mountain, and easier to obtain accurate counts by situating boards in favourable positions. Indeed, the board situated at the bottom of the Wythburn path was easy to renew, and, being positioned by a stile, was virtually impossible to miss. Comparisons between the totals observed during fieldwork and those recorded on the boards may be made from table 5.1.

It can be seen that generally the Wythburn board recorded quite well, in contrast to the summit board, which was variable in accuracy, depending on the path and the weather. It was noticeable that on the Wednesday and Thursday the board at the summit matched the observed counts almost perfectly; both days were cool and windy; so presumably, people used the shelter and saw the board. The Wythburn board appeared to be over-recording on Sunday 9 November, but the observed count was near the summit and it was expected that some people would not climb beyond the top of Comb Crag - a good view point about two thirds of the way up - especially in November when sunset is about 16.30 hrs.

The results were promising enough to make it worthwhile continuing the experiment, especially since there was no vandalism of the boards and since the outcome of conversation with some of the visitors was encouraging. It was decided to increase the numbers of access points monitored by boards, but well away from the road in each case, and abandon the idea of a summit board.

5.3.2 Path Width Surrogate for Recreation Pressure

The Brathay counts (1969, 1972, 1974) were used for comparison with path widths for the relevent paths, that being the only available measure of recreation pressure. In an effort to standardise environmental site factors as far as possible, all the measurements of path width were taken on or near to the summit ridge of Helvellyn. This was compatible with the Brathay counts which did not take account of bifurcations further down the mountain. The soil type

TABLE 5.1 Totals of walkers obtained from noticeboard and observed counts of walkers on Helvellyn, November, 1975

DAY	WEATHER	OBSERVED COUNTS	WYTHBURN BOARD	SUMMIT BOARD WYTHBURN	OTHER PATHS (NAME)	SUMMIT BOARD (OTHER PATHS)
Sat	mild drizzle	-	-	30		
Sun	mist, sun later	32	-	11		
Mon	clear some cloud	37	31	17		
Tue	Wet	-	8	0		
Wed	clear cloud wind	59*	35	34	south summit ridge	54
Thu	occasional showers windy	39/6*	18	12	Striding/ Swirral Edge	39/6
Fri	clear sun cloud	3	16	9	Dollywagon Pike	0
Sat	warm sun	163*	95	49	north summit ridge	36
Sun	clear bright cloud	151	174	105		

NOTE: All totals are the sum of people going up and down.
Totals with "*" in "observed count" column refer to the named path in "other paths, name" column.

was a thin ranker and the vegetation a grassland community - Pearsall and Pennington's "upland grassland" type (Pearsall and Pennington, 1973). The topography of the area near to and at the summit ridge is such that little water run off is produced on the paths and the path slopes themselves are rarely more than 15 degrees. Thus, on these sections of path there is virtually no distortion of the path width as a result of footpath erosion. From observation, differences in path width among sites appeared to be the result of differences in recreation pressure and differences in the slope across the path; cross slopes varied from 0 to 30 degrees.

From the Brathay counts, 8 paths were available for sampling. Unfortunately, some of these were very short sections, being, in some cases, only the join of two paths near the summit. This meant that for 5 of the path sections there were only a few sites on each, because the slope variation over such a small distance was limited. However, the remaining 3 paths produced sufficient range of cross slope for relationships to be investigated between cross slope and path width. This was necessary, because, to compare the different paths in relation to the recreation counts, it was first necessary to remove the effect of cross slope.

The paths at the summit of Helvellyn are clearly defined within the upland grassland, being surfaced with earth and small stones. Because they form easy walking surfaces, there is no incentive to walk off them. Different path sections were identified from differences in cross slope, and a ten metre section was chosen randomly. Within this section, path slope, cross slope and path width were measured at ten random points; the slope measurements were made using a fixed interval, 3 ft (0.91m), pantometer similar to that described by Pitty (1968); the cross slope measurements were divided between the upslope and downslope side of the path.

Results

(a) Slope relationships

Path width, path slope and cross slope were averaged at each site and then, for the 3 paths with sufficient data, simple descriptive regression was used to represent the relationships between width and slope variables.

The results are summarised in table 5.2 and suggest that, for these paths, cross slope is the most influential factor in determining path width. The effect of path slope is, not surprisingly, supressed because the range is too small to have a noticeable effect. The effect of cross slope, which is that width decreases as cross slope increases, means that any comparison of the paths with the recreation counts may be misleading unless some standardisation to one slope value is carried out.

Table 5.3 records the values obtained from the short path sections. On these sections three sites were chosen, but as can be seen from the data, there was often on a limited range of values of cross slope, for example, the north summit ridge, although there is considerable variation in path width, possibly because there is in fact some diversion from the path on the summit ridges by walkers wanting to look down the cliffs at certain viewpoints.

(b) Relationships between path width and recreation pressure

From table 5.2 it can be seen that there is no significant difference between the rates of change of path width with cross slope for the three paths, the values being 0.10, 0.07 and 0.08 respectively. The differences lie rather in the "base" value of the path, the width that would be expected

TABLE 5.2 (a) Regression relationships between path width (w) and cross slope (ϕ) for the Wythburn, Dollywagon and Swirral Edge paths, Helvellyn.

PATH	No. OF SITES	REGRESSION EQUATION	CORRELATION COEF.
Wythburn	10	$w = 4.51 - 0.10\ \phi$	0.81
Dollywagon Pike	6	$w = 3.68 - 0.07\ \phi$	0.90
Swirral Edge	5	$w = 3.21 - 0.08\ \phi$	0.98

(b) Relationships for path width including path slope as well as cross slope

PATH	CORRELATION COEFFICIENTS CROSS SLOPE ONLY	CORRELATION COEFFICIENTS PATH SLOPE AND CROSS SLOPE
Wythburn	0.810	0.813
Dollywagon Pike	0.903	0.905
Swirral Edge	0.980	0.980

TABLE 5.3 Values of average width, path slope and cross slope for paths with only three sites.

PATH	SITE	AVE. WIDTH (metres)	AVE. PATH SLOPE (degrees)	AVE. CROSS SLOPE (degrees)
Whiteside	1	1.7	15.2	17.7
	2	1.7	15.2	13.0
	3	2.6	11.7	2.5
Browncove Crag	1	1.7	9.6	13.4
	2	1.5	9.6	7.5
	3	2.2	8.8	11.0
North summit ridge	1	2.3	5.7	9.6
	2	3.7	5.6	8.2
	3	4.8	6.1	9.0
South summit ridge	1	3.8	5.2	14.2
	2	2.7	8.6	18.2
	3	3.0	12.5	15.8
Striding Edge	1	3.5	7.9	19.8
	2	3.5	4.4	19.1
	3	2.0	8.1	26.7

for zero slope, these being 4.51, 3.68 and 3.21m respectively (Table 5.2). This being so, it is reasonable to construct estimates of the base value for the paths with only three sites, using the average value of the regression coefficients of the three longer paths, assuming that the same relationships are valid. The alternative is simply to compare individual cases on all the paths, but the same assumption of similar relationships on all paths would have to be made, if the paths are to be ranked in order of path size to be compared with recreation pressure.

The estimates were made from the equation:

$$a = w + 0.083\,\phi$$

where a = the estimate of the base width, the width at zero cross slope

w = the average measured width

ϕ = the average measured cross slope

0.083 = the average rate of change of width with slope

Since each path had three sites, there were three estimates of the base value of the width and so these were averaged. Table 5.4 gives the estimates of the base width for each path, including those used in the regression, and also gives the rank order of the paths by width and recreation pressure. The ranks of recreation pressure were derived from the acculated counts taken by Brathay. Data were accumulated for all the days on which counts were taken on all the paths simultaneously, 23 days in all. The relationship between the ranks was measured using the Spearman Rank correlation coefficient, which has a value of 0.90. It was also possible to investigate the numerical relationship, using the counts. When graphed, the data show a definite non-linear trend: the rate of increase of path width with recreation pressure decreases as recreation pressure increases

TABLE 5.4 Estimates of base width and recreation pressure for each path, based on fieldwork and Brathay recreation survey

PATH	BASE WIDTH VALUE (m)	BASE WIDTH RANK	BRATHAY COUNTS (RANK)
Whiteside	2.9	2	1
Browncove Crag	2.7	1	2
North summit ridge	4.3	5	6
South summit ridge	4.5	6.5	8
Wythburn	4.5	6.5	5
Dollywagon Pike	3.7	4	4
Striding Edge	4.8	8	7
Swirral Edge	3.2	3	3

Note: Paths are ranked from low to high values.

(Figure 5.1). A logarithmic transformation applied to the data yields a relationship between the estimate of base width, a, and the accumulated counts in hundreds of people, N, as:

$$a = 1.07\ N^{0.43}$$

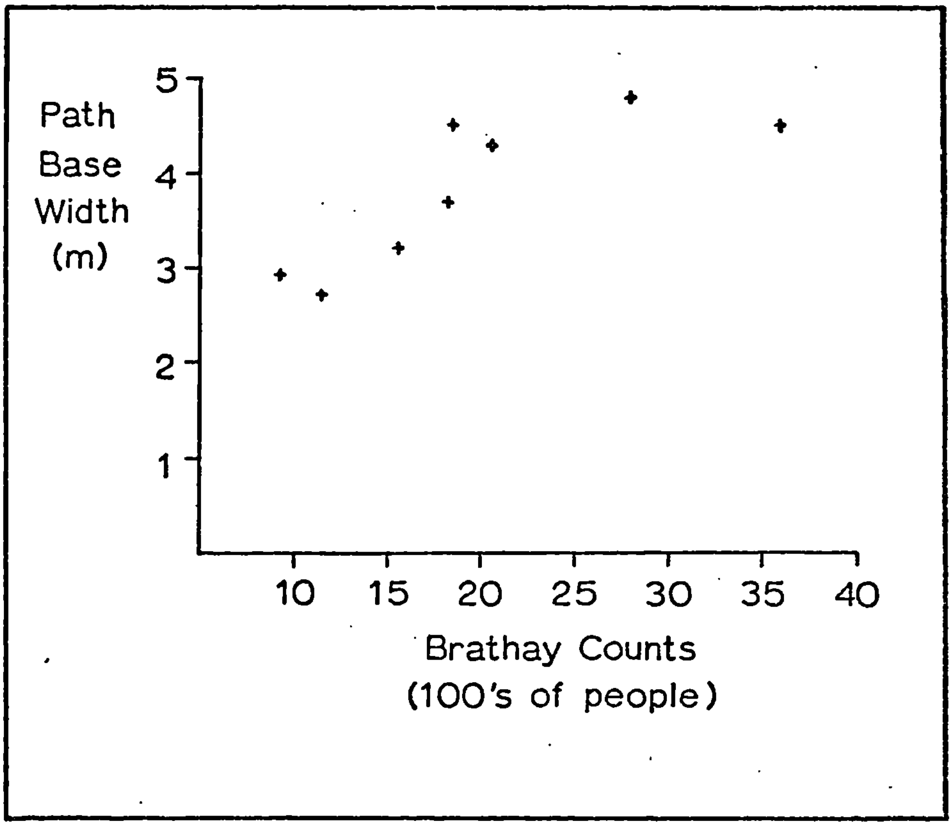
with a correlation coefficient of 0.87. From this data, therefore, the width of the paths is approximately proportional to the square root of the recreation pressure in terms of numbers of people.

Many assumptions have been made in performing the above calculations, and no account has been taken of the errors produced by the sampling, but in spite of this it was thought that the results were sufficiently reliable and encouraging for path width to be used as a surrogate for recreation pressure if sufficient data were not available from notice board counts. It should be noted, however, that, although using path width is advantageous in that past use will be taken into account, it has two disadvantages: its use could be criticised as part of a circular argument for looking at path morphology and its values will be strongly influenced by site conditions on paths which differ in vegetation and other factors, even if width values are standardised for slope.

5.3.3 Conclusions from preliminary work

It was felt that two methods had been found which might produce reasonable estimates of the differences in recreation pressure between the paths. Problems could arise if some of the paths in the sampling area proved to be difficult to monitor with notice boards for any reason, and if the range of environmental site conditions, particularly slope, made comparisons of width among the paths meaningless. Thus,

FIGURE 5.1 Relationship between path width and recreation pressure (Brathay counts)



estimation of recreation pressure was likely to be possible for all paths, but, as a safeguard, the original sampling scheme was adhered to - this provided for sufficient sites on each path to permit some path by path analysis.

5.4 ESTIMATION OF RECREATION PRESSURE FROM NOTICE BOARD COUNTS AND OBSERVATIONS

5.4.1 Methods of counting and analysis

The self recording notice boards described in section 5.3.1 were maintained as often as possible, to provide repeat counts. The Wythburn path up Helvellyn was chosen as a base path, to which other counts could be related, as experience proved that it was reliable, because the board was at a stile which could not be avoided. Moreover, the path was fairly central in the fieldwork area and so the board could be serviced easily on the way to and from other paths. The main path up Causey Pike (Newlands Valley) was chosen as a secondary base path, for two reasons. It was possible to observe, from a local vantage point, five of the Newlands Valley paths, including the Causey Pike path, and this was the most accessible and popular of them. A second reason was that it was thought that the Helvellyn area might have different patterns of recreation use from the Newlands valley paths at different times of the year. This was thought to be a possibility because Helvellyn is very accessible to day and weekend visitors travelling up the motorway, and so is popular for weekend walking at off peak times of the year, particularly in the winter. It was thought that comparisons would be more reliable if made between paths with similar patterns of use. The Causey

Pike counts also acted as a check on any counts at Wythburn which were thought to be in error, and vice versa. Other paths were monitored as the opportunity arose, although, whenever possible, each was recorded simultaneously with one or more of the others, and always with the Wythburn path.

Notice board counts were supplemented by observed counts, taken either during fieldwork or on days specifically set aside to count several paths simultaneously. Such days were used particularly for paths which were too inacessible or which had too many alternative routes to be monitored by board counts.

Each path was compared with Wythburn and/or Causey Pike, by expressing its accumulated count as a percentage of the count for the equivalent number of days for the two base paths. When a board became full or nearly full, it was observed that newcomers sometimes ignored it; occasionally a board was defaced and it was not known whether subsequent groups recorded themselves in the remaining space. Fortunately such occasions were rare at Wythburn and never occurred at Causey Pike. Upon such occasions when the counts were suspected, they were not used in the eventual analysis.

5.4.2 Accuracy of the board counts

Whenever the opportunity arose, a check was carried out on a number of people signing the boards. Counts were taken during fieldwork and then compared with board counts. Discrepancies could arise from board inaccuracies, from people turning back part of the way along the path, and of course from errors in counting during fieldwork. Tables 5.5. (a) - (c) compare the observed and self recording totals. It can be seen that most boards record reasonably accurately, especially if the counts are over a period of time, during

TABLE 5.5 (a) Accuracy of the Wythburn board counts

DATE	OBSERVED COUNT	BOARD COUNT
3 Nov 1976	37	31
9 Nov	151	174
15 Apr 1976	215	205
16 Apr	204	212
21 Apr	52	47
14 Jun	39	37
25 Jul	122	123
5 Sep	90	96
8 Apr 1977	178	183
5 Jun	100	102
TOTAL	1188	1210

Board count as a percentage of the observed = 102%

TABLE 5.5 (b) Accuracy of the Causey Pike counts

DATE	OBSERVED COUNT	BOARD COUNT
19 Apr 1976	18	16
5 Jun	11	15
3 Aug	56	50
30 Aug	61	56
8 Sep	20	28
TOTAL	166	165

Board count as a percentage of the observed = 99%

TABLE 5.5 (c) Accuracy of other board counts

DATE	PATH	OBSERVED COUNT	BOARD COUNT
20 Apr 1976	Skiddaw	411	382
6 Jun	Rowling End	20	21
30 Aug	Rowling End	47	49
7 Jun	Helvellyn Gill	37	49
24 Jul	Helvellyn Gill	109	136
18 Aug	Helvellyn Gill	53	51

which over and under-estimates seem to cancel each other out.

It was found from experience gained at the beginning of the counts that correct positioning of the board was essential and needed care, because walkers were surprisingly unobservant; a board had to be very obvious to both up and down traffic to be seen, in spite of its contrast with its surroundings. In spite of the care taken, not all boards were accurate: Fisher Gill and White Stones were both monitored from the same access point and it was thought that occasionally walkers did not know which path they were using and so these paths were checked from visual counts; Helvellyn Gill was found to over-record upon occasions, which it was thought might have been due to the fact that picnicers from the adjacent nature trail and lake side car park may have been walking part of the way up the path; the path up Skiddaw was so popular that one board was insufficient for the day on which it was checked, but since it occurred on a Bank holiday, it was assumed that at other times the results were acceptable. It was not possible to ascertain which of the Helvellyn Gill counts were in error for all the counts taken, but it was thought that, even if the path was slightly over-recorded at times, such as estimate was better than none.

5.4.3 Results of the combined counts from board and observation

Table 5.6 gives the accumulated counts expressed as a percentage of the Wythburn path, in addition to the number of days on which counts were taken. It can be seen that, for some of the paths, the number of counts is small. These paths were counted by observation, usually at the same time as observations for other paths. Thus, although the counts should be accurate, when used as an estimate for recreation

TABLE 5.6 Recreation pressure estimates, from observed and notice board counts, 1976. All paths are expressed as a percentage of the Wythburn path.

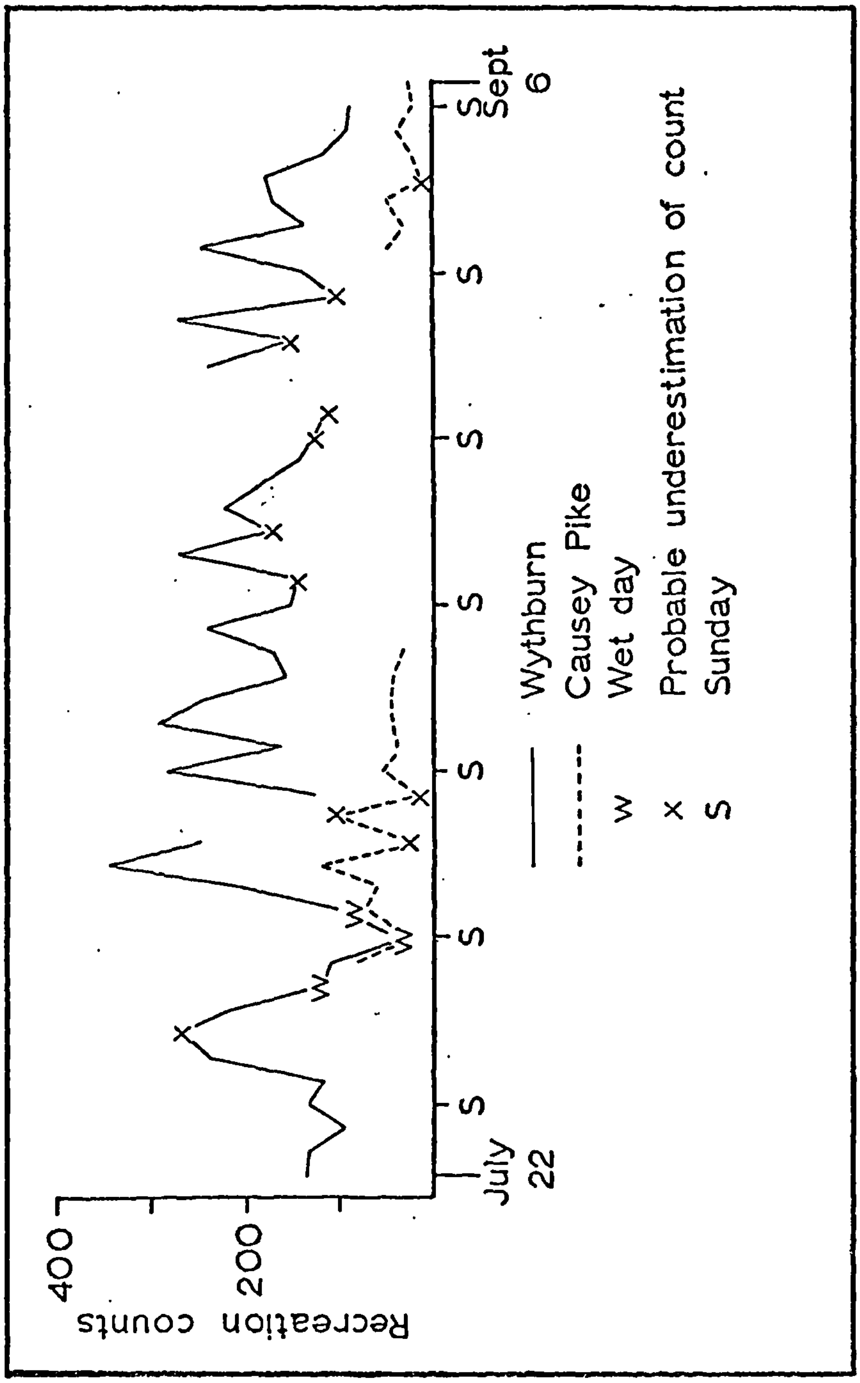
PATH	NO. OF COUNTS	RECREATION PRESSURE ESTIMATE
Causey Ridge	2	58
Sail	2	30
Scar Crag	2	50
Grisedale Pike	4	27
Red Tarn	3	37
Swirral Edge	3	69
Kepple Cove	3	23
Mires Beck A	2	14
Mires Beck B	2	27
Dollywagon Pike	4	85
Striding Edge A	4	125
Striding Edge B	4	138
Wythburn	87	100
Helvellyn Gill	48	53
White Stones	6	50
Browncove Crag	5	77
Fisher Gill	5	25
Tongue Gill	3	42
Causey Pike	50	34
Rowling End	32	24
Skiddaw	6	160
Cat Bells	2	100

pressure, they may misrepresent the particular path value because of the variation in recreation use of a path from day to day. To a certain extent, recreation use variation on paths depends on factors which operate throughout the area, such as weather conditions and Bank Holiday pressures, but there are pseudo-random fluctuations; for example, the presence of a school party centre in the Newlands Valley means that on certain days large parties will use the paths up some of the nearby fells; Causey Pike is particularly affected in this way.

The variation of daily figures of counts taken on the Wythburn and Causey Pike paths is shown in figure 5.2. Throughout the main holiday season there seems to be a weekly cycle, with a midweek peak and a Saturday trough, Saturday being the day when most holidaymakers arrive and leave. There is possibly a small peak on Sundays when day or weekend visitors are present, but this is most noticeable at "out of season" times, as was apparant during the field-work carried out in November, March and September.

In most years, the effect of weather would be expected to confuse the pattern of path comparisons, but, in the summer of 1976, the Lake District weather was extremely uniform, being clear, dry but with cloud throughout most of the period June - August. This meant that excessive heat, low cloud and heavy rain, all of which might be expected to influence the levels of recreation pressure, rarely interfered and so comparisons between paths were easier.

FIGURE 5.2 Variation of daily counts on the Wythburn and Causey Pike paths



5.5 COMPARISON OF RECREATION PRESSURE ESTIMATES WITH THE SURROGATE, PATH WIDTH, AND RESIDUALS FROM THE REGRESSION ANALYSIS

Since the preliminary work had suggested that the average width of uneroded paths might be a reasonable surrogate for recreation pressure, the recreation estimates from the counts - board counts and observed counts - were expected to be related to these widths. It was also thought that the residuals from the regression of path width as a function of the environmental site variables should reflect differences in recreation pressure. Thus, the average residuals should be comparable with the recreation estimates by counting.

The regression of path width as a function of site variables is described in chapter seven. A definition for an uneroded path is given in chapter six, section 6.1.4. It was therefore possible to produce values of the average width of uneroded paths and the average residual width and depth for each path studied. Scattergrams of the recreation estimates with the average uneroded path width, and the recreation estimates with the average residuals for each of the path variables, path width, bare ground and maximum depth, are given in figures 5.3 (a) - (d).

It can be seen from the scattergrams that there is a relationship between the variables in each case, although one or two anomalies appear to be present. The clearest relationships occur for recreation pressure estimates with average width, and for recreation pressure estimates with average residual width, suggesting perhaps that width is the path characteristic most influenced by recreation pressure. The most anomalous paths for both the width relationships are Scar Crags and Sail A (Figures 5.3 (a) and (b)). One possible explanation for this is that the estimation of

FIGURE 5.3 Key to numbered paths in figures 5.3 (a) - (d).

1. Causey Ridge
2. Sail A
3. Sail B
4. Scar Crags A
5. Scar Crags B
6. Grisedale Pike A
7. Grisedale Pike B
8. Red Tarn
9. Swirral Edge
10. Kepple Cove
11. Mires Beck A
12. Mires Beck B
13. Dollywagon Pike
14. Striding Edge A
15. Striding Edge B
16. Wythburn
17. Helvellyn Gill
18. White Stones
19. Browncove Crag
20. Fisher Gill
21. Tongue Gill
22. Causey Pike
23. Rowling End
24. Skiddaw
25. Cat Bells

FIGURE 5.3(a) Relationship between recreation estimates and the average width of uneroded path sections

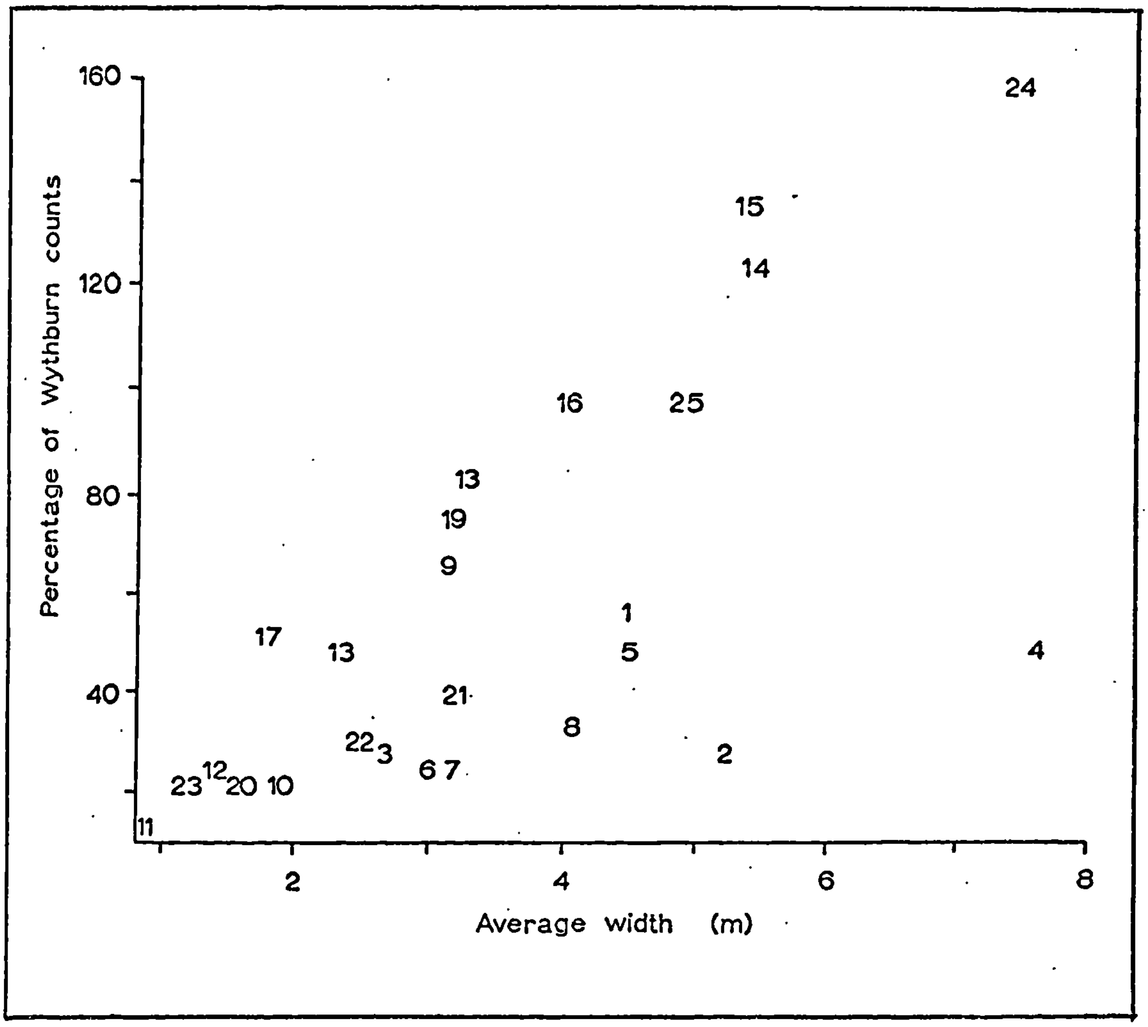


FIGURE 5.3(b) Relationship between recreation estimates and average path width residuals

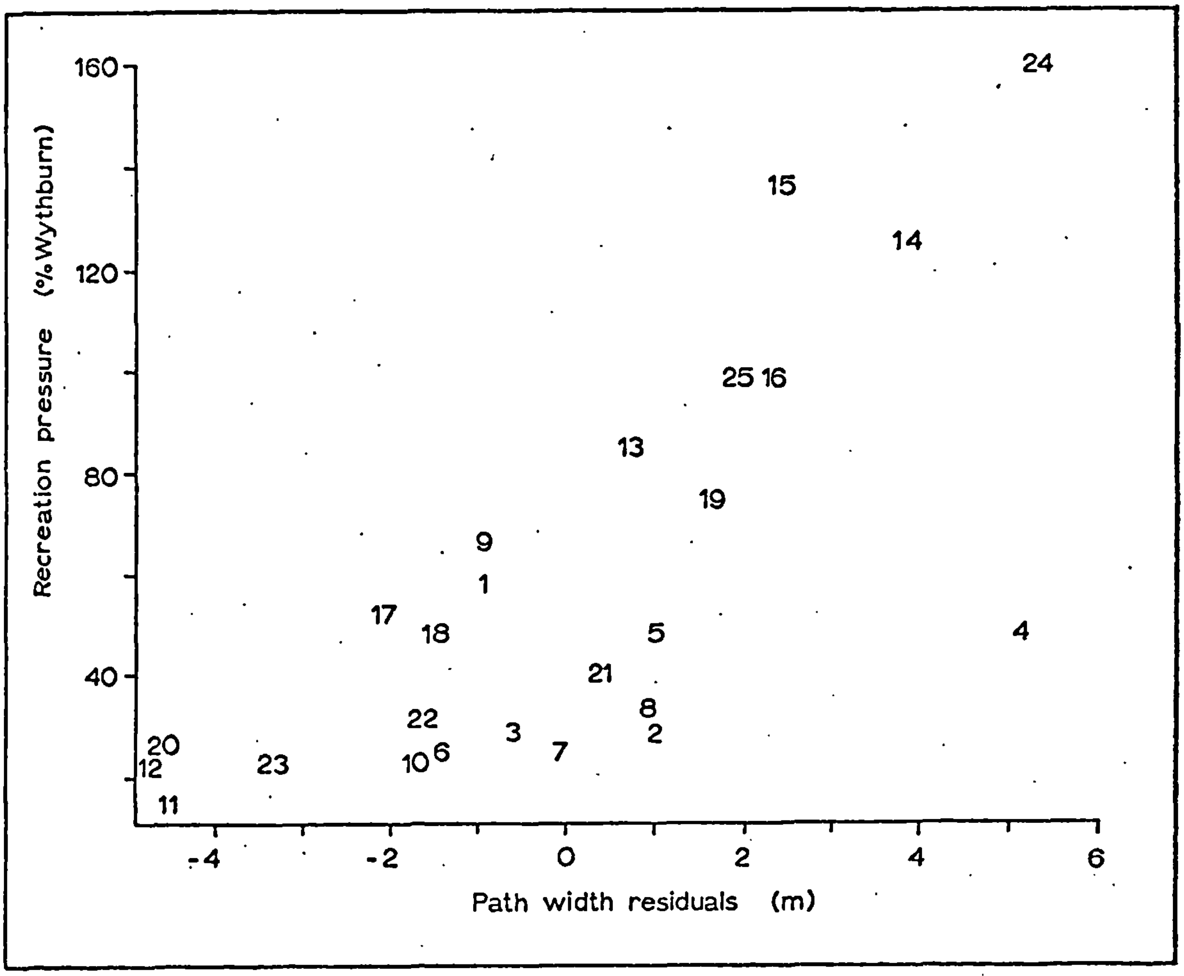


FIGURE 5.3(c) Relationship between recreation estimates and average bare ground residuals

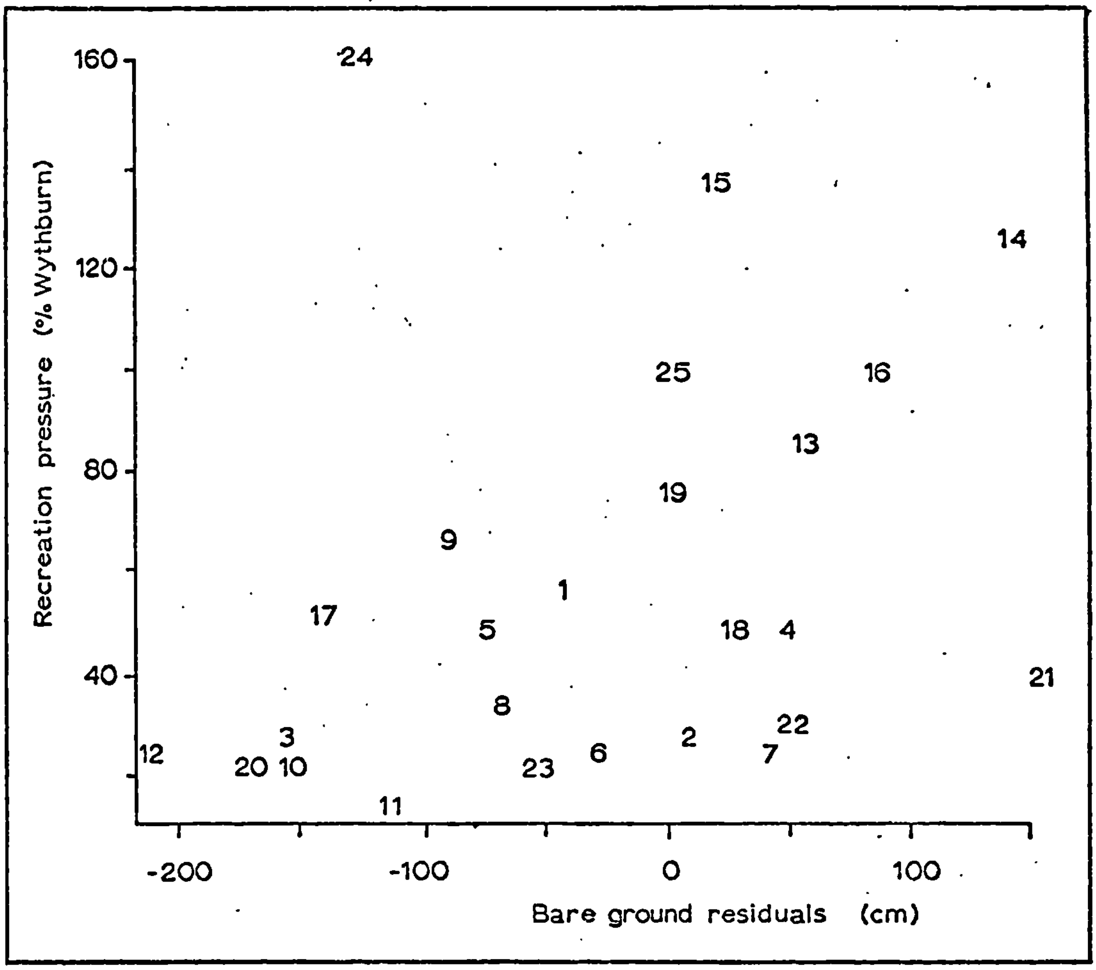
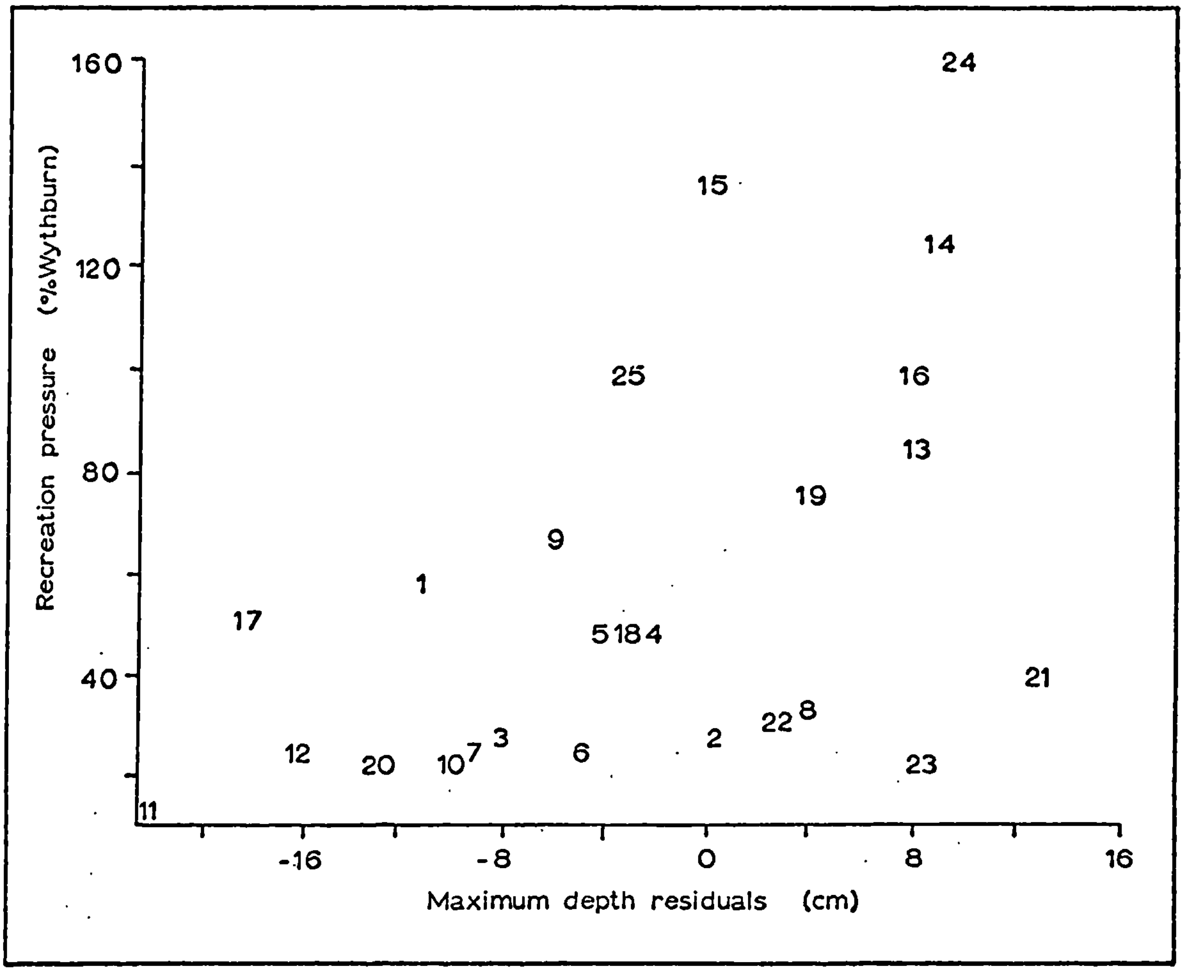


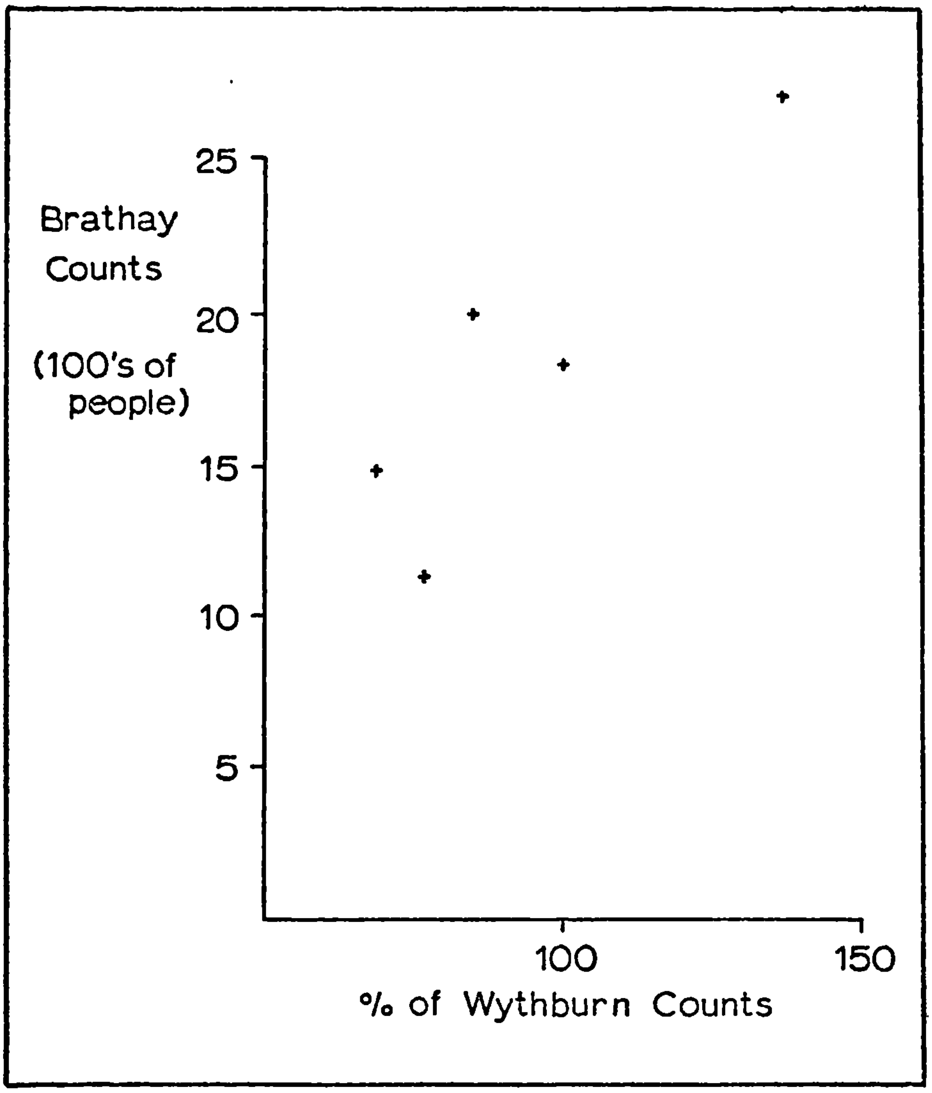
FIGURE 5.3(d) Relationship between recreation estimates and average maximum depth residuals



recreation pressure by counting is very inaccurate. However, if this were to be the case, then one would expect the same paths to be anomalous in the scattergrams of recreation pressure with bare ground and recreation pressure with maximum depth. This is not so. In fact, Tongue Gill and Skiddaw stand out as anomalies in figure 5.3 (c), and Tongue Gill and Rowling End in figure 5.3 (d). It seems likely therefore, that there are other factors, unaccounted for, contributing strongly to the morphology of these paths, and that the estimates of recreation pressure by counting, although containing errors, are as reasonable an approximation to this force as any other that it was possible to obtain under the circumstances.

Another point to be noted in all the scattergrams of figure 5.3 is that the relationships appear to be non linear. In the preliminary work, the relationship between average width and the Brathay counts was found to follow a similar pattern: width was approximately proportional to the square root of the numbers of people counted on the paths. The receation pressure estimates obtained from the board and observed counts are consistent with this, as can be seen in figure 5.3. The relationship between the relevent board counts and the Brathay counts is shown in figure 5.4, again as a scatter diagram. Although the number of comparable paths between the two data sets is not very large, it can be seen that the correspondence between them is reasonable, in view of the discrepancies that must arise with such methods of counting and sampling of counts.

FIGURE 5.4 Relationship between notice board counts and Brathay counts



5.6 CONCLUSIONS

As estimates of recreation pressure on the footpaths, the results from the board and observed counts were far from perfect. However, in spite of the shortcomings of the method, it was decided to use the values because there was no visible alternative. Moreover, such evidence as it was possible to find suggested that, if not an exact representation of recreation pressure, at least the estimates appeared to be reasonable approximations.

Since it appeared that the relationship between footpath morphology and recreation was not a linear one, in the analysis of the total data set, a square root transformation was applied to the recreation estimates, in accordance with the evidence of this preliminary work. This is in itself an interesting result, if generally valid, because the implication is that an n-fold increase in recreation pressure does not necessarily result in an n-fold increase in erosion. In some experimental work, Liddle (1973) found a quadratic equation for the percentage of remaining vegetation cover in terms of the logarithm of the number of walker passages; Quinn (1977) found a linear relationship between soil loss and the number of walking passages; Bayfield and Lloyd (1973) also found a linear relationship between path extent on the Pennine Way and levels of use. However, these research reports are of work carried out under different conditions such that it is difficult to compare them, either with each other or with the results from the Lake District paths.

CHAPTER SIX

THE MORPHOLOGICAL SURVEY: FIRST PHASE OF SAMPLING

6.1 FOOTPATH MORPHOLOGY: CHOICE AND SAMPLING OF VARIABLES

The main aim of the first phase of sampling in the morphological survey was to establish some path-slope relationships. It was felt that these would, with recreation pressure effects, be fundamental to the whole footpath system, because slope affected so many aspects of the force applied to path surfaces. The other factors discussed in chapter two were considered during subsequent phases, because it was felt that their effect was to modify the basic effect of slope and recreation,

Certain other variables were recorded during this first phase, since general site conditions were easy to identify; a note was also made of features of sites which appeared to be relevent to their morphological characteristics. Thus, at all sites, the dominant vegetation types, the soil type, altitude, aspect and the general wetness and roughness characteristics were recorded. Details of this are given below, in section 6.2

Before collecting the data, some preliminary work was carried out to investigate variables to be used to describe the path morphology and the method of sampling them.

6.1 FOOTPATH MORPHOLOGY: CHOICE AND SAMPLING OF VARIABLES

Most recreation studies have been ecologically based with the interest centred on the changes in the species composition of trampled vegetation. Such studies are too numerous to quote, but good examples are the work of Bell and Bliss (1977) and Willard and Marr (1970) in alpine areas of U.S. National parks, Chappel et al (1971) on chalk grassland, Boorman and Fuller (1977) and Liddle (1973) on sand dune vegetation, Burden (1969) on a Surrey nature trail and Leney (1974) on various picnic sites.

Less work has been done on footpaths specifically in mountain areas; Bayfield (1973 (b)) and Easton (1975) worked in Scotland, and Gardner (1976) and Willis (1976) worked in Snowdonia.

Most of the ecological work has employed quadrat sampling or similar methods. The work done on mountain paths was done using an index of erosion or path extent modified from the one first used by Bayfield. These indices utilise measures of path width, bare areas, damaged vegetation and other similar properties of possible path degradation.

For this research, it was decided that path width, the amount of bare ground and the depth of path gullying should be investigated separately because the available literature suggests that the same factors may not be responsible for each aspect of path morphology (chapter two).

The preliminary work carried out to investigate surrogates for recreation pressure (section 5.3.2) utilised average values of transects across path section. It was felt that transect sampling represented a quick method for obtaining the essential path information, since path width, the portion of that width consisting of bare ground and the depth of gullying could all be measured at the one transect. A choice had to be made however, between "point sampling", consisting of one transect at a site, or area sampling, consisting of the average of several transects at one site. In making the choice, speed of measurement - hence the number of sites visited - and level of detail had to be considered in the light of possible analytical techniques. Paths which are eroded appear to exhibit some variability within a "homogeneous" site. The causes of the variability are not only variations in microtopography and other site factors, but also the discontinuous nature of much footpath development - for example "the catastrophic" collapse of pieces of turf and soil, or intense localised gullying during a storm. Preliminary observations suggested that of all the factors, small slope variations were the most obvious cause of heterogeneity. Particularly, slope appeared to influence the occurrence of bare patches. Using average values over an area would suppress local variation, but on the other hand using single values would increase the probability of picking up an extreme value at a site. The proposed method of analysis should affect the choice of sampling method. It was hoped that the use of regression analysis might be appropriate; while the use of average values is permissible in description, it is not so desirable for more rigorous analysis (Mather, 1976). On the other hand, if the variability of measurements within sites was to be greater for sites with more erosion than for those with less, there were obviously going to be problems of heteroscedasticity in any regression analysis.

In addition to the morphological characteristics of a site, it was desirable to know whether or not it was subject to continuing erosion. There is the possibility that footpaths may be eroded, in the sense that they are wide and that considerable amounts of bare ground are exposed, but that a new state of equilibrium may be established, at which the form of the path is balanced with the number of people using it. In this case, the path, although wide, would not necessarily constitute a problem in the management sense. It was hoped that criteria could be established for distinguishing paths with continuing erosion from those which were apparently stable.

Some preliminary work was undertaken with the following aims:

(1) investigation of possible path variables in terms of ease of definition and measurement,

(2) investigation of the variability of path variables within sites, and

(3) identification of criteria indicative of active erosion at a site.

This work and the results are described below.

6.1.1 Methods of measurement

Path Width was measured across the path at right angles to the path direction. It was defined as the width of path showing visible signs of trampling, either as vegetation species composition changes, damaged vegetation or patches of bare soil or rock exposed by erosion. It was found that for most paths, identification of the width presented no problems, but on some, a gradually merging boundary between the path and the surrounding vegetation created difficulties. *Nardus* grassland was particularly difficult when other species in the community were few, although for some sites it was possible to see a reflected sheen on the trampled area when the light was favourable; the sheen is caused by the leaves, which tend to become oriented in a downslope direction. The main reason for the identification problems in Nardus grassland is that the turf is often poor in species diversity, particularly lacking in herbaceous plants. On the Festuca-Agrostis grassland, the boundary of the trampled area is generally marked by a reduction in species which do not tolerate trampling. In particular, the otherwise frequently occurring species of flowering plants, heath bedstraw (Galium saxtile) and tormentil (Potentilla erecta), and the almost ubiquitous mosses (Sphagnum spp) disappear on footpaths. Vegetation communities other than grasses, that is the various heath species and bracken (Pteridium), are generally intolerant of trampling and there is usually a clearly marked boundary between the trampled and untrampled zone.

Bare Ground was measured along the line of the path width transect. It was defined as soil or other mineral matter completely without roots or fragments of vegetation. This variable proved to be less ambiguous than another which was considered, "damaged vegetation". Damaged vegetation can often be identified on footpaths, but its extent varies in time, depending on season or weather/recreation conditions.

Vegetation was described as "damaged" if its leaves were badly bruised, broken or smeared with mud, if bare patches of earth occurred or it roots were exposed in comparison with adjacent areas of vegetation. However, as a variable it was not very reliable. When a period of heavy recreation pressure coincides with weather unfavourable to vegetation growth, there is an increase in the amount of damaged vegetation on the path, but this is often only temporary (Plates 4 (a) and 4 (b)).

Maximum Depth was measured as the maximum distance of the eroded surface, if present, below an estimated original surface. As such, it involved assumptions about the original surface pre-dating the path. Where the cross slope is low, the depth of an incised surface below some former surface is not too difficult to estimate, unless the topography is hummocky or convex. Even then, it is often possible to use adjacent and similar areas for comparison. However, where the cross slope is high, estimation is more difficult. On such slopes, the downslope side of the path usually becomes ridged upwards by slumped material from the upslope side, which in turn often becomes incised back into the slope. Thus estimates of path incision depths on such paths may be less realistic than those on others. The considerable assumptions that have to be made for the measurement of this variable render its accuracy doubtful, but as an order of magnitude, the result should be reliable. It was likely, however, that the ambiguity or inaccuracy might be reflected in poor results from the eventual analysis.

Area of cross-section was considered as a possible variable because it supposedly represents the amount of soil removed. Areas were calculated from depth measurements taken every 10 cm across any bare eroded section of the transect. This area estimate suffered from the same identification problem as did maximum depth. In addition to the calculated areas, estimates were made of the area from the maximum depth and bare ground variables. Half the product of the maximum depth and the length of bare ground was used as an area estimate, to see whether it was possible to approximate the area quickly, since on very wide paths its measurement was likely to be slow and inaccurate.

A total of 40 sites was picked randomly from 4 paths, using air photographs. In the field, the path variables mentioned above were measured and the results added to those from a further 38 sites, measured for monitoring rates of change (chapter four).

6.1.2 Comparison of the path variables

(a) Simple descriptive correlation was used to evaluate the extent to which the various path variables were related to each other. The results for the measured variables and the area calculated from the 10cm interval depths are tabulated below - the square root of the area is used in order that it may have the same dimensions, length, as the other variables.

	Bare Ground	Maximum Depth	Area
Width	0.73	0.44	0.56
Bare Ground		0.63	0.68
Maximum Depth			0.91

These results are consistent with the view expressed previously that the different aspects of path morphology, its overall width, the extent to which the vegetation is worn away, or the surface gullied, are not attributed to the same factors, and so will not necessarily be well related. In particular, the extent of gullying and the width are not related strongly; this is to be expected because gullying, although initiated by recreation pressure wearing away the vegetation cover, is determined to a great extent by the force of the water running down the path. From this data, it appears that the most influential component in the area of the cross-section is the maximum depth, the two being related with a correlation coefficient of 0.91. This emphasises what can be observed, that much lateral erosion proceeds at the side of a path, without incision, and in fact what may happen is that gullying in a path subsequently channels all its surface water so that incision is less likely elsewhere on the surface.

(b) The calculated areas were compared with the estimates of the areas obtained from the product of bare ground and depth. These comparisons were done on a path by path basis, lest different paths should have different relationships; for example, it was thought that a ridge path, with limited opportunity for vertical incision because of the proximity of bedrock, might produce different relationships from paths with deep soils. In fact this was not true to any great extent, as the overall correlation shows (Table 6.1).

TABLE 6.1. Correlation of area and area estimate

PATH	NO. OF SITES	CORRELATION COEFFICIENT
Wythburn	17	0.97
Causey Pike	16	0.93
Hawse End	5	0.93
Causey Ridge	10	0.99
Sail	10	0.80
Browncove Crag	10	0.97
Helvellyn Gill	10	0.96
Total data set	78	0.87

The results suggested that, at least in the first stages of the survey, area might reasonably be estimated from the measurements of maximum depth and bare ground.

6.1.3 Variability of path measures within a site

It was suspected that the variability of the path variables within any one site might increase with the amount of erosion. The establishment of 5 sites to test the efficiency of monitoring change by using measurements of random transects, provided a useful data set for considering the variability within sites. Further preliminary work to test the effect of run off downslope (section 7.1.3) provided another 3 sites. In addition to this data, 41 sites had been measured in the preliminary work on recreation pressure (section 5.3.2) each with ten random transects.

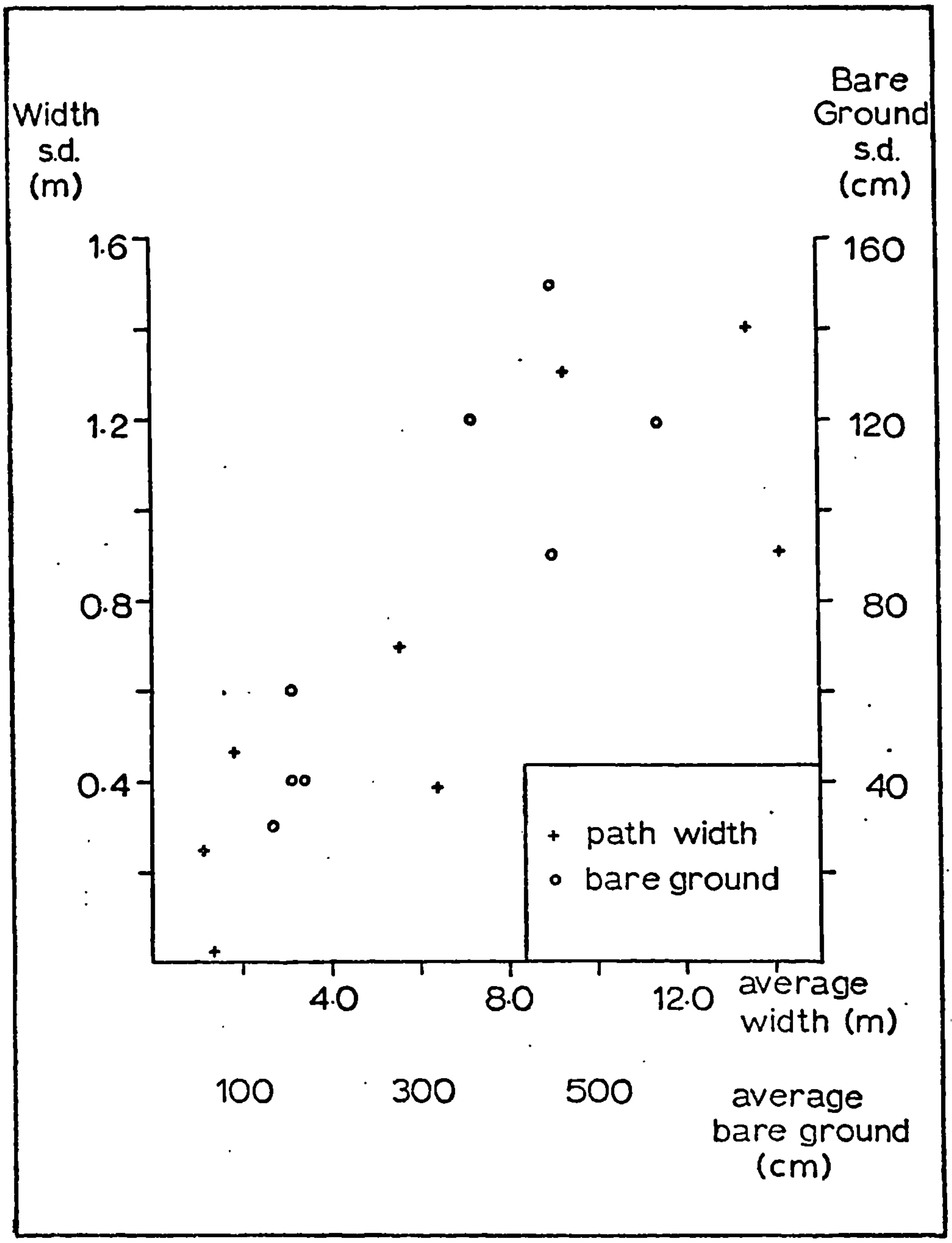
Each site was considered to be homogeneous in the sense that any variation was considered to be a fluctuation about the mean for the site. The 41 sites mentioned above, were by the definition of that particular exercise for which they were collected, all sites which appeared to be stable, little eroded and varying mainly as a result of recreation and cross slope differences. Expressing the variation within each site as the standard deviation from the mean, the relationship between erosion amount and site variability for these sites was calculated as the correlation coefficient between the mean and the standard deviation. The coefficient is 0.37, which suggests that the relationship is weak.

In contrast, the other 8 sites mentioned ranged from paths little eroded to those with considerable erosion, including gullying. For these sites information had been collected for both path width and bare ground. The values of the means and standard deviations are given in table 6.2, together with the coefficient of variation. Clearly, for these sites, with a greater range of erosion than those above, the amount of variation within a site increases with the amount of erosion, although the proportion - the coefficient of variation - does not. The relationship can be seen in figure 6.1, in which the values of the standard deviations and means, for both path variables, are expressed in scattergram form.

TABLE 6.2 Variability within sites for path sections treated as homogeneous

SITE	PATH WIDTH			BARE GROUND		
	Mean	Standard Deviation	Coefficient of Variation	Mean	Standard Deviation	Coefficient of Variation
	(m)	(m)	%	(m)	(m)	%
1	3.5	0.4	11.4	280	70	24.9
2	7.3	1.2	16.0	99	46	46.6
3	3.4	0.4	12.5	323	39	12.2
4	11.5	1.2	10.0	709	91	12.9
5	2.8	0.3	9.5	75	01	1.9
6	9.1	1.5	16.7	675	140	20.7
7	9.1	0.9	9.7	470	130	27.6
8	3.2	0.6	18.1	58	24	40.7

FIGURE 6.1 Relationship between path variation within a site and the magnitude of erosion at that site



6.1.4 Criteria for the identification of current erosion

A list of suitable indicators was compiled which could assist identification of active processes on sites which were subject to current erosion. Since the two main erosive agents are water and feet, signs of water scouring and deposition were of major importance, together with obvious foot scars, skids, collapsed turf and boot marks. However the influence of other processes cannot be neglected. Frost heave mounds are evident, at path sides where this process operates, in the spring and early summer, and by the same process traces of lichen and moss are removed from the sides. The removal of wind borne particles can be observed in appropriately dry and windy weather, but not at other times.

One or more of the following criteria were taken as indicative of active erosion continuing on a path, but it should be emphasised that the absence of all of them might not mean that there was no active erosion, especially if the erosion was infrequent in operation.

List of criteria

1. Earth, stones spilled on top of adjacent vegetation areas.
2. Recent water gullying - channels with rectangular cross-sections cut after rain.
3. Skid marks and other boot scars on turf, on collapsed turf masses, turf "steps" and path "banks".
4. Obviously recent bank collapse - not necessarily due to foot pressure - often occurring as a result of undermining by water or frost heave, and recognisable from the tearing of new turf and roots.
5. Absence of lichen and moss cover at path sides.
6. Frost heave mounds at the sides of paths - most evident in the spring and early summer because subsequently the loose earth tends to be washed away or trampled down.

Using these criteria, it was possible to place each site in an erosion category, irrespective of the size of the path or how much erosion had occurred there previously. Occasionally it was not possible to allocate a path to a category of "eroding" or "not eroding", in which case it was recorded as unclassified.

6.2 ENVIROMENTAL VARIABLES AND SAMPLING ADOPTED FOR THE FIRST PHASE OF THE MORPHOLOGICAL SURVEY

6.2.1 Variables

Following on from the preliminary work, described in 6.1.1 and 6.1.2, the easily measured variables of path width, bare ground and maximum depth were chosen. In addition, the erosion category was used, as described in 6.1.4.

Other variables which were recorded were as follows:

Path slope This was measured at each transect by laying a 2m ranging pole on the ground, parallel to the line of the path, along the vegetation at each side of the path. The angle of the pole, to the nearest degree, was measured using an Abney level and the two results were averaged. This was quicker than sighting to a vertical pole. The 2m interval was a compromise between averaging the microtopographical effects and accurately representing the slope at a transect. Trampling at the sides of paths generally creates an even surface and thus gives a good representation of slope at that site.

Cross slope The effect of trampling does not extend far beyond the visible limits of a path; so the cross slope was measured between two points, 2m away from the visible edge of the path at each side, along the line of the transect. There were occasions when this was not possible because the path was adjacent to some obstacle, or not sensible because there was a sudden change of slope; in such cases the distance had to be reduced and an estimate was made as far as possible in an unbiased way. Measurements were taken with an Abney level, sighting to a vertical pole.

Vegetation Type The dominant vegetation species were recorded at each site - identification of grasses was made using Hubbard (1968). The variety in the Lake District fellside vegetation is small and the probable range of communities was known (Pearsall and Pennington, 1973, chapters nine and ten). The first classification was into:

1. *Pteridium aquilinum*, dominant and vigorous growth.
2. *Pteridium*, intermittent, with *Agrostis-Festuca* grassland.
3. *Agrostis-Festuca* grassland.
4. *Nardus stricta*, dominant, dry.
5. *Nardus*, dominant, wet, with *Sphagnum* species.
6. *Calluna Vulgaris*, dry.
7. *Calluna*, wet with *Sphagnum* spp.
8. *Vaccinium myrtillus*, dry, occasionally co-dominant with *Empetrum nigrum*.
9. *Vaccinium*, wet with *Sphagnum* spp.
10. Montane zone "grassland" with a varying species composition, but usually *Festuca* spp with one or more of the following although in rather stunted form: *Nardus stricta*, *Vaccinium* spp, *Empetrum nigrum*, *Deschampsia flexuosa*, *Rhacomitrium* and *Lycopodium* spp.
11. *Juncus squarrosus*, also often with *Nardus*.

In the event, many of the categories had few members, and during subsequent analysis it was felt that the effect of vegetation type was being confused by its division into too few individuals in each. The final classification was much simpler and it proved more effective in analysis. It was:

1. Pteridium, Agrostis-Festuca combinations
2. Nardus-Juncus squarrosus
3. Calluna-Viccinium-Empetrum (heath species)
4. Montane grassland - as no. 10 above.

Soil Type This was established by auger holes in the vicinity of the path. Sometimes, path incision gives an indication of profile form, but it can be misleading because trampling seems to be able to alter the character of some soil types. For example, within an area of podsolic soil under Calluna and mor humus, the path area is often grass and mull humus over a brown undifferentiated soil. Leney (1974) found that iron pans were broken up by trampling. Also sheep often feed preferentially on path grass and they return nutrients to the soil in their faeces. The soil types found were named according to their general profiles (Bridges, 1970) and reflected those distinguished by the soil survey in similar types of area - Coniston and Grizedale forest, SW Cumbria (Hall and Folland, 1970) - no soil survey mapping having been done for the central fells. The soils distinguished were:

1. Acid brown earths - mull humus, no horizon differentiation.
2. Brown podsolic soils - mor humus, no real horizon development, but occasional bleached layer below mor humus, occasional iron concentration.
3. Podsol with bleached layer below mor humus, and iron pan, intermittent at times.
4. Peaty rankers developed over stony clays.
5. Thin peat rankers developed over bedrock or stratified scree and similar bedded stony material - usually associated with the high altitude sites.

Altitude The approximate altitude of each site was obtained from identification of the sites on air photographs where possible, which were subsequently compared with maps at the 1 : 10,000 scale - available for the Helvellyn range - or at the 1 : 25,000 scale. For areas without air photograph cover, the altitude values were estimated from maps. In either case the values were only estimates.

Aspect The aspect of the path site was recorded, using a prismatic compass.

General surface characteristics These were recorded with reference to permanent wetness, usually caused by local seepage areas, and to the presence of boulders in large numbers in the site area. Other relevent features were recorded as they were observed.

6.2.2 Sampling

The results of the measurement of site variability within a "homogeneous" section (section 6.1.3), posed a problem in the choice of sampling method. It was almost certain that regression analysis based on single transect sampling would be beset by problems of heteroscedasticity (Mather, 1976). This had to be weighed against the problems of using mean values. Johnston (1972) discusses both problems, and methods for correcting them, from which it appears that heteroscedasticity is easier to deal with, if something is known about the cause of the heteroscedasticity. In the event, the choice was made of single transect sampling, rather than the average over an area because, apart from the greater speed of measurement, it was felt that even using average values the data might still be heteroscedastic, thus creating two problems of analysis rather than one.

The general sampling framework for the first phase has already been outlined in chapter three, namely that the 14 paths chosen were divided into homogeneous sections, within which one random point was chosen for the transect across the path. The paths are listed in table 6.3, together with general information on each.

6.3 DATA ANALYSIS

Initially, descriptive regression was used, for each path separately, for the variables measured on a continuous scale, namely path width, bare ground, maximum depth, path slope and cross slope.

6.3.1 Form of the relationship

Inspection of bivariate scattergrams showed clearly that path variables were related to path slope, but not in a linear fashion. The general trends in all the scattergrams for each of the 14 paths were similar, differing mainly in the amount of scatter and the rate of change of the variable with slope. It appeared that in general, the closest relationships were between path width and slope; that bare ground and maximum depth were also related to slope but to a lesser extent. Other factors were apparantly of greater importance to the amount of bare ground and depth than to path width overall. The constraining effect of cross slope on the width can be seen for each path. It should be noted, however, that there is an inherent relationships between path slope and cross slope, in so far as high values of both are unlikely to occur together.

The types of relationships found can be seen in figures 6.2 - 6.5 the scattergrams for the Wythburn path. They are no more typical than others, but have been chosen because the

TABLE 6.3 General information on the footpaths used in the first phase of sampling.

PATH	STARTING POINT	GEOLOGY[1]	ALTITUDE RANGE[2]	GENERAL ASPECT	PATH SITUATION
1. Causey Pike	NY22 233212	SS	800 - 1700	NE	Across hillside
2. Rowling End	NY22 233212	SS	800 - 1700	E	Mostly on ridge top
3. Cat Bells	NY22 248211	SS	500 - 1400	N	Mostly on ridge top
4. Skiddaw	NY22 281252	SS	1000 - 2700	S	Across hillside
5. Fisher Gill	NY31 317178	BVS	1000 - 2700	W - NW	Across hillside
6. White Stones	NY31 317178	BVS	1000 - 1900	W	Across hillside
7. Helvellyn Gill	NY31 316170	BVS	1000 - 1900	W	Across hillside
8. Browncove Crag	NY31 377173	BVS	1900 - 3000	W	Mostly across hillside
9. Wythburn	NY31 324136	BVS	1000 - 2900	NW - SW	Across hillside
10. Tongue Gill	NY30 337092	BVS	750 - 1700	W - S	Across hillside
11. Dollywagon Pike	NY31 350123	BVS	1800 - 2900	S	Part across hillside/ ridge
12. Striding Edge A	NY31 382158	BVS	900 - 2300	SE	Across hillside
13. Red Tarn	NY31 365174	BVS	1000 - 2300	NE - N	Across hillside[3]
14. Kepple Cove	NY31 352176	BVS	1300 - 2700	SE	Across hillside

1 SS Skiddaw Slate
BVS Borrowdale Volcanics

2 Altitude Range is given in feet, in accordance with the existing maps of the area; 100 ft = 30.5m approx.

3 Red Tarn: a path crossing boggy terrain in places

FIGURE 6.2 Relationship between path width and path slope for the Wythburn path

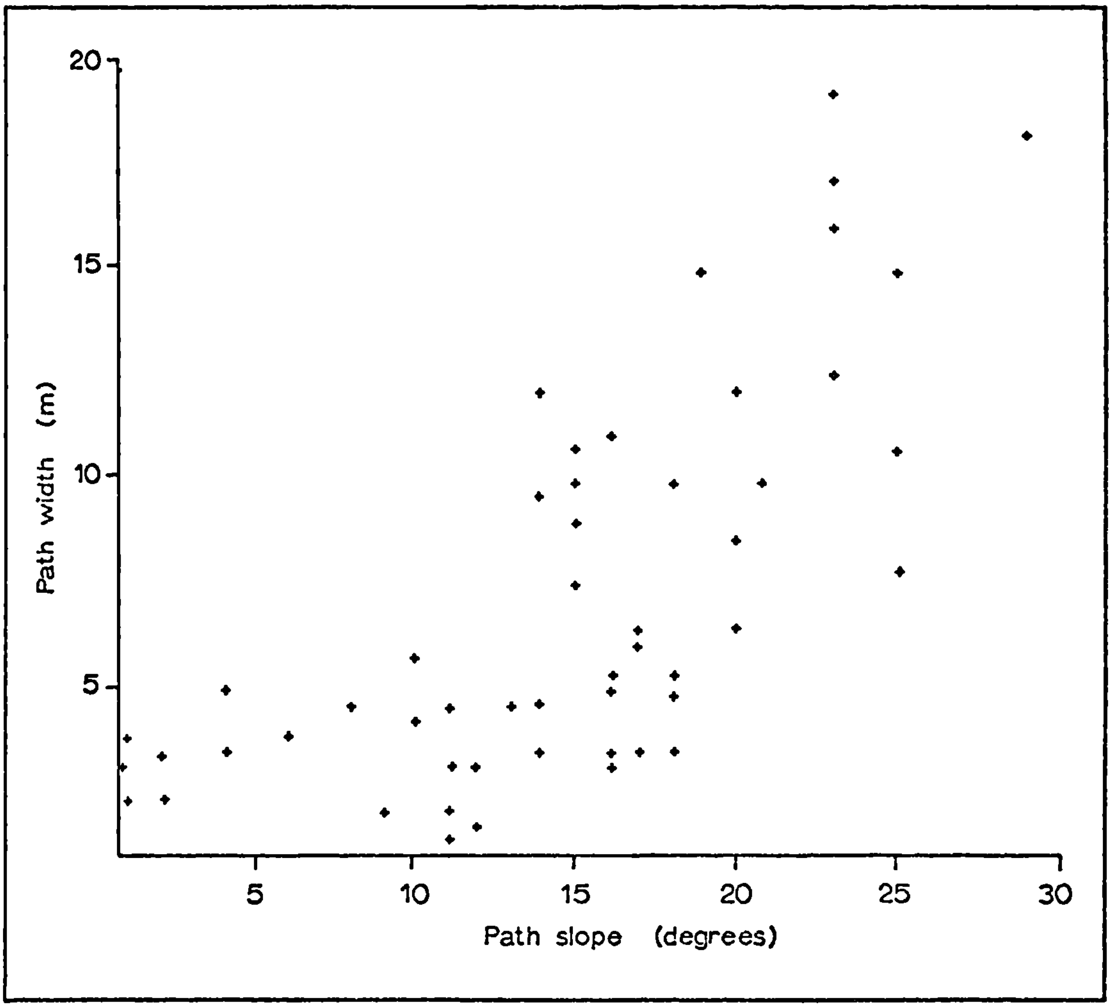


FIGURE 6.3 Relationship between bare ground and path slope for the Wythburn path

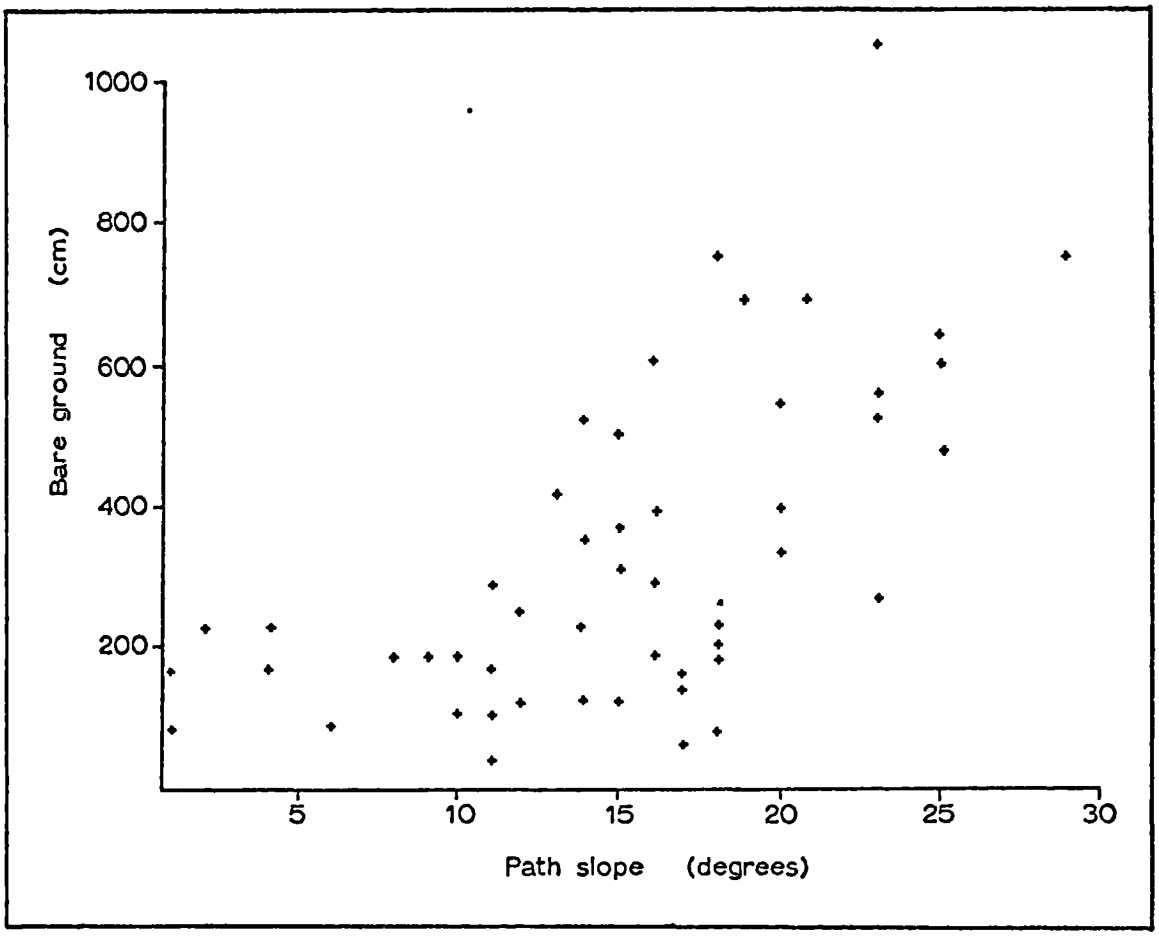


FIGURE 6.4 Relationship between maximum depth and path slope for the Wythburn path

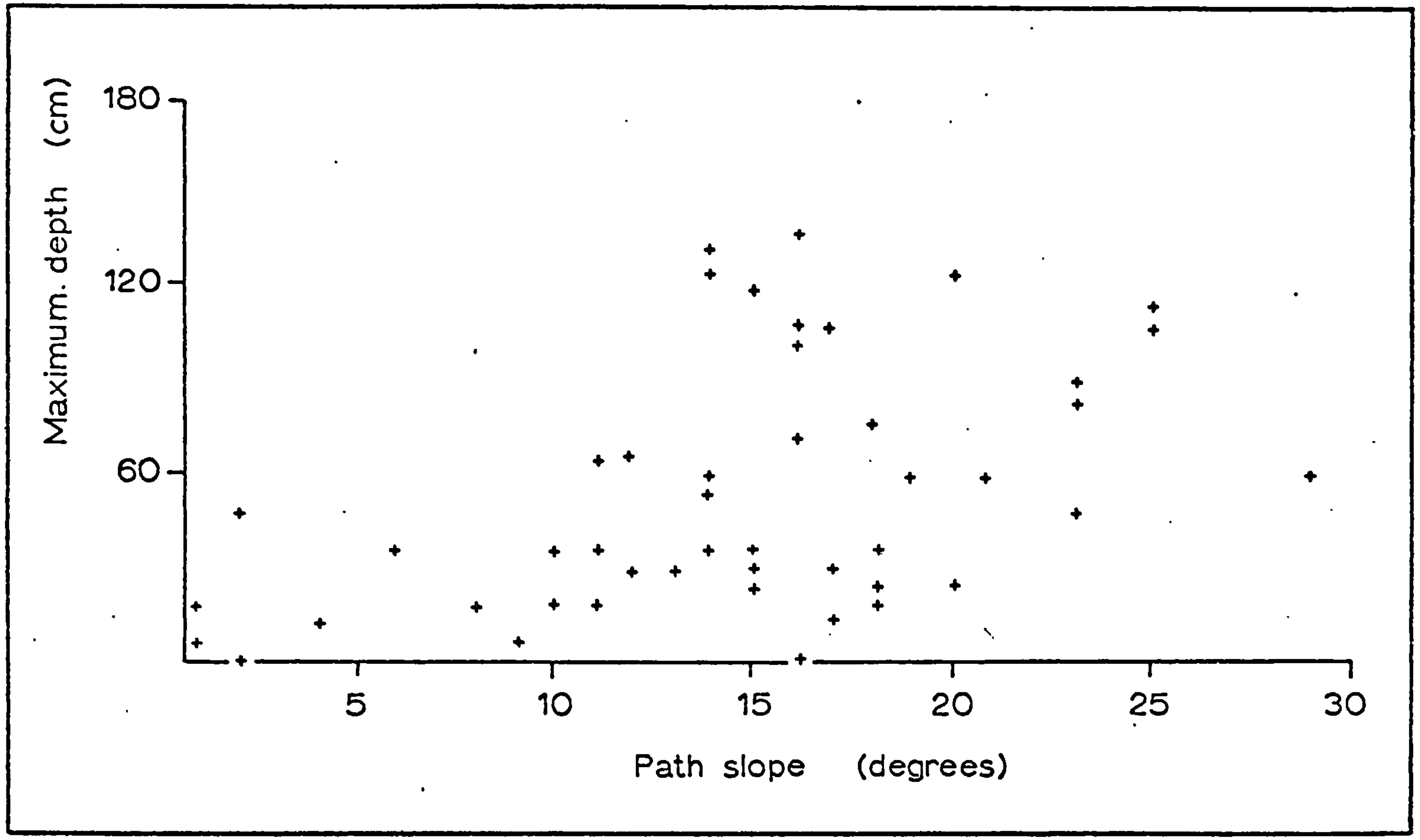
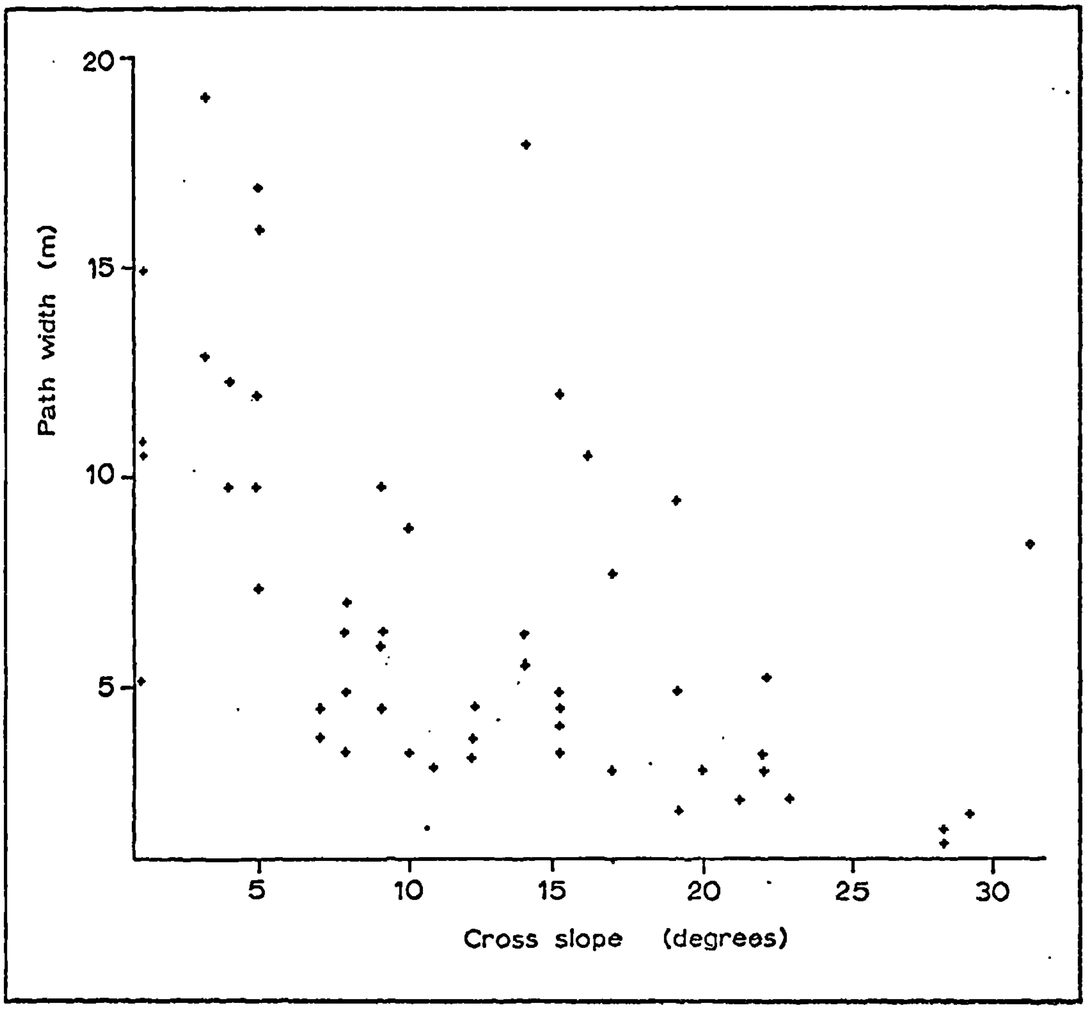


FIGURE 6.5 Relationship between path width and cross slope for the Wythburn path



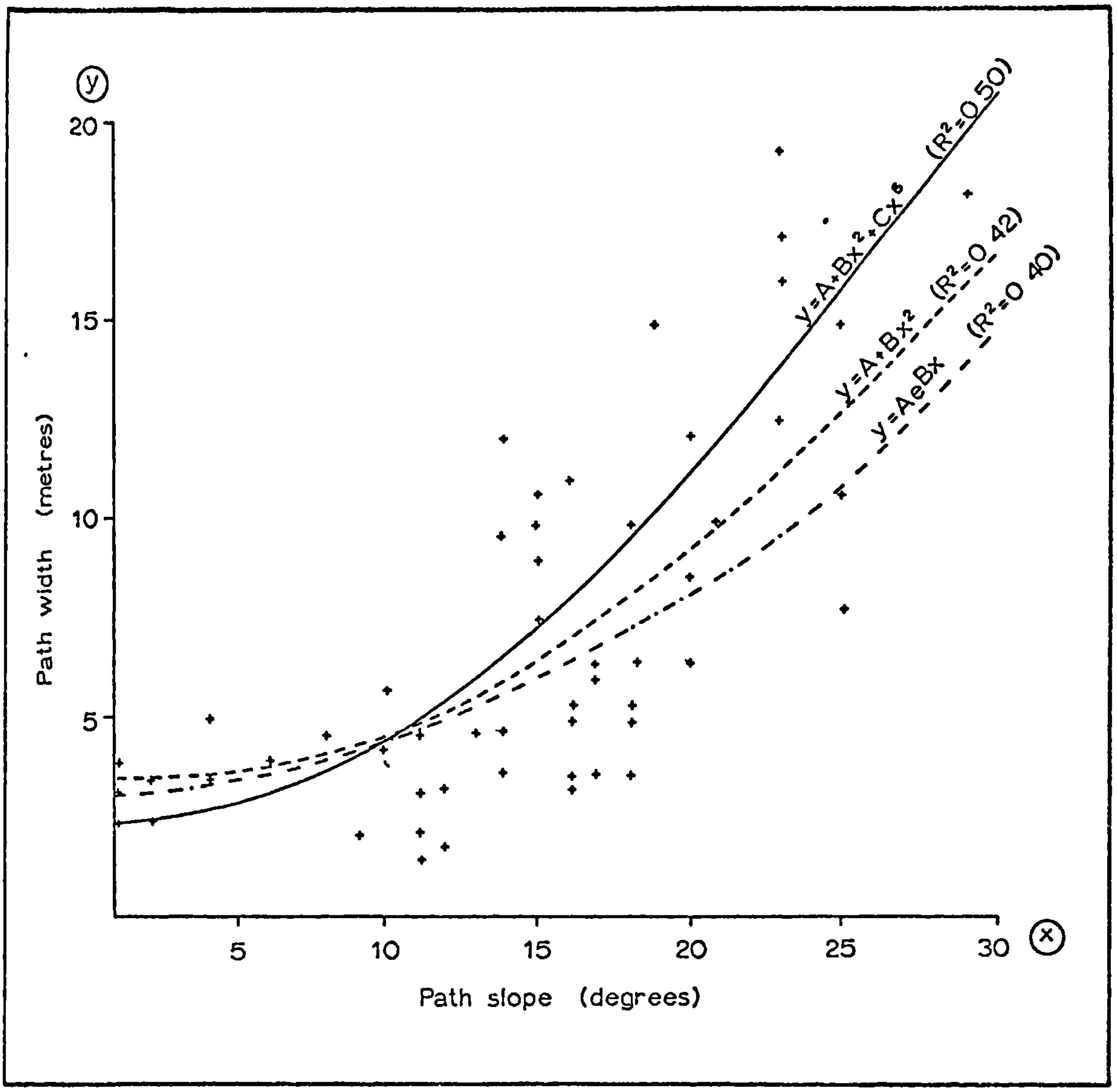
the largest sample of sites, 52, occurred on this path.

6.3.2 Quantification of the Relationship

Multiple regression was used for each path separately, to effect a quantitative description of the relationships between the path variables and both slope variables. (All the regression analyses were run on an ICL 1906S computer using the Statistical Package for the Social Sciences (SPSS), version 5/6).

Several curves were fitted to the data, including logarithmic and trigonometrical transformations, and polynomials of powers up to six. However no single curve was ideal. Because all the data patterns were similar, the testing was done initially using the Wythburn data for path width. Most of the curves fitted were inadequate not because they failed to account for a reasonable proportion of the data variation, but rather because the residuals were directly related to the slope angle. In other words, the wrong curve was being fitted. The extent to which the three best curves fit the data - and their shortcomings - can be seen in figure 6.6. The polynomial in path slope gives the best fit, but it should be remembered that the effect of cross slope is ignored in this bivariate covariation, and it was found that the addition of cross slope accounted for some of the scatter. It was also evident that if polynomials in path slope were to be fitted to each path, for each of the three morphological variables, the resulting polynomials would vary slightly as a result of sampling errors and other path variables not included in the relationships. Thus for simplicity it was desirable to find a common slope "parameter" if possible.

FIGURE 6.6 The three "best fit" curves to the Wythburn data: a polynomial of power six, a quadratic and an exponential relationship



6.3.3 Path width relationships for all paths

(a) SLOPE RELATIONSHIPS

A polynomial of power six in path slope (θ) plus the variable cross slope (ϕ) were fitted, using multiple regression, to the width data for each path. Table 6.4 indicates which values of the path slope parameters: θ, θ^2, ..., θ^6 are significant and whether the cross slope is also significant, for each path separately. It can be seen that for most of the paths a combination of the square of path slope, and cross slope was adequate, although for some paths other combinations explained the width variance a little better. If only one parameter was to be used from the path slope variable, which was what was intended for subsequent analysis with all the paths combined, then it appeared that the square of path slope was the best choice.

The proportion of width variation attributable to slope, path slope and cross slope, is considerable for some paths, for example on Kepple Cove, White Stones and Dollywagon Pike. Part of the explanation for this might be that these paths pass through similar vegetation, grass, throughout their length, whereas some of the other paths pass through a variety of vegetation types.

In contrast to those paths above, for some other paths the covariance between path width and slope is low, especially for Helvellyn Gill, where the proportion of variance accounted for is only one third, but also for Red Tarn and Fisher Gill, for both of which the proportions are 58%. There are many other factors which might affect path width other than slope and which could account for the relatively poor relationships found. As indicated in table 6.3, Red Tarn is a path passing across boggy ground in places; paths are generally wider in waterlogged areas,

TABLE 6.4 Slope parameters accounting for the variation of path width

PATH	CROSS SLOPE (ϕ) AND PATH SLOPE (θ) PARAMETERS CONTRIBUTING TO THE VALUE OF THE SQUARED CORRELATION COEFFICIENT (R^2)		
	R^2 value for the "best" combination*		R^2 value for the parameter ϕ and θ^2
	R^2	Parameter	R^2
1. Causey Pike	0.65	ϕ, θ	0.61
2. Rowling End	0.74	ϕ, θ^2	0.74
3. Cat Bells	0.72	ϕ, θ, θ^2	0.67
4. Skiddaw	0.78	ϕ, θ	0.76
5. Fisher Gill	0.61	θ, θ^2	0.58
6. White Stones	0.86	ϕ, θ^2	0.86
7. Helvellyn Gill	0.34	ϕ, θ^2	0.34
8. Browncove Gill	0.76	θ, θ^3	0.69
9, Whythburn	0.71	ϕ, θ^2	0.71
10. Tongue Gill	0.74	ϕ, θ^2	0.74
11. Dollywagon Pike	0.81	ϕ, θ, θ^2	0.79
12. Striding Edge A	0.72	ϕ, θ^2	0.72
13. Red Tarn	0.58	ϕ, θ^2	0.58
14. Kepple Cove	0.90	ϕ, θ^2	0.90

* The "best" combination is taken from the variables which add .05 or more to the value of the squared correlation coefficient, that is, at least 5% of the total variance of width.

because people search for dry routes. Fisher Gill is a path relatively little used which might account for the poorly defined width-slope relationships; Helvellyn Gill has sections of its length confined by boulders and seepage zones which also might be expected to modify width-slope relationships.

(b) OTHER VARIABLES

Two possible variables in addition to slope have been noted above: width restriction due to a variety of constraining factors, and wetness. Residuals from each path's regression line were compared with field notes taken and the other data gathered at each site. Such comparisons were subjective, but were only intended as a guide to variables which might be investigated during the next phase of sampling. Several factors were found to recur, namely that

(1) width restriction (see section 7.1.1), stable rock, and easy walking surface all tended to be associated with narrower paths than those predicted by the regression;

(2) The presence of boulders or permanent wetness, generally seepage areas, were associated with wider paths than predicted.

It was found that the range of sites on one path was generally insufficient and the variability due to other factors too great for the potential influence of soil and vegetation type to be investigated. The one exception was on the Fisher Gill path, where the sites on <u>Pteridium</u> and <u>Nardus</u> were identified as being narrower than those on the submontane grassland, after taking slope into account.

It was hoped that when the sample was considered as a whole rather than on a path by path basis, the influence of other variables could be identified more easily.

(c) SPATIAL CORRELATION

The paths were tested for spatial correlation in the variables, width, slope and cross slope, by calculation of the autocorrelation coefficient between pairs of adjacent sites. Some spatial correlation was expected. Not only are paths continuous so that one section may affect the next, there are many potentially influential variables unaccounted for in the analysis at this stage which might themselves be spatially correlated. For example, vegetation is altitudinally zoned; also because of the nature of much of the Lake District glaciated topography, steep lower and middle slopes tend to give way to gentler upper slopes.

It was found that on some paths spatial correlation was marked; the extent can be seen in table 6.5. Usually, spatial correlation in path width is associated with that found in the slope variables, but that is not to say that other factors are not also producing a spatially correlated effect. It was evident that the extent of spatial correlation would have to be evaluated in any final relationships reached since in effect, the information obtainable from the data is reduced by its presence and any relationships produced are likely to be unreliable (Johnston, 1972). It was not feasible to avoid spatial correlation in the data because of the nature of the sampling area.

(d) DIFFERENCES BETWEEN PATHS

In this preliminary phase, it was desirable to test whether the differences which were expected to occur between paths as a result of differences in recreation pressure did exist in the data. This was done using dummy regression (Johnston, 1972) which allowed the total data set of 362 sites to be analysed simultaneously with binary dummy variables to represent differences between the paths.

TABLE 6.5 Spatial autocorrelation coefficients for path width, slope and cross slope.

PATH	AUTOCORRELATION COEFFICIENTS		
	PATH WIDTH	PATH SLOPE	CROSS SLOPE
Causey Pike	0.72	0.70	0.59
Rowling End	0.59	0.54	0.21
Cat Bells	0.11	0.00	0.08
Skiddaw	0.73	0.82	0.49
Fisher Gill	0.18	0.62	0.33
White Stones	0.36	0.47	0.70
Helvellyn Gill	0.55	0.05	0.37
Browncove Crag	0.34	0.27	0.38
Wythburn	0.54	0.41	0.64
Tongue Gill	0.50	0.53	0.32
Dollywagon Pike	0.48	0.55	0.22
Red Tarn	0.45	0.63	0.35
Kepple Cove	0.22	0.20	0.44

$$\text{Autocorrelation coefficient} = \frac{\sum_{i=1}^{n} x_i y_i - \bar{x}\bar{y}/n}{\left[\left(\sum_{i=1}^{n} x_i^2 - \bar{x}^2/n\right)\left(\sum_{i=1}^{n} y_i^2 - \bar{y}^2/n\right)\right]^{1/2}}$$

where x_i = the ith measurement of the variables in question

y_i = the (i + 1)th measurement of the same variable

n + 1 = number of sites on path

The model tested for relationships between path width and path and cross slope in (a) above, was

$$w = a_i + b_{1i}\,\theta^2 = b_{2i}\,\phi \qquad \text{where } w = \text{path width},\ \theta = \text{path slope},\ \phi = \text{cross slope}$$

and a_i, b_{1i} and b_{2i} are regression coefficients, $i = 1,2,......14$.

Different paths may have one of a_i, b_{1i}, or b_{2i} varying, if recreation pressure affects one or more of the regression constant and the rate of increase of path and cross slope.

The model tested with dummy regression is

$$w = A + B_1\theta^2 + B_2\phi + \sum_{i=2}^{14} A_i D_i + \sum_{i=2}^{14} B_{1i} D_i \theta^2 + \sum_{i=2}^{14} B_{2i} D_i\,\phi$$

where D_i is 1 for path i and 0 otherwise. Then, the a_i, b_{1i} and b_{2i} can be found for each individual path from

$$a_i = A + A_i$$

$$b_{1i} = B_1 + B_{1i} \qquad \text{for } i = 2,3.......14$$

$$b_{2i} = B_2 + B_{2i}$$

and $a_1 = A$, $b_{11} = B_1$, $b_{21} = B_2$

According to the number of significantly different values of the A_i, B_{1i} and B_{2i}, it can be decided which paths are different from each other.

Using the simple model for each path separately, results were obtained which suggested that there are indeed differences between the paths; these results are given in table 6.6. Using dummy regression, it was possible to separate paths by differences in their regression coefficients. Paths which were apparantly similar were grouped together and then the dummy regression was run again. The resulting coefficients and the groups are shown in figure 6.7.

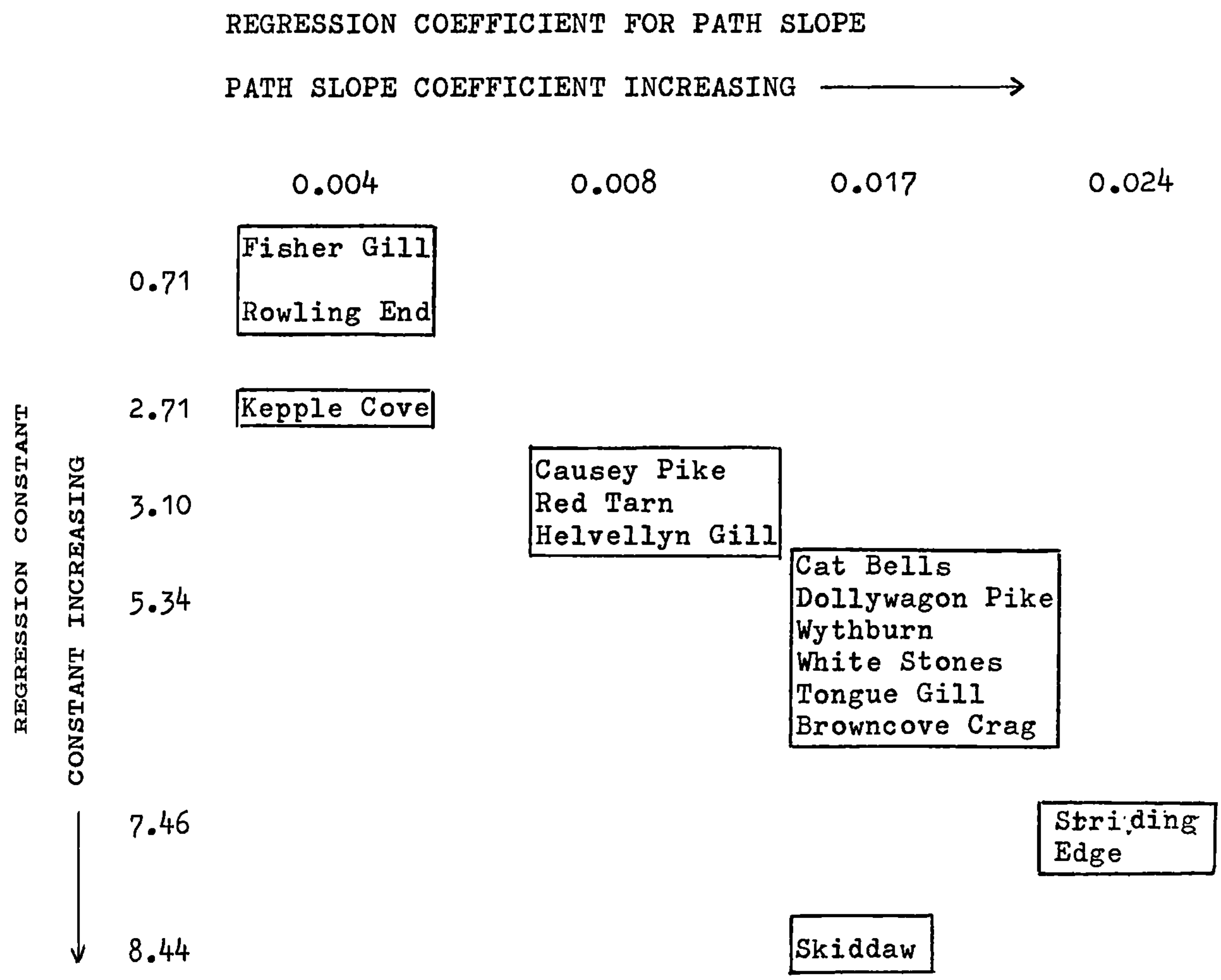
Significant differences between paths can only be a matter of degree, since if it is assumed that path equations

TABLE 6.6 Regression coefficients for relationships between path width and the slope variables, obtained by consideration of each path separately.

PATH	No. IN SAMPLE	REGRESSION COEFFICIENTS		
		CONSTANT (m)	SQUARE OF PATH SLOPE (m/degree^2)	CROSS SLOPE (m/degres)
Causey Pike	34	2.95	0.008	-0.08*
Rowling End	26	0.45	0.005	-0.11*
Cat Bells	19	5.98	0.004	-0.16
Skiddaw	23	11.14	0.014	-0.46
Fisher Gill	29	0.77	0.003	<0.00*
White Stones	18	7.21	0.015	-0.32
Helvellyn Gill	17	0.61	0.012	-0.03*
Browncove Crag	21	-0.98	0.025	0.02*
Wythburn	52	6.09	0.017	-0.25
Dollywagon Pike	43	5.66	0.016	-0.26
Tongue Gill	24	2.49	0.020	-0.08*
Striding Edge A	21	9.72	0.022	-0.41
Red Tarn	19	4.38	0.007	-0.19
Kepple Cove	16	2.85	0.003	-0.08

* Variable is of little significance. It adds less than 5% to the regression explanation of the variation in path width.

FIGURE 6.7 Groups of paths produced by dummy regression analysis (diagram not to scale)



are responding to differences in recreation pressure, it follows that in theory, the regression coefficient should vary continuously according to this pressure. Thus the fact that certain paths appear to be grouped is to a certain extent fortuitous; the method is being used merely to indicate that there are major differences between paths.

Two points can be noted from table 6.6 and figure 6.7. Cross slope is not picked out as a significant variable to separate the groups although there are differences in the coefficients when each path is considered separately. It also seems that some differences in the values of individual path slope coefficients are more apparant than real. A good example of this is the inclusion, in one group, of paths with such disparate constant terms as -0.98 (Browncove Crag), 2.49 (Tongue Gill), and 7.21 (White Stones).

From existing knowledge of the paths, the groups appear to reflect differences in recreation pressure with the most popular paths having the highest regression coefficients.

6.3.4 Bare Ground and Maximum Depth Relationships for All Paths

Without repeating much of the above, it can be said that the general pattern of results for the variables, bare ground and maximum depth, is similar to that for path width.

Table 6.7 gives the regression coefficients for each path for the two relationships: bare ground with path slope and cross slope; maximum depth with path slope and cross slope. The squared value of path slope was used, as for path width relationships. Comparison of this table with table 6.4 shows that the proportion of the total variance explained by the slope variables is greater for width than for either bare ground or maximum depth, an average value of 69% compared with 49 and 50%. Cross slope is less significant

TABLE 6.7 Regression coefficients for the relationships between bare ground, maximum depth and path slope, cross slope

PATH	BARE GROUND				MAXIMUM DEPTH			
	R^2	a_i	b_{1i}	b_{2i}	R^2	a_i	b_{1i}	b_{2i}
Causey Pike	0.41	-51.6	0.57	2.92•	0.26	-3.7	0.07	0.69•
Rowling End	0.58	-20.3	0.29	2.57•	0.75	3.5	0.05	0.69•
Cat Bells	0.89	-29.2	0.27	4.65	0.71	-2.9	0.05	0.48
Skiddaw	0.10	299.9	0.28•	-4.49•	0.24	11.8	0.05	0.08•
Fisher Gill	0.54	-27.4	0.10	1.87	0.21	-4.4	0.02	0.54
White Stones	0.70	72.0	1.07	-5.43•	0.30	5.4	0.08	0.00•
Helvellyn Gill	0.53	-81.8	0.38	-3.32	0.60	-9.5	0.04	0.19•
Browncove Crag	0.66	-156.1	1.13	9.83•	0.75	-9.7	0.08	0.71•
Wythburn	0.40	207.9	0.62	-4.68•	0.45	-2.7	0.08	0.84
Tongue Gill	0.71	-53.0	1.03	5.03•	0.63	-5.7	0.11	0.98
Dollywagon Pike	0.58	239.1	0.85	-6.87•	0.64	5.5	0.09	0.19•
Striding Edge	0.57	81.3	0.94	2.34•	0.64	-3.1	0.10	0.73
Red Tarn	0.12	62.8	0.21	-0.54•	0.42	-5.4	0.07	1.19
Keppie Cove	0.02	74.3	0.00•	-1.28	0.24	25.0	-0.01•	-0.83

• Variable adds less than 5% to the value of R^2

R^2 = squared multiple correlation coefficient

a_i = constant term for path i (i = 1,2,........14), in m

b_{1i} = regression coefficient for square of path slope, in m/degree^2

b_{2i} = regression coefficient for cross slope, n m/degree for the variable bare ground than for width and depth; it is significant on only three paths for bare ground, compared with seven and eight for depth and width. The regression coefficients for the variable the square of path slope, vary among the paths, as for width, but in the case of maximum depth, the variation is small, whereas for bare ground it is considerable.

Other variables effecting bare ground amounts and maximum depth were difficult to detect - residuals were examined as in the case of path width - but vegetation and soil types were possibly important. A contrast was noticed in the residuals on Causey Pike for example, those for the heath vegetation types being greater than those for the Pteridium or grass/sedge communities; greater depth residuals were noticed on Red Tarn path and the Striding Edge path for podsolic soil types. From field notes, water run off appeared to be associated with deep gullying on Causey Pike, Rowling End and Tongue Gill paths. However, inevitably at this stage such observations were subjective and merely suggested that these other variables should be investigated more thoroughly.

Although it was thought that, as in the case of path width, variations in regression coefficients among the paths maight reflect differences in recreation pressure, for these variables the results were not consistent. The regression coefficients of some paths known to be popular, were similar to those of paths known to be less popular. For example, both Wythburn and Dollywagon Pike had regression constants larger than that of the very popular Striding Edge path. However, since the general level of explanation of the variance of path variables is lower for bare ground and maximum depth, not only is there the possibility that other variables as yet not used in the analysis may be as important as recreation pressure, but the regression coefficients will have greater statistical sampling errors.

Autocorrelation coefficients were not calculated for the bare ground and maximum depth variables because, since spatial correlation was known to exist for the slope variables and path width, it was likely to exist in the data overall.

6.4 CONCLUSIONS FROM THE FIRST PHASE OF THE MORPHOLOGICAL SURVEY

The analysis indicated that about 50% of the variation in path morphology, for any particular path, might be attributed to slope angle variation. However, there were clearly many other factors which might be important. If the paths were to be considered together, the effect of differences in recreation pressure would have to be taken into account, since it appeared that the way in which slope modified the morphology of a path was possibly affected by recreation. The effect of path slope was non-linear and the relationships between path variables and slope could be expressed in a quadratic form. The effect of cross slope on the other hand appeared to be linear. This last result is consistent with results obtained in the preliminary work on Helvellyn to assess methods of measuring recreation pressure. Linear relationships were found between path width and cross slope for the three paths analysed (section 5.3.2).

To find that path morphology is related to path slope in quadratic or other polynomial terms is not consistent with the experimental force plate results mentioned in chapter two. It is not possible to give a complete explanation for this, but one can be suggested. Force plate experiments, whether the subjects are walking up or down the slope of the ramp, are limited by the fact that there is insufficient length of the ramp for the walker to build up speed. On footpaths, walkers, in particular on the way down, sometimes move very fast. Although the impact time may be shorter - this is unknown - the force generated may be greater: the ground is resisting a force resulting from both the effect of slope and the effect of momentum. If, as appears likely, greater momentum is generated on steep slopes, then the effect of slope can be expected to be more than the linear effect apparant in the force plate experiments.

The first phase of the survey had indicated how slope variables appear to affect paths, that recreation pressure should be considered and that other variables' effect might be identified when the data from all the paths were amalgamated.

CHAPTER SEVEN

THE MORPHOLOGICAL SURVEY: SECOND PHASE OF SAMPLING

7.1 VARIABLES AND THEIR MEASUREMENT

The second phase of the morphological survey was designed to take into consideration the range of factors proposed in chapter four as relevent to footpath morphology. Thus, an attempt was made to estimate the effect of variables such as the amount of water run off, and the distribution of walkers on paths. At this stage, detailed soil parameters were not measured, because to do this on 200-300 sites was not feasible.

A summary of the forces and the main variables relevent to them, as discussed in chapters two and three, is given in table 7.1. Some of these variables were measured and discussed in the first sampling phase, chapter six, or in preliminary work on the estimation of recreation pressure, chapter five. The remaining factors and variables are discussed below, with the exception of the detailed soil factors, which are left until chapter eight.

TABLE 7.1 The forces operating in the footpath system and the main factors influencing them.

RECREATION FORCE	Number of people Distribution of people - vegetation type and height cross slope boulders and wetness potential for width of path path morphology and roughness
GEOMORPHOLOGICAL FORCES	Frost heave, Wind - altitude aspect position (on/off ridge) Water - vegetation soil type soil depth soil texture/permeability slope curvature area of hillside contributing length of path above contributing path morphology (degree of incision/shape)
VEGETATION RESISTANCE	Vegetation type Altitude Aspect Position (on/off a ridge)
SOIL RESISTANCE	Soil type Texture Organic horizons Organic matter in soil Depth Stoniness Size of largest particles Shear strength
GRAVITY	Slope angle

7.1.1 Distribution of walkers across the path

The distribution of walkers across the path and its surrounding area depends mainly upon the ease of the path walking surface relative to that of the surroundings. Erosion of the path may make the surface difficult to walk on, but this does not necessarily drive walkers on to the surrounding area; it is equally true that absence of erosion does not mean that walkers will keep to the path. The following factors will probably tend to restrict walkers to the path:

(1) a steep cross slope, which makes walking off the path uncomfortable,

(2) tall or woody vegetation, which is difficult to walk through,

(3) very rough or unstable surfaces, such as loose scree or boulders,

(4) physical obstacles, such as a steep drop, a rock outcrop, or a stream or other water body.

The factors which tend to encourage walkers to spread away from the path across the surrounding vegetation are:

(1) low cross slope,

(2) short grass types of vegetation,

(3) a scatter of boulders within grass, permanent or semi-permanent wetness, both of which encourage walkers to spread out to find easy/dry ways through,

(4) very eroded surfaces with many stones/boulders, which can be tiring to walk on.

Some of the restriction factors are already included in variables which were measured during the first phase, namely, cross slope, vegetation type, boulders/wetness presence. However, the most satisfactory method of dealing with the path restriction factor was thought to be a variable which could describe the extent to which the path development had or had not reached its potential width in terms of the general site characteristics. Thus three categories of path restriction was used, for which, at each site, it was decided whether a path was

(1) restricted - less than 2m of potential extra width,

(2) moderately restricted - 2 to 6m of potential extra width, or

(3) unrestricted - more than 6m of potential extra width.

The potential extra width considered was that which was likely, beyond the existing width of the path, given the site conditions at the path section.

Factors which were taken as indicative of path restriction were:

(1) vegetation types: Pteridium, all heath vegetation except the very stunted/sparse communities found (a) at high altitudes, and (b) where heath burning had destroyed the soil/peat to such an extent that vegetation colonisation was limited/slow;

(2) cross slope greater than 20 degrees (classed as moderately restricted);

(3) cliffs, rock outcrops, streams, tarns, walls and fences.

Cross slope as a precise variable was already being recorded, but steep cross slopes appear to have such an inhibiting effect on path width development that to record the path as unrestricted did not seem sensible.

7.1.2 Water run off at Path Sites

Of all the path site variables the amount of water running down a path was the most difficult to estimate. Yet all the evidence from the measurements at monitored sites (chapter four) showed that this was one of the most important factors.

Differences in the amount of rainfall input to the various sites were incalcuable, because the character of upland rainfall is relatively unknown. Generally, rainfall is thought to increase with altitude, and in Britain to be greater on west facing slopes, but valley convergence causes local intensification and local wind patterns can mean that maximum falls occur to the east of the upland area (Pedgley, 1971, Taylor, 1976). How well these generalised patterns can be applied to detailed topography is also unknown. There was, therefore, no easy way of calculating any likely differences in the amount of run off as a result of differences in the amount of rainfall.

Other differences in run off arise from two basic sets of conditions: (i) the conditions governing the infiltration rates and (ii) the conditions governing the site of the contributing area of the land surface.

(i) Infiltration characteristics, although complex in reality were approximated by assuming that they would largely be accounted for by the type of vegetation and soil obtaining at the site.

(ii) Run off amounts in terms of the area of land surface, and of course sub-surface contributions, were difficult to estimate. It was assumed that amounts would depend on two contributions: one from the water seeping out of the vegetation, litter, humus and soil layers at the side of the path; the other from water accumulated in sections of the path above the site in question, and running down these path sections to the site.

Water from the site surroundings was estimated in terms of the general characteristics of the site. Sites can be classified as:

(1) water shedding - sites at the top of slopes, convex fans

and other landforms, ridge tops and sites where local drainage carries water away from the path.

(2) water collecting - sites with a long length of slope above, concave landforms and local drainage into the path, such as seepage areas.

However, in practice, the classification is not so simple because some sites do not clearly fall into either category. Such sites were given an intermediate classification. It should be noted that straight slopes were, for the purposes of estimating path water, classified as water collecting, whereas for many geomorphological or soil classifications they would be classified as "normal". However, the incision of paths, which occur by compaction of the surface even at sites which are little eroded, encourages the flow of water moving down a "normal" slope to be diverted into the path, thus providing path "gutters".

Run off amounts down the paths were estimated, by inspection, and assigned to three categories, as for water at the site. Path run off was considered to be "collecting" if there was a well channeled path section above the site, clearly leading water into the site. Path run off was considered to be "shedding" if either the path sections above were such that water was diffused rather than channeled, thus allowing time for infiltration, or if water from paths above was clearly diverted down the adjacent hillside rather than the path. An intermediate category was used for paths which did not fall clearly into either category.

In later analysis, it was found that the effect of run off water did not appear to be significant; it was thought that probably there was an important interaction effect, in that run off was enhanced by the combination of water collecting sites and path run off amounts. The run off variable was therefore redefined as

(1) high run off - if sites were defined both as water collecting and path collecting,

(2) low run off - if sites were both water shedding and path shedding,

(3) intermediate for all other combinations.

One further effect was investigated. Following the theoretical approach of Horton (1945), erosion depth would be expected to increase downslope because of the increment of water added for each increment of distance from the start. It was therefore possible that, within a section of path, although the site conditions were generally homogeneous, the maximum depth of erosion might increase downslope through the section. Some preliminary work was done to investigate this possibility, before starting the second phase, in case it was necessary to include a variable to allow for this effect. This preliminary work is described in the next section.

7.1.3 Preliminary work to investigate changes in depth of erosion downslope

To investigate the pattern of erosion depths downslope, a series of sites was required which were homogeneous internally, with respect to site conditions, but which differed among themselves. Ideally, sites were required which were of sufficient length to demonstrate any increase in erosion downslope, should the reality be consistent with the theory; thus sites of length 40-50m were sought. In practice it proved difficult to find sites where water appeared to have an uninterrupted passage downslope for long distances, since many paths change direction slightly even though relatively homogeneous terrain, and such direction changes usually are sufficient to divert any run off away from the path, down the hillside. However, five sites were found, of lengths ranging from 40 to 70 metres.

Methods of sampling and measurement

Each path section was divided into 5m sections, within which one transect was allocated, randomly. At each transect, measurements were made of path slope, path width, bare ground and maximum depth.

Analysis

Transects sampled in such close promimity and in sequence downslope, were not statistically independent; so the analysis was based not on the actual values at each transect, but on the changes from one transect to the next. This is the method of "first differences" (Hauser, 1974). Thus, a section 70m long would have 14 transects, which would yield 13 sets of "differences" or changes from one transect to the next. The extent to which the changes in the variables covaried was measured using correlation coefficients. These are listed in table 7.2.

Results

It is clear from table 7.2 that there is no simple relationship between the variables and the distance downslope. A systematic effect could sometimes be seen in some of the variables; for example, in site 2, slope angle increases downslope. Maximum depth shows no such systematic variation in any of the sites, suggesting either no variation, random variation or some cyclical effect which would be lost in the calculation of the correlation coefficient. This last possibility was suggested by inspection of the raw data, in which, for sites 1, 2 and 5 particularly, maximum depth appeared to increase and decrease over short distances. The best example of this is site 1, which is also the longest

TABLE 7.2 Variation of path variables with distance downslope - correlation coefficient between succesive increments of the variables: path width, path slope, bare ground, maximum depth and distance downslope.

SITE 1	PW	BG	MD	PS	DD
PW	1.00	0.65	0.32	-0.00	-0.42
BG		1.00	0.20	0.01	-0.60
MD	N = 13		1.00	0.55	-0.08
PS				1.00	-0.01

SITE 2	PW	BG	MD	PS	DD
PW	1.00	0.33	-0.46	0.42	0.30
BG		1.00	0.29	0.50	0.04
MD	N = 8		1.00	-0.05	0.04
PS				1.00	0.77

SITE 3	PW	BG	MD	PS	DD
PW	1.00	0.66	0.55	0.82	0.59
BG		1.00	0.36	0.42	0.60
MD	N = 8		1.00	0.46	-0.03
PS				1.00	0.59

SITE 4	PW	BG	MD	PS	DD
PW	1.00	0.21	0.57	0.79	-0.20
BG		1.00	0.36	0.42	-0.45
MD	N = 12		1.00	0.64	-0.10
PS				1.00	-0.40

SITE 5	PW	BG	MD	PS	DD
PW	1.00	0.01	0.64	0.17	0.08
BG		1.00	0.32	0.44	0.19
MD	N = 7		1.00	0.50	-0.09
PS				1.00	-0.26

PW - path width, BG - bare ground, MD - maximum depth, PS - path slope, DD - distance downslope, where all the variables measure changes in the value of the parameter between one transect and the next.

site. Figure 7.1 demonstrates how the 70m or so of the path section fluctuates with respect to the variables measured. This fluctuation can be seen in many of the other sites, in the correlations between the path variables, excluding distance downslope, these correlations sometimes being quite high.

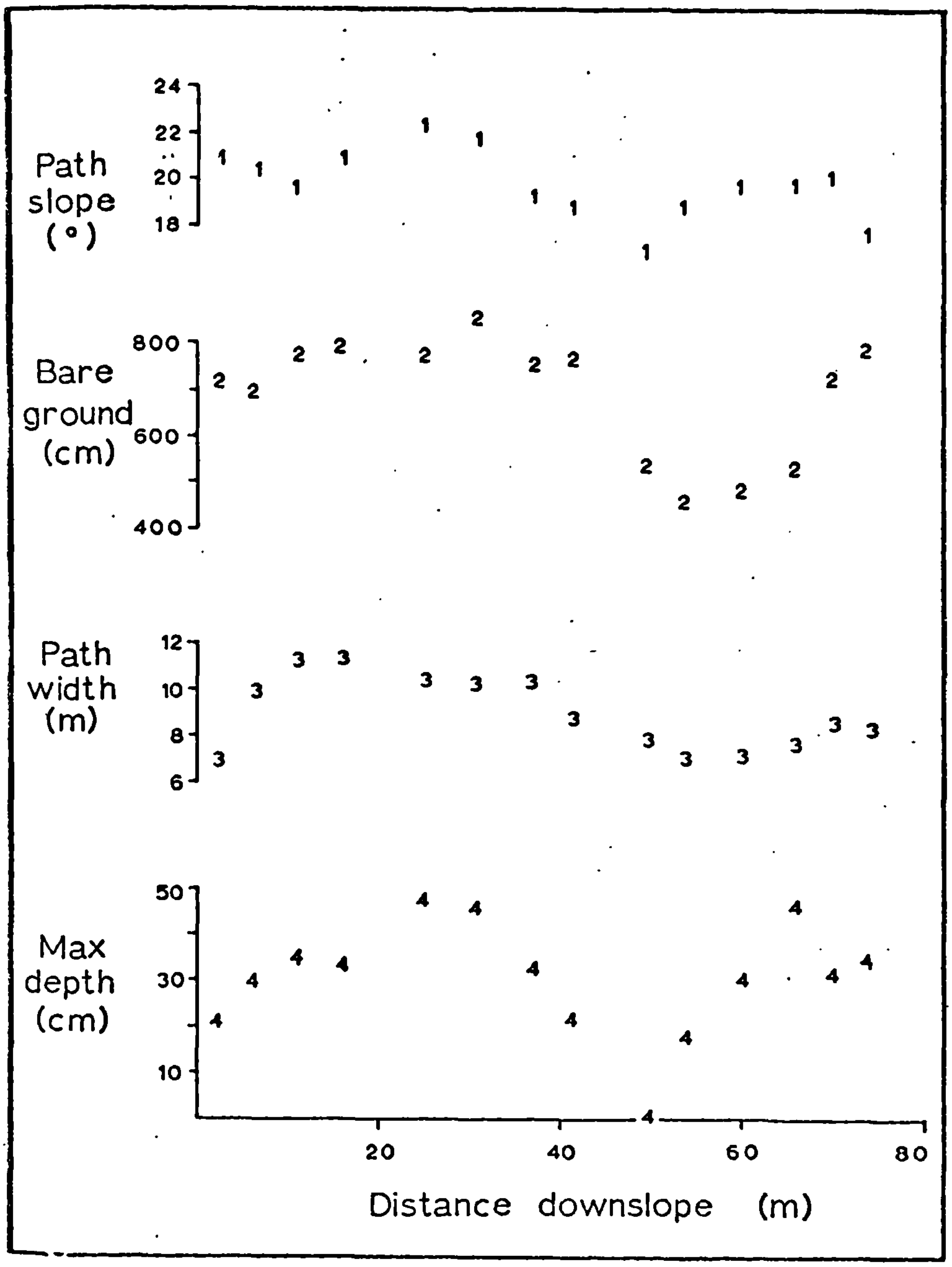
Even this small sample shows how complex in detail is the morphology of one "homogeneous" site. It did not appear, however, that position on the slope section would be an effective variable for explaining erosion amounts, since any part of a fluctuation might be encountered by chance, leading to a higher or lower than average value. Had it been possible to establish a wave length for the fluctuations, distance downslope might have been used, but some sites fluctuated over distances as small as 10m, while others seemed to produce no cycles in the whole site.

Conclusions

Although these rather negative results are consistent with neither theory (Horton, 1945) nor experimental empirical work (for example, Zingg, 1940; Smith and Wischmeier, 1957; Meyer et al, 1975), they are perhaps not surprising, in view of the stony, irregular surfaces found on most paths, in comparison with the agricultural soils studied in much of the work cited above.

The effect of distance downslope on run off was therefore not included in the second phase of sampling, and all estimates were made on the basis of the categories described in the previous section.

FIGURE 7.1 Fluctuation of path variables with distance downslope



7.1.4 Soil Characteristics

Soil characteristics of a detailed nature, such as soil texture, bulk density and organic matter, are variable at a site (see chapter eight) and because of the stony nature of the mountain soils, they require large samples for representative results to be obtained. Hence, the measurement of these characteristics is not practical for a large scale survey with limited resources. Thus, for the measurement of soil parameters it was necessary to substitute soil type, in the hope that this would provide an adequate means of identifying sites which were vulnerable to erosion, or otherwise. Since many chemical and physical processes which may be relevent to erodibility, infiltration and shear strength are subsumed in the description of soils by soil type (Stocking and Elwell, 1974), it was hoped that the surrogate would be satisfactory.

An important factor in path surfaces is the type of residual material left after the humus layers, or peat, and fine particles have been washed or blown away. If the residual material is fairly small in size, then, although it may be vulnerable to the run off from heavy rain or snow melt, it provides a comfortable walking surface and so walkers are less likely to erode more vegetation by using the area adjacent to the path. Examples of such fine material can be seen particularly on the lower slopes of the Skiddaw Slate mountains, where there are extensive deposits of periglacial materials, the "stratified screes" overlying till described by Boardman (1977).

At sites where the residual particles are large, boulders and cobbles, a surface veneer is formed which requires a considerable amount of water to move it, although such materials may move considerable distances downhill if dislodged by walkers. However, these surfaces are often very uncomfortable underfoot and so there may be considerable use of the vegetation at the side of the path, with subsequent path widening.

In order to take some account of these differences between paths, the dominant path materials were recorded at each site, as

1. grass
2. earth and small stones
3. large stones and boulders
4. bedrock

In addition, the recording of geological type, as in the first phase, provided a rough guide as to whether particles would be flat, easily broken and weathered, and slide (Skiddaw Slates) or whether they would be round, hard and roll (Borrowdale Volcanics). Moreover, the two geological types generally differ in the amount of nutrients they release during the weathering process, the slates being dificient in bases, such as calcium, in comparison with the volcanics. This might affect rates of vegetation rejuventation after trampling.

At each site, the type of organic horizon was recorded, as mull humus, mor humus, an intermediate moder humus, or peat. This choice of categories was made following those used by Hall and Folland, in the upland area of the southern part of the Lake District (Hall and Folland, 1970). The categories were distinguished by the following characteristics:

1. mull humus - brown/black friable, mixed with the mineral horizon;
2. mor humus - black amorphous or matted, clearly defined boundary with the mineral horizon;
3. moder humus - intermediate between mull and mor;

4. peat - organic layer greater than 15 in (47 cm).

Thus, the soil characteristics of each site were distinguished by three factors: the type of organic horizon, the type of soil, and the type of residual material on the path surface.

7.1.5 Other variables

(1) To obtain a more accurate value for the estimated area of cross-section eroded, in addition to the maximum depth, the depth every 10cm across the bare ground sections of the transect was recorded.

(2) To allow for the fact that some of the characteristics of a path may be influenced by those of the path above or below, the erosion category of path sections immediately above and below the site in question were recorded.

The complete list of variables measured in the second phase of sampling is given in table 7.3

7.2 SAMPLING IN THE SECOND PHASE OF THE SURVEY

All the paths in the sample area not used in the first phase were added in the second phase; also some of the first phase measurements were "upgraded" to the level of those in the second phase. It had been intended to bring all 24 paths up to the second phase level of detail, but the time available was not sufficient. The number of paths in the second phase was 15 and they are listed in table 7.4.

The methods of sampling within the paths were the same as those used for the first phase of the survey.

TABLE 7.3 Variables measured during the second phase of the sampling

PATH MORPHOLOGY	path width bare ground maximum depth depth every 10 cm erosion category
RECREATION PRESSURE	recreation counts cross slope path restriction* presence of boulders* presence of permanent wetness* path surface characteristics*
GEOMORPHOLOGICAL FORCES SOIL AND VEGETATION RESISTANCE	vegetation type* soil type* water run off of site and path* altitude aspect position on/off a ridge* organic horizon type* geology*
OTHER FACTORS	path slope erosion category of path above and below* any other relevent site details

*variables recorded at the nominal scale

TABLE 7.4 General information on the footpaths used in the second phase of sampling

PATH	STARTING POINT GRID REFERENCE	GEOLOGY	ALTITUDE RANGE (ft) (1000 ft ≏ 305m)	GENERAL ASPECT
Grisedale Pike A	NY22 228236	SS	750 - 1700	NE[1]
Grisedale Pike B	NY22 209229	SS	1700 - 2550	NE[2]
Sail**	NY22 204205	SS	2000 - 2500	NE[1]
Crag Hill	NY12 199203	SS	2250 - 2750	E[2]
Scar Crags A	NY22 204105	SS	2000 - 2250	SW[2]
Scar Crags B	NY22 211207	SS	2250 approx. constant	E - W[2]
Mires Beck A	NY31 376166	BVS	900 - 1500	NE[1]
Mires Beck B	NY31 372161	BVS	1500 - 2250	E - NE[2]
Swirral Edge	NY31 350155	BVS	2300 - 2800	SE[2]
Striding Edge A	NY31 382158	BVS	900 - 2300	SE[1]
Striding Edge B	NY31 359155	BVS	2300 - 2750	ENE[2]
Wythburn	NY31 324136	BVS	1000 - 2900	NW - SW[1]
Dollywagon Pike	NY31 350123	BVS	1800 - 2900	S [1/2]
Red Tarn*	NY31 365174	BVS	1000 - 2300	NE - N[1]
Kepple Cove	NY31 352176	BVS	1300 - 2700	SE[1]

1 path across hillside

2 path mostly or wholly along a ridge

** path through area burnt for heather/grazing growth so severely that soil and vegetation are thin

* path crosses boggy terrain in places

7.3 RESULTS AND ANALYSIS OF PHASE TWO DATA

Two approaches were taken to the analysis of this data. One was an attempt to identify groups of characteristics of paths, using a multivariate classification technique, in the hope that certain characteristics would appear to be related to eroded paths and others to non-eroded paths. The other approach was to find relationships between path morphology parameters and site characteristics using multivariate regression, in order that it might be possible to predict erosion amounts from site characteristics and that it might be possible to identify the most important variables.

Thus, the results are set out in two parts, the analysis by classification and the analysis by regression.

7.3.1 Analysis by classification

One of the problems in applying a classification procedure to the data gathered in the second phase of the survey, was that the levels of measurement were different, some being nominal or ordinal and others ratio - measured on a continuous scale. Thus the first step was to reduce the data to a common level of measurement, nominal. This meant that arbitrary choices had to be made about the categories into which the continuous scales should be divided. There was always the possibility that the choice of categories would affect the interpretability of the results of the classification, but it was hoped that, if the classes were not made too large, the groupings of path sites would be such that two or more adjacent classes could be distinguished; for example, the path slope values ranged from 0 to 35 degrees and the categories chosen for path slope were seven, at five degree intervals; if the eroded paths were associated with slopes greater than, say, 20 degrees, then the three relevent slope categories should all appear in the "eroded" group of sites as important variables. However, the fact that the categories had to be chosen arbitrarily, and the consequent difficulties of interpretation that were expected, suggested that good results might not be obtained from these data using classification as the method of analysis.

The classes that were created for the variables measured on a continuous scale were as follows:

path slope - seven 5 degree classes from 0 to 35 degrees

cross slope - seven 5 degree classes from 0 to 35 degrees

altitude - six 500 ft classes from 0 to 3000 ft (0 to 914 m)

aspect - four classes: NW to NE (north facing)
NE to SE (east facing)
SE to SW (south facing)
SW to NW (west facing)

All the other variables used in the classification were originally collected in nominal form. It should be noted here that the path morphology variables of width, bare ground and maximum depth were not used in the classification, nor was the effect of recreation pressure introduced. This was because the variable "erosion category" had been recorded, and had the advantage of being independent of recreation pressure, in terms of the exact amount. Thus, the classification was seeking to establish site characteristics of paths which appeared to be related to active erosion as identified by the criteria listed in section 6.1.4. Adopting this approach,is, to a certain extent, a simplification of the problem because it is possible that certain site conditions which exacerbate erosion do not operate below a certain threshold of recreation pressure. However, it can be observed that the highest values of recreation pressure encountered on the Lake District paths do not, by themselves, cause erosion problems and on even the least used paths there are small amounts of erosion; hence the approach seems reasonable.

(a) Classification Procedure

The classification procedure used was that of the Clustan Classification programme (Wishart, 1969). The procedure is an agglomerative one, grouping individual sites together, and amalgamating sub-groups until the required number of groups is reached. Apart from the structure of the data set, three choices by the user affect the resulting groups of sites:

(1) a similarity coefficient has to be chosen to measure the likeness of individual sites and/or sub groups to each other,

(2) a grouping method has to be chosen for amalgamating the most similar sites/sub groups, and

(3) the ultimate number of groups in the classification has to be decided.

In a comparative review of classification procedures, Frenkel and Harrison (1974) found that the greatest influence upon the results of the classification was the method chosen to sort the individuals and subgroups into the groups. They concluded that the most satisfactory procedure was that of Ward's Method (Ward, 1963). This method produces groups in which the variance of the "distance" of each individual from its group centroid is minimised; the "distance" in variable space for binary variables - which is the procedure for dealing with nominal data - is given by the statistic:

$$X_{ij}^2 = (A + B)/N$$

where X_{ij} is the distance in variable space between individuals i and j,

A is the number of binary attributes possesed by both i and j,

and B is the number of binary attributes possesed by neither i nor j.

In the absence of any reason for choosing one procedure rather than another, it seemed advisable to choose the recommended method of Ward, which then necessitated the use of the distance coefficient defined above.

The choice of the number of groups is generally dependent upon the reason for the classification being performed, as there is no simple definition of a "best set" of groups (Johnston, 1976). Since, in this case, the aim was to divide path sites into those which were and were not eroded, the number was chosen by inspection of the groups produced at several stages of the clustering, to produce as clear a division of the sites as possible, in terms of the interpretation of other variables and the achievement of groups relatively homogenous in the erosion category variable.

(b) Results

The first attempts to produce a useful classification were disappointing in that an interpretable result did not appear to be produced. There are many reasons why this might have been so; a classification is the product of the data and any shortcomings in these will be reflected in the type of groups produced. Any highly correlated variables, such as, in this particular case, vegetation and soils, will bias the groups (Johnston, 1976). Also, since all the variables are reduced to binary form, each is given equal weight, which is another source of bias, particularly as the categories of the "continuous" variables were selected arbitrarily.

However, it was thought that a major cause of confusion in the classification might be the fact that a number of the site variables could not logically be predicted to cause or not cause path erosion. For example, although it can be argued that vegetation resistance might decrease with altitude because the climate becomes more severe, it is not sensible to predict that all high altitude sites will be eroded and that all low altitude sites will be uneroded. On the other hand it is sensible to predict that, for example, sites with high slope angles will be eroded. It seemed necessary therefore, to distinguish between variables which act directly to cause erosion and those which only modify the extent of erosion.

The variables were reconsidered in the light of this, as to whether or not they were suitable for predicting the dichotomous situation of the erosion category variable. Those chosen for a second attempt at classification were:

1. path slope
2. cross slope
3. path restriction
4. water run off at site
5. water run off down path
6. erosion category of path above
7. erosion category of path below
8. erosion category
9. presence of permanent wetness
10. presence of boulders
11. path surface characteristics

Thus, the variables rejected were altitude, aspect, vegetation, soil and organic horizon type, all of which are proposed as factors largely affecting the relative vulnerability of a site, once erosion conditions obtain.

The second attempt produced some interpretable groups with the agglomerative procedure halted at 10 groups. Five of these groups belonged clearly to the "no erosion" category, two to the "erosion" category and three were mixed. The groups are shown in table 7.5. Variables are listed as significant in a group if 60% or more of the individuals in that group have that variable as an attribute - A, the percentage occurrence in the group, table 7.5. However it is possible for a variable to have a high rate of occurrence in a group because it has a high rate of occurrence in the data overall; so the ratio of the variable's group occurrence to its occurrence in the data overall is also listed, along with any variable which has a particularly high ratio - B in table 7.5. In addition to the important variables for the group, the number of sites in the relevent erosion category is given; also the range of slope angles.

(c) Discussion of results

"No erosion"groups. Examining the values of the variables in columns A and B, bearing in mind that ratio of group occurrence to total occurrence values less than 1.5 are probably not very significant, the characteristics that these sites have in common are:

(1) low slope angles,
(2) water run off at the site and down the path either in the "low" or "intermediate" category, and possibly
(3) moderate restriction of the path.

For one of the groups the erosion category of the paths above and below is such that there is greater erosion than at the site, but since most of the sites in the groups are classified as "no erosion", this is to be expected almost by definition - in other words, the fact that adjacent sites may be more eroded is not a significant characteristic of uneroded sites.

"Erosion" groups. These groups have sites which are characterised by:

(1) high slope angles,
(2) water run off at the site and down the path which is in the "high" category
(3) paths unrestricted for one group, and

TABLE 7.5 Classification of footpath sites, using Clustan analysis for selected variables

(A) Groups with most path sites in the "no erosion" category.

GROUP	No. IN GROUP	VARIABLES	A*	B**
1	37	Erosion category of path above, greater erosion.	84	3.6
		Path restriction, moderate.	78	1.3
		Erosion category of path below, greater erosion.	78	3.4
		Path slope class 5-10°.	65	2.6

94% of group in erosion category "no erosion"
14% of group with path slope less than 10°
79% of group with path slope less than 15°
100% of group with path slope less than 20°

GROUP	No. IN GROUP	VARIABLES	A*	B**
2	37	Path restriction, moderate.	93	3.2
		Erosion category of path above equal.	78	1.9
		Cross slope class 0-5°.	74	2.5

100% of group in erosion category "no erosion"
52% of group with path slope less than 10°
74% of group with path slope less than 15°
100% of group with path slope less than 20°

GROUP	No. IN GROUP	VARIABLES	A*	B**
3	17	Erosion category of path above equal.	94	2.2
		Erosion category of path below, equal.	88	2.1
		Water run off at site, low.	88	3.4
		Water run off down path, low.	82	2.0
		Path restriction, moderate.	82	1.3
		Cross slope class 10-15°.	65	3.2
		Path slope class 0-5°.	59	5.2

100% of group in erosion category "no erosion"
94% of group with path slope less than 10°
100% of group with path slope less than 15°

GROUP	No. IN GROUP	VARIABLES	A*	B**
4	24	Path restriction, moderate.	92	1.5
		Water run off at site, intermediate.	92	1.8
		Erosion category of path below, equal.	88	2.1
		Erosion category of path above, equal.	67	1.6

100% of group in erosion category "no erosion"
79% of group with path slope less than 10°
100% of group with path slope less than 15°

GROUP	No. IN GROUP	VARIABLES	A*	B**
5	26	Water run off at site, low.	85	2.5
		Path restriction, moderate.	85	1.4
		Water run off down path, low.	65	2.6

70% of group in erosion category "no erosion"
34% of group with path slope less than 10°
57% of group with path slope less than 15°
72% of group with path slope less than 20°

(B) Groups with most path sites in the "erosion" category

GROUP	No. IN GROUP	VARIABLES	A*	B**
6	14	Water run off at site, high.	93	2.1
		Water run off down path, high.	100	3.6
		Erosion category of path below, equal.	93	2.2
		Erosion category of path above, equal.	77	1.8
		Path restriction, none.	85	3.0

100% of group in erosion category "erosion"
86% of group with path slope greater than 20°
100% of group with path slope greater than 15°

GROUP	NO. IN GROUP	VARIABLES	A*	B**
7	37	Water run off at site, high.	82	1.8
		Water run off down path, high.	80	2.9
		Cross slope class 30-35°.	22	6.4

59% of group in erosion category "erosion"
31% of group with path slope greater than 20°
81% of group with path slope greater than 15°
92% of group with path slope greater than 10°

(C) Groups with path sites of mixed an intermediate erosion category

GROUP	NO. IN GROUP	VARIABLES	A*	B**
8	39	Path restriction, intermediate.	90	1.4
		Water run off at site, high.	85	1.7
		Water run off down path, intermediate.	67	1.5
		Cross slope class 20-25°.	49	3.8

50% of group in erosion category "no erosion"
33% of group in erosion category "erosion"
10% of group with path slope less than 10°
54% of group with path slope less than 15°
93% of group with path slope less than 20°

GROUP	NO. IN GROUP	VARIABLES	A*	B**
9	32	Erosion of path above, less.	78	2.3
		Erosion of path below, less.	75	1.2
		Water run off at site, intermediate.	72	1.8
		Cross slope class 0-5°.	66	2.2

30% of group in erosion category "no erosion"
36% of group in erosion category "erosion"
32% of group with path slope less than 15°
44% of group with path slope less than 20°
76% of group with path slope less than 25°

GROUP	NO. IN GROUP	VARIABLES	A*	B**
10	31	Water run off at site, inter.	84	2.1
		Water run off down path, inter.	84	1.8
		Path restriction category, inter.	74	1.2

56% of group in erosion category "no erosion'
29% of group in erosion category "erosion"
32% of group with path slope less than 15°
61% of group with path slope less than 20°
94% of group with path slope less than 25°

*A: % occurrence of variable within group

**B: Ratio of "A" to % occurrence overall

(4) paths with very high cross slopes for the other group.

Mixed and intermediate groups. There are three of these, which combine sites with and without erosion with sites which are unclassified in similar amounts. The classification procedure has apparantly grouped the sites on the basis of:

(1) Water run off generally in the "intermediate" category,

(2) Path slopes in the middle of the 0 to 35 degree range,

(3) A high slope angle for one group, and

(4) A low cross slope angle for another.

These groups are not really informative, being a mixture of the different erosion categories. They have resulted from the particular choice of variables in the data set, some of which do not appear to be relevant.

The combination of eroded sites, unrestricted paths, water run off in the "high" category, and high slope angles is as expected. The combination of uneroded sites, water run off in the "low" category, low slope angles and moderately restricted paths is also as expected; however, it was thought that a group of sites might exist with the site characteristics of uneroded sites, but with adjacent sites eroded and affecting the sites in question; this was not found, although that does not mean that such sites do not occur.

It is clear that the slope angle factor is of prime importance in the division of these sites into groups. Whether the association of uneroded sites with small amounts of water run off and eroded sites with large amounts of water run off is more apparant than real is not possible to ascertain because of the overiding slope factor. Had groups been found with high slope angles and "low" water run off in the uneroded category, and groups with low slope angles and "high" water run off in the eroded category, conclusions would have been easier to draw.

In conclusion, it should be emphasised that this classification was based on the identification of erosion of any type. Thus, since some variables will enhance the effect of gullying, others the effect of amounts of bare ground, it is perhaps not surprising that slope has appeared as the most important variable. The separation of the different aspects of path morphology, which was carried out for the regression analysis, made the isolation of other effects than slope easier than in the classification analysis. Other forms of the classification, possibly using different variables or different categories for the "continuous" variables, could have been carried out, but they were not pursued, because it did not seem likely that manipulations of the data set would substantially alter the type of results obtained, since these were dictated by the manner in which the original data had been collected.

7.3.2 Analysis by regression

The other form of analysis, from which it was hoped to be able to establish the most important factors in path morphology, was that of multivariate regression. There were two possible advantages in using this technique: since much of the variation in path morphology was likely to be attributable to slope and recreation pressure, and since these variables were measured on a ratio scale, regression analysis was suitable because it did not require that any arbitrary classification of the data be made; it was also hoped that it would be possible to predict the path morphology from the site conditions and recreation pressure obtaining at any point on a path.

The main analysis was preceded by preliminary analysis to examine the nature of interrelationships among the various site variables, and to investigate path-site relationships on a path by path basis, without the effect of differences in recreation pressure. These analyses are described below.

(a) Associations among site variables

It was expected that certain site environmental variables would be found in combination, mainly because of an underlying common causative factor. For example, the change in meso-climate, which results from changes in altitude and aspect, and possibly from local topographic effects, is associated with differences in soil development and the type of vegetation. Thus, the data was first checked to see the extent of such relationships, because, if they were strong, the reliability of the regression analysis would be affected.

A classification analysis was carried out in a similar way to that in section 7.3.1. The site variables included were:

vegetation type
soil type
humus type
geology
altitude
aspect

with the altitude and aspect variables categorised as before (section 7.3.1). From inspection of the groups obtained, the clearest division between sites, in terms of interpretability, occurred at seven groups. These results are shown in table 7.6.

The divisions of these groups are arbitrary to the

TABLE 7.6 Association between site environmental variables

GROUP	NO. IN GROUP	VARIABLE	% OCCUR. IN GROUP	RATIO % OCC. IN GROUP TO % TOTAL DATA
1	61	Skiddaw Slates	100	2.9
		mor humus	100	1.2
		heath vegetation	82	3.9
		aspect W facing	72	1.3
2	18	peat ranker over stony clay	100	4.3
		aspect W facing	83	1.5
		alt. 2000-2500 ft*	67	2.1
3	33	brown earth	94	8.6
		Pteridium	88	7.0
		alt. 1000-1500 ft*	85	4.4
		mull humus	76	6.7
		alt. 500-1000 ft*	15	8.9
4	46	Submontane veg.	100	4.6
		Borrowdale volcanics	100	1.5
		mor humus	100	1.2
		alt. 2500-3000 ft*	98	5.4
5	37	*Nardus*	100	3.0
		Borrowdale volcanics	100	1.5
		alt. 2000-2500 ft*	97	3.1
		mor humus	92	1.1
		peat ranker over stony clay	68	2.9
6	37	mor humus	97	1.2
		Nardus	89	2.7
		Borrowdale volcanics	78	1.2
		alt. 1000-1500 ft*	65	3.4
7	61	Borrowdale volcanics	100	1.5
		mor humus	87	1.1
		Nardus	86	2.5
		alt. 1500-2000 ft*	74	2.6

* 1000 ft ≙ 305 m

extent that the altitude and aspect variables were arbitrarily divided for the analysis. It is evident that groups 6 and 7 should really be one, with an altitudinal range of 1000-2000 ft (305-610 m). Also, by replacing the two altitudinal ranges in group 3 by the one: 500-1500 ft (152-457 m), the percentage occurrence in the group sites becomes 100.

This particular classification demonstrates by figures the groupings which appear evident in the field, namely that

(1) the heath vegetation is associated with the Skiddaw Slates,

(2) the lower slopes are predominantly Pteridium growing on acid brown earths,

(3) the 1000-2500 ft (305-762 m) altitudinal range on the Borrowdale volcanics is dominated by Nardus stricta, growing on a range of soil types, but on peat rankers over stony clay above 2000 ft (610 m), and

(4) above 2500 ft (762 m), a submontane grassland type predominates.

This is associated with the volcanics, but this is because few of the Skiddaw Slate mountains in the sample extend to sufficient height for this type of vegetation to occur.

If the groups are considered in relation to the paths on which they occur, it can be seen (Table 7.7), that there is very strong spatial correlation, in that few paths have sites from more than three of the groups.

The way in which soil and vegetation are associated with altitude is summarised in table 7.8. Mor humus or peat over thin rankers or stony deposits at high altitudes grade to deeper, more fertile brown earths at low altitudes. Vegetation, dependent on both the soil and climate, is zoned, with the upper limit of Pteridium at approximately 1650 ft (503 m) in this data set, submontane grasland above 2500 ft (762 m) approximately, and, depending on the geology, in these

TABLE 7.7 Distribution of sites on the paths, in terms of the relevant groups of table 7.6 (Note that groups 6 and 7 are considered as one)

PATH	GROUPS TO WHICH THE PATH SITES BELONG
Causey Ridge	1
Sail A and B	1, 2
Scar Crags A and B	1
Grisedale Pike A and B	1, 3, 4 (and one "2")
Red Tarn	2, 4
Swirral Edge	4, 6
Kepple Cove	4, 5, 6
Mires Beck A and B	2, 4 (and one "5")
Dollywagon Pike	4, 5, 6
Striding Edge A and B	4, 5, 6
Wythburn	3, 4, 5, 6

TABLE 7.8 Association of vegetation and soil type with altitude. The table gives the frequency of occurrence of each type in the different altitude groups.

VEG./SOIL TYPE	ALTITUDE CLASS (ft*) 500-999	1000-1499	1500-1999	2000-2499	2500-2999
Pteridium	6	24	5	0	0
Heath veg.	0	7	32	39	1
Nardus	0	21	53	54	0
Submontane	0	0	0	2	49
Brown earth	6	22	5	0	0
Brown podsolic	0	18	17	0	0
Podsol	0	5	23	5	0
Thin ranker	0	5	30	56	39
Peat ranker over stony clay	0	2	18	34	11

*1000 ft $\simeq$ 305 m

data, either heath vegetation or Nardus grassland in between.

The existance of these clear relationships suggests that any one of the three, altitude, vegetation and soil type, might prove at least a partial surrogate for the other two. In addition, this correlation has implications for the use of these variables in regression analysis, since one of the assumptions of the regression model is that there are not correlations between independent variables. A further important correlation exists between geological type and the incidence of the heath vegetation types. A few of the Borrowdale Volcanic sites on Helvellyn do carry a heath type vegetation, for example an area of Calluna and Vaccinium on the central part of the Striding Edge path, but, for the most part, the slopes of Helvellyn in the area studied are grassland apart from the lower bracken (Pteridium) zone. In contrast, the slopes of comparable altitude on the Skiddaw Slates are mostly Calluna dominated, with patches of Vaccinium and/or Empetrum. The probable explanation of this is that the history of land use of the two areas is different, the Newlands Valley slopes having been maintained in the past for grouse shooting, whereas the Helvellyn area has been used as sheep walk for a long time (Pearsall and Pennington, 1973).

(b) Analysis of selected individual paths by regression

Some explanatory analysis was carried out on those paths which had enough sites to provide a range of one or more of the variables, vegetation, soil, water run off, path restriction, path surface characteristics, as well as variation in slope and altitude. For any one path, geology, aspect, position on or off a ridge and recreation pressure were either constant or varied only a little. Not all the 15 paths were used at this stage; for example, Swirral Edge had only eight sites, with almost uniform conditions except for slope angle;

Causey Ridge had more sites, but throughout the length of the ridge the run off was apparantly little, the vegetation and soil were uniform and path surface materials varied little apart from the incidence of bedrock in the path. Some of the paths were eventually subdivided to allow for possible differences in recreation pressure part of the way along, for example, the Striding Edge path is joined by the path from Mires Beck at the start of the ridge section, at which point also, some walkers appear to turn back. However at this stage the paths were not divided. The paths which appeared to be suitable for analysis were:

Sail (including Crag Hill)
Grisedale Pike
Red Tarn
Dollywagon Pike
Striding Edge
Wythburn

Also, at this stage no account was taken of the fact that some of the variables would be related, as already outlined in the previous section. At this stage, the particular relationships which might exist on any one path were of less interest than the possibility of variables other than the slope variables being significant in the explanation of the variability of the path variables, path width, bare ground and maximum depth. In the event it was found necessary to exclude path surface materials as a variable because it was as much a product of erosion as a cause, and hence always had a very strong correlation with all the path variables. It was also found that neither the water run off at a site nor that down the path was significant on its own as a variable. This possibility had been forseen, since, for the amount of water flowing down a path to be of any magnitude, it is necessary for the surrounding catchment area to be large. It is also evident that, however large the catchment area, if the water does not drain into the path, but instead is diverted elsewhere down the hillside, the potential erosive force is small, being limited to the water draining into the site alone, without added amounts from further up the path. To combine the two measures, the run off was taken to be: high - if both path and site water run off were apparently high, low - if both path and site water run off were apparently low, and intermediate - for all other combinations. This has already been mentioned (section 7.1.2). Variables measured on a nominal scale were introduced into the regression using Dummy variables (Johnston, 1972).

The results of the regression analysis are shown in table 7.9. Forward stepwise regression was used (SPSS manual) Variables are included in the table as significant if, by their addition to the regression, 0.01 or more is added to the value of R^2, the square of the multiple correlation coefficient. R^2 represents the proportion of the variance of the dependent variable attributable to the regression and so an addition to R^2 of 0.01 or more means that the variable is adding 1% or more to the "explanation" of the dependent variable. This is an approximate guide to variables which might be important; it is not a rigorous test, since the order in which variables are entered into the regression and the amount added to R^2 will be dependent upon the amount of collinearity in the data set. However, at this stage the data were only being used to investigate variables which might be relevent and so the multicollinearity effect was not needed. As a consequence of this, it is possible that certain variables might be excluded. For example, if vegetation is entered into the regression as a significant

TABLE 7.9 Regression analysis of data from selected paths, Variables contributing 1% or more to the regression explanation of the dependent variables: path width bare ground and maximum depth

INDEPENDENT VARIABLES	SAIL			G. PIKE			RED TARN			DW. PIKE			STRID. EDGE			WYTHBURN		
	PW	BG	MD	PW	BG	MD	PW	BG	MD	PW	BG	MD	PW	BG	MD	PW	BG	MD
$(\text{Path Slope})^2$	•	•	•	•	•	•	•		•	•	•	•	•	•	•	•	•	•
Cross slope		•	•	•		•	•		•	•			•			•		•
Pter. veg.				•										•	•			
Heath veg.					•													
Nardus veg.				•	•	•									•			
Brown earth					•	•											•	
Brown pods.					•	•	•	•	•					•	•		•	
Podsol					•	•	•	•	•				•	•	•	•	•	•
Run off low	•			•		•	•	•	•									
Run off high	•	•	•	•		•								•	•		•	
Path restricted	•											•				•		
Path unrestricted	•			•	•	•			•	•			•	•		•		
Total R^2	.76	.50	.55	.66	.72	.45	.58	.35	.76	.79	.64	.64	.85	.71	.83	.77	.55	.55
R^2 for cross slope only	.48	.48	.49	.55	.37	.06	.54	.12	.42	.77	.58	.61	.76	.58	.58	.71	.40	.45

PW - path width

BG - bare ground

MD - maximum depth

• Variable contributing 1% or more to the regression explanation variable, because of its correlation with soil type, the latter would be excluded, even though it might be significant otherwise.

Table 7.9 demonstrates that for some of the paths, the environmental variables can contribute substantially to the explanation of the regression; for example, maximum depth for the Grisedale Pike path can be "explained" - in terms of the regression - better by the environmental variables than by the slope variables, the R^2 values being 0.45 and 0.06 respectively. However, this is an exception: for most of the paths, the environmental variables add quite small amounts to the value of R^2. The general level of regression explanation is quite high on some of the paths, for some of the path variables: The Striding Edge path in particular exemplifies this; however, for several path variables the value of R^2 is low, with approximately 50% of the variance only explained by the regression. However, these sets of variables were not necessarily optimal, since the fact that there were interrelationships among some of the variables meant that the inclusion of one rather than another might have precluded the introduction of a third. Another possibility, arising from the small data sets, was that some of the relationships found were fortuitous; for example, for the Grisedale Pike path, paths with high run off were found to be narrower than those with low run off, for which no logical explanation could be found - it would be expected that high run off would produce deeper gullying, which walkers would avoid and so would widen the path.

Having considered the effect of environmental variables in the situation of constant recreation pressure, and their effect having been found to be noticeable, the data were subsequently considered as one, with the paths differentiated by the introduction of the variable, recreation pressure, using the estimates obtained from the sample counts, as described in chapter five.

(c) Regression analysis of the total data set

METHODS The data set of 293 sites was analysed in terms of the following variables:

path width bare ground maximum depth area of cross section	dependent variables
recreation pressure path slope cross slope path restriction* altitude vegetation type* soil type* organic horizon type* water run off* aspect (degrees from south) aspect (degrees from west) position on/off a ridge* geology* erosion category of path above* erosion category of path below* presence of boulders* presence of permanent wetness*	independent variables

(*variables collected at the nominal scale)

The categorical variables were included in the regression by the introduction of dummy variables. For example, for water run off, there were three categories: high, low and intermediate. In order to avoid the "dummy variable trap" (Johnston, 1972) two dummy variables were introduced for this variable, one for high run off, for which the site value was 1 if the run off was high and 0 otherwise, the other for low run off, for which the site value was 1 if the run off was low and 0 otherwise, thus the intermediate category was represented by zero values for both the dummy variables.

The following variables had already been demonstrated as being related:

altitude
vegetation type
soil type
organic horizon type

and so it was necessary to order the introduction of these variables into the stepwise regression, in four different analyses, such that in each analysis a different variable was introduced first. For most of the analyses, the result of doing this was that the correlated variables were excluded in favour of other variables; that is, generally, only one of vegetation, soil, altitude and organic horizon were included.

It was thought that paths situated in a ridge position might be different from paths crossing hillsides, in that either the relationships between variables might differ or that different variables might be important, or both; paths on ridges are spatially restricted in development, the soils are usually thin, the vegetation is exposed to extreme climatic conditions and the amount of water running off most sites is small. Thus the data were separated into two sets corresponding to the position of a site on or off a ridge; the data analysis was run for the two sets separately and for the total data to see where there were differences.

Apart from the relationships existing because of the altitudinal zoning of soil and vegetation, there were other variables which were related to each other to some extent. There was a certain amount of overlap between the variables, path restriction and cross slope, which has already been mentioned (section 7.1.1); path and cross slope were also related at high slope angles because paths with high values of path slope usually had low values of cross slope. The simple correlations between these variables were -0.37 (path slope and cross slope) and -0.39 (path 'restricted' and cross slope). Since the measurement of cross slope was more precise than that of path restriction, the former variable was introduced first and the latter second to see whether it provided a significant amount of additional explanation.

At this stage, which was exploratory, the information required was the particular variables which could contribute to an explanation of the variation in path morphology. Thus the "best" set of variables was required; in other words, those which produced the highest value of R^2, the proportion of the variation explained by the regression. Where the introduction of a variable increased the value of R^2 by 0.01 or more, that variable was deemed to be worthy of further attention and so was recorded as "significant". In some cases, the addition of a variable reduced the effect of one entered earlier, a consequence of the multicollinearity in the data, and in such cases the analysis was re-run, reversing the order of entry of the variables in question.

The results of the analysis, for the best sets of variables, are given in table 7.10 (a) - (c). The variable, cross-section area, is not included because the correlations found were so low; for the total data, ridge sites and off-ridge sites, respectively, the "best" multiple correlation coefficients when squared were 0.24, 0.36, and 0.39.

RESULTS

(1) Path width There are some small differences in the particular variables picked out by the regression analyses for the data as one set, for ridge sites and for off-ridge sites. However, the main factors are the same, namely, path slope, recreation pressure and some form of width restriction variable, the path restriction or the cross slope. (Note that the actual variables used for path slope and recreation pressure were the square and the square root respectively, consistent with the preliminary work).

The values of the regression coefficients also vary for these main factors. It appears that the rate of increase of path width with slope and recreation pressure is greater for

TABLE 7.10

Exploratory regression analysis for the total data set in phase 2 of the sampling; the variables contributing more than 1% to the regression explained variance of the path variables, width, bare ground and maximum depth.

(a) PATH WIDTH

DATA	INDEPENDENT VARIABLES	R^2 (CUM.)	ADDITION TO R^2	REGRESSION COEFFICIENTS	UNITS
Total data set	Path slope (square)	0.26	0.26	0.0093	m/degree^2
	Recreation press.	0.42	0.17	1.51	m/% count
	Path unrestricted	0.57	0.15	3.26	m
	Nardus vegetation	0.60	0.03	0.91	m
Ridge sites	Recreation press	0.46	0.46	1.20	m/% count
	Path slope (square)	0.58	0.12	0.0036	m/degree^2
	Cross slope	0.63	0.05	-0.078	m/degree
	Nardus vegetation	0.66	0.03	1.09	m
Off-ridge sites	Path slope (square)	0.34	0.34	0.0108	m/degree^2
	Recreation press.	0.51	0.16	1.65	m/% count
	Path unrestricted	0.62	0.11	3.30	m
	Geology, BVS	0.66	0.04	1.87	m
	Cross slope	0.67	0.01	-0.064	m/degree
	Nardus vegetation	0.67	0.01	0.79	m

(b) BARE GROUND

DATA	INDEPENDENT VARIABLES	R^2 (CUM.)	ADDITION TO R^2	REGRESSION COEFFICIENTS	UNITS
Total data set	Path slope (square)	0.21	0.21	0.52	cm/degree^2
	Altitude	0.37	0.16	0.15	cm/ft
	Recreation press.	0.44	0.07	42.77	cm/% count
Ridge sites	Path slope (square)	0.21	0.21	0.42	cm/degree
	Recreation press.	0.36	0.15	27.62	cm/% count
	Nardus vegetation	0.42	0.06	-94.81	cm
	Cross slope	0.48	0.05	5.00	cm/degree
	Run off, high	0.51	0.03	-195.44	cm
Off-ridge sites	Path slope (square)	0.22	0.22	0.60	cm/degree^2
	Altitude	0.38	0.16	0.16	cm/ft
	Recreation press.	0.50	0.13	55.52	cm/% count

(c) MAXIMUM DEPTH

DATA	INDEPENDENT VARIABLES	R^2 (CUM.)	ADDITION TO R^2	REGRESSION COEFFICIENTS	UNITS
Total data	Path slope (square)	0.25	0.25	0.048	cm/degree^2
	Geology, BVS	0.31	0.07	8.37	cm
	Recreation press.	0.38	0.06	3.65	cm/% count
	Cross slope	0.43	0.05	0.57	cm/degree
	Run off, high	0.45	0.03	6.25	cm
Ridge sites	Path slope (square)	0.25	0.25	0.022	cm/degree
	Cross slope	0.42	0.17	0.54	cm/degree
	Nardus vegetation	0.47	0.05	-4.06	cm
	Recreation press.	0.50	0.03	0.86	cm/% count
Off ridge sites	Path slope (square)	0.29	0.29	0.066	cm/degree^2
	Recreation press.	0.40	0.11	5.25	cm/% count
	Cross slope	0.47	0.07	0.55	cm/degree
	Pteridium veg.	0.52	0.04	-10.73	cm
	Path, restricted	0.54	0.02	10.37	cm

sites which are not on ridges, but this is what one would expect since most off-ridge sites allow some, if not unlimited, space for path development. However, the results suggest that in any analysis of this type of data, provision must be made for the two groups of sites.

Two other variables appear in the results: Nardus as a vegetation type at a site seems to be associated with wider paths, particularly on ridge sites; the Borrowdale volcanic sites, in other words those on Helvellyn, also seem to be associated with wider paths, on the off-ridge sites. However, the significance of these variables is not very high and it is possible that the relationships are spurious. For example, the Nardus sites occurring on ridges are found on three of the Skiddaw slate mountains, in positions either at the summit or at subsidiary summits where there is space for walkers to walk off the path; this in contrast with adjacent sites where the paths pass through Calluna or similar.

(2) Bare Ground The main factors relating to amounts of bare ground are path slope, altitude and recreation pressure, although the effect of the latter is reduced when the data set is not divided. The division of the sites into the two groups is beneficial for providing better explanations of the dependent variable in terms of the regression variables. For ridge sites, altitude is apparantly not relevent, which may be because the range of this variable is less in that group. On ridge sites, the effect of cross slope, Nardus and run off is apparantly relevent, but not very significant. Sites with high values of the cross slope variable have more bare ground, Nardus vegetation sites have less, as apparantly do sites with high run off. The last result would appear to be a spurious correlation since there is no theoretical reason why high run off should be associated with lesser

amounts of bare ground; in fact the reverse would be expected. This suggests that such low values of significance, in terms of the addition to R^2, are not to be relied upon, even if they are statistically significant, in terms of the standard errors of the coefficients.

(3) Maximum depth Path slope is, as for the other path variables, a major explanatory variable. The importance of other variables depends upon the data set, although cross slope and recreation pressure occur in all three groupings of the data. The subdivision of the data again improves the level of explanation.

CONCLUSIONS

It is evident from this data that approximately 50% of the variation in path erosion characteristics can be explained by the variables measured, even though these variables are often somewhat simplistic. Variation in path width can be explained to a greater extent than the other path variables, with R^2 values greater than 0.60, more than 60% explanation.

The most important variables identified by this method of analysis are the slope characteristics, recreation pressure and path restriction factors, with an important altitude effect for the incidence of bare ground. Other variables are identified, including, particularly, some vegetation characteristics, but these variables contribute small amounts to the general level of explanation and would possibly vary with different data sets.

At this stage, no account was taken of the interaction effect between recreation pressure and the path slope variable, although it was thought that such an interaction would be found, since differences between slope regression coefficients had been found which were apparently related to differences in recreation pressure (chapter six, figure 6.7). The introduction of an interaction term would be expected to increase the levels of explanation. There was also the possibility that other variables would interact, since there was no reason why all the relationships should be additive.

(d) <u>Further analysis of the total data set</u>

If important variables are missing in the regression relationships or if some of the variables included have been poorly defined, then there is the probability that, for the residuals,

(i) the three measures of the path morphology may be correlated, and

(ii) there may be spatial correlation between the sites.

The relevent correlation coefficients are listed in table 7.11 from which it can be seen that the residuals are related, positively, as suggested. The greatest correlation between path variable residuals are for sites off ridges, for which path width and bare ground, and maximum depth and bare ground have correlation coefficients of 0.56 and 0.54 respectively. Bare ground is the variable most spatially correlated, with an autocorrelation coefficient of 0.43. It was hoped that the introduction of one or more interaction variables would remove some of these correlations, but not necessarily all.

The very large positive and negative residuals were examined individually, in association with notes taken in the field. Some large residuals were clearly caused by factors which would be difficult to categorise; for example, one eroding site was in the process of being undercut by a small stream nearby; another site was extremely confined between two rock outcrops. A few sites were across marshy ground, but the number was presumably too small for the effect to be noticeable in the regression analysis. Some residuals

TABLE 7.11 Correlation between residuals from the regression of path and environmental variables.

A. CORRELATION MATRICES BETWEEN RESIDUALS FROM PATH VARIABLES

1. Ridge Sites

	Bare ground	Maximum depth
Path width	0.31	0.22
Bare ground		0.36

2. Off-ridge sites

	Bare ground	Maximum depth
Path width	0.56	0.30
Bare ground		0.54

B. AUTOCORRELATION COEFFICIENTS FOR RESIDUALS

Path width	0.33
Bare ground	0.43
Maximum depth	0.17

were grouped by path, which suggested that either the estimate of recreation pressure was particularly inaccurate or that the path in question had some characteristic peculiar to itself, and not related to the variables measured. This examination did not yield any consistent factors for further consideration.

Since the regression analysis had suggested as important variables which had, for the most part, been measured in the first phase of the sampling, it seemed sensible to combine the data to give a sample covering a greater area, and, it was hoped, a greater range of conditions. From this, it was expected that more reliable relationships could be established, which might reasonably be expected to be consistent in other parts of the National Park which were similar in character. The results of this are considered in the next section.

It is perhaps pertinent at this stage to consider some of the variables which were measured during the second phase, but which did not appear as significant in the regression.

Referring back to table 7.3, the variables which were measured, other than those discussed in the analysis above, are:

erosion category of adjacent paths,
presence of boulders,
presence of permanent wetness,
path surface characteristics,
aspect,
organic horizon type.

1. Path surface characteristics was rejected as a possible variable for use in regression, as already explained, because it was as much a consequence as a cause of erosion, and was very strongly correlated with all the path variables.

2. Although the presence of boulders or permenent wetness at a site appeared to result in wider paths, neither variable operated consistently or frequently enough to make a significant

contribution to the regression. 3. The *type of organic horizon* is related to the soil type and to altitude, but, above about 1500 ft (457m), it is fairly constant. Thus the other variables to which organic type is related are more useful in differentiating between sites. 4. Aspect did not appear to be significant at all. Ceizlinski and Wagar (1970) found aspect a significant variable in vegetation reactions to trampling experiments, but the climatic conditions were more extreme. In the Lake District, north facing slopes may be cold and inhibit early spring vegetation growth, but south facing slopes are more likely to suffer from drought during the summer; the snow may accumulate more to the east of mountain tops, but effect is perhaps relatively unimportant since much of the mountain snow cover is dispersed by the advent of a warm front with its accompanying rain, effective on both east and west facing slopes. However, this is conjectural; the insignificance of aspect may have been a consequence of insufficient range of the values, or its effect may be simply too small to be measured by such crude measurements. 5. For some sites, the erosion state of *adjacent parts of the path* certainly affected the amount of stone debris accumulated. Deeply gullied sites sometimes supply sheets of eroded material to be deposited on sites below (plate 2). However, the effect is not sufficiently consistent to appear in the analysis, since, for many sites, the transported debris is deposited down the hillside rather than on the path.

It was thought worthwhile to retain the aspect variables, and those for the presence of boulders and permanent wetness for the combined data analysis, since there was always the possibility that with a larger data set, their presence might become more significant.

7.4 REGRESSION ANALYSIS OF TOTAL DATA

7.4.1 Introduction

The previous section had demonstrated that quite simple measures of variables could be used to describe the relationships between some environmental site conditions and measures of path morphology, or erosion. It was possible to expand the data set to include the sites measured in the first sampling phase, at the expense of few of the relevent variables.

The two variables which were not available at all in the first data set were the two categories of water run off used in the regression above. There was no way in which the water run off could be estimated from the maps and air photographs, since part of the variable was derived from field examination of the type of path run off likely to be entering the site from up the path. Since the effect of this variable was very small and only relevent to the explanation of maximum depth of erosion, it was hoped that its loss would not be too significant. However, it was unfortunate, because the amount of run off water ought to be important for the estimation of erosion according to the established theories (chapter two).

The variables for path restriction were assessed for the first phase data, using field notes, values of cross slope and, for some paths, air photographs. The variable for the ridge position was also obtained, from photographs and maps.

Thus, for the combined data, the variables to be considered were:

path width
bare ground

maximum depth
area (estimate of area = 0.5 x bare ground x max. depth)*
path slope (the square of this variable)
recreation pressure (square root of this variable)
cross slope
path restriction
altitude
aspect
vegetation type
soil type
presence of boulders
presence of wetness

(* see section 6.1.2(b))

These variables were used in the regression in a similar manner to that described in the previous section. In other words, the altitude, vegetation and soil type variables, which were known to be related, were ordered in the regression so that the optimum choice could be made - optimum in terms of maximising the proportions of the variance of the dependent variable explained by the regression.

One of the results of the first stages of the analysis (section 6.3.3(d)) demonstrated that the rates of change of path width and the other path variables were dependent on path slope in a way that depended upon the recreation pressure. In other words, footpath morphology depended not only upon the two variables in a simple additive relationship but also upon their interaction. Since these two variables were manifestly the most important ones to be isolated in the analysis of the previous section, it was desirable to include an interaction factor in any subsequent analysis. Some interaction between many of the path site variables can be expected, since some will act to modify the effect of others. However, because it is not possible to specify the expected model exactly, it is not possible to predict which of the various site variables may interact. In the early stages of the analysis of the combined data set, therefore, the interaction effects, if they existed, were ignored, and thus any such effects will be subsumed in the residual terms. The exception to this was the interaction between path slope and recreation pressure, already mentioned.

7.4.2 Results

Overall, the results were very similar to those obtained in the previous section for the second phase. The interaction of the path slope and the recreation pressure, using the square and the square root as before, accounted for most of the variability of the path morphology measures; with the added effect of the slope and recreation variables separately, relatively little of the regression explanation remained to be attributed to the other significant variables. Of these other variables, the most important appeared to be the path restriction factor for path width, altitude for the amount of bare ground, and cross slope for the maximum depth of gullying.

The vegetation type, Calluna, apparantly was relevent to the width of the path and the bare ground, but the effect was not very significant, although it acted as might be expected, since Calluna is vulnerable to trampling. A ridge effect of "less bare ground and depth of gullying" accounted for a small amount of the variation in those variables; two soil types, brown earth and podsol, appeared to be relevent to the depth of gullying, producing less than average depths for brown earths, and greater than average depths for podsols. It was possible that the soil effects represented differences in run off at sites, since the infiltration rates and depths of brown earths are greater, and those of podsols may be less than the brown podsolic soils, but in that case it is difficult to see where the peaty rankers and thin rankers fit into the framework. An alternative suggestion is that brown earths are the least erodible of the various soil types, because the well incorporated organic matter under a mull humus type should increase the aggregate stability of the soil. Moreover, the extensive network of Pteridium rhizomes may assist in retaining the soil; remnants of these rhizomes survive long after the surface vegetation has disappeared. Podsols may be more erodible than other soil types because of the nature of the elluviated horizon, which tends to be deficient in colloidal material, clays and organic matter; Bryan (1969) found that podsols were more erodible than other soils, in his study of some Peak district soils. However, the foregoing remarks are conjectural and are only suggested as possible reasons for the observed relationships. It should be emphasised that the individual significance of these variables, as that of the ridge effect and of Calluna, is relatively small, amounting to a contribution of 5% or less to the total variance explained by the regression. Thus there is always the possibility that such variables appear significant by a chance coincidence with some other variable, and that a different data set might not be consistent if taken from another area within the National Park.

The complete results are given in table 7.12 with the relevent variables, their regression coefficients and their values. The F values are included because they describe the relative contribution of each variable to the explained variance; F is the ratio of the variance explained by the variable in question, independently from other variables, to the residual variance. The F values are not tested for their statistical significance because not all the variables are

TABLE 7.12 The analysis of the total data set from the first and second phase of sampling, Variables contributing 1% or more to the squared multiple correlation coefficient, R^2.

PATH VARIABLE	SITE VARIABLES	REGRESSION COEFFICIENT**	F	R^2
Path width	interaction of slope and recreation	0.0027	122.3	
	path unrestricted	0.902*	52.4	
	path slope, squared	-0.011	36.0	
	cross slope	-0.089	25.3	
	recreation pressure	0.280	14.0	
	<u>Calluna</u>	0.902*	12.1	
	constant term	0.735		0.66
Bare ground	interaction of slope/recreation	0.065	242.4	
	altitude	0.101	62.3	
	recreation pressure square root	15.70	26.4	
	<u>Calluna</u>	79.92*	25.7	
	position on ridge	-58.02*	10.4	
	constant term	-244.8		0.52
Maximum depth	interaction of slope/recreation	0.0079	356.9	
	cross slope	0.71	62.5	
	brown earth soil type	-8.80*	22.7	
	podsol soil type	9.49*	19.3	
	position on ridge	-5.41*	10.8	
	constant term	-1.44		0.46

** units as for table 7.10

* regression coefficient for dummy variable

independent of each other, an effect which causes the significance of a variable to be underestimated.

It should also be noted that the "area" variable was unsatisfactory, in that its relationship to other variables was weak, $R^2 = 0.23$. Thus this variable was rejected.

7.4.3 Discussion of the analysis

The inductive use of stepwise regression in this analysis can be criticised in that the lack of a clearly defined prior model may result in a regression equation which is unique to the peculiar circumstances from which the data are taken. Moreover, a systematic search for the best subset, through all possible subsets of the independent variables, is in reality, impossible, since the number of permutations of variables is so high (Hauser, 1974). The type of stepwise regression used, the particular algorithm, may yield different results (Hamaker, 1962). The order in which variables are introduced may prejudice the inclusion of others at a later stage, if the "independent" variables are in fact interdependent - the problem of multicollinearity.

Much consideration was given to the choice of variables, to include the most important ones and to order the steps of the regression so that major errors should not arise. Logically defined alternative sets of variables were considered, which indeed yielded consistent results; for example, much the same proportion of the variance of bare ground could have been obtained from using altitude, vegetation or soil type as variables. However, several aspects of the regression were considered to be in need of further investigation.

The variables were accepted by the criterion of their contribution to R^2, the proportion of the regression explained variance in the dependent variable. This raises three immediate questions:

(i) is the significance of these variables and their regression coefficients a stable characteristic, or dependent on the particular data set - in other words are the results reliable?

(ii) would a better model be produced if the interactions of all the variables were to be considered, instead of the simple linear additive model above, with only the interaction between the main slope and recreation components?

(iii) does the value of the squared multiple correlation coefficient, R^2, accurately describe the extent to which the independent variables chosen account for the variation in the dependent path variables?

In effect, these questions are really asking whether the sample data collected have produced unbiased, minimum variance estimates of the population from which they have come. The extent to which the sample coefficients, namely the regression coefficients, their standard errors, and the multiple correlation coefficient, are unbiased and are estimators with the minimum variance depends upon the extent to which the assumptions of the linear regression model used are adequately fulfilled. Certain features of the regression analysis of section 7.4.2 suggest that the results may not be entirely reliable. These are discussed below within the context of some of the assumptions of a linear regression model which are not fulfilled in the data collected.

1. The first condition, defined by the title "linear regression", is that the dependent variable shall be a linear

combination of the independent variables. However, since, for example, the effect of slope on paths has been demonstrated to be affected by the effect of recreation, it is reasonable to expect that other relevent variables should interact. If an interaction model is preferable, then the regression obtained in section 7.4.2 will (a) have some of the interactions included in the residual terms and (b) have the regression coefficients adjusted to the incorrectly specified linear additive model. Thus, the incorrect specification will be likely to cause errors. One possibility is that the residual terms will be related to the interaction terms such that the magnitude of the residuals is likely to increase with increases in the value of the predicted dependent variables. Thus, the variance of the residuals would not be constant. The effect of heteroscedasticity in the residuals is not to bias the coefficients obtained, but to produce variances of these coefficients which are not minimised; thus, overestimates of coefficient errors or underestimation of coefficient significance may result. However, the effect of an incorrect specification of the model resulting from the exclusion of relevent interaction terms would cause bias in the coefficients, (Johnston, 1972, pp 168-9, 210).

2. Multicollinearity, interdependence among the "independent" variables, is inevitable within this data set, to a certain extent, because of the way in which some of the variables are defined or because of the natural interactions within the system. The interaction between path slope and recreation is related to the two factors considered separately; cross slope is related to path slope to some extent when values of the latter are high; cross slope is also related to the path restriction factor to some extent. Although the individual pairs are not highly correlated as, for example, are altitude

and vegetation type, there still remains a considerable amount of multicollinearity within the data. The main consequences of multicollinearity are that

(a) estimation precision falls, so that estimated coefficients may have large errors;

(b) the significance of variables may be underestimated, because that particular data set may not enable their influence to be identified;

(c) estimators of the regression coefficients become sensitive to particular data, and the addition of more data, or the use of different data may result in very different coefficients;

(Johnston, 1972 p 160).

3. The third aspect of the regression which was found to be inadequate centred around the spatial correlation of the residuals. The existance of serial correlation was suggested by the values of the Von Neumann ratio (Johnston, 1972 p 250) which with a large sample is virtually equivalent to the Durbin-Watson statistic calculated in the SPSS regression programme. Calculation of the value of the autocorrelation coefficient between adjacent sites confirmed that the residual terms were not independent. The effect of auto-correlation among the residual terms is that (a) the residual variance is likely to be underestimated, and so the value of R^2 may be inflated, and (b) the variances of the coefficients are likely to be underestimated, and so the significance of the variables may be overestimated, (Johnston, 1972 pp 246-248).

Given the shortcomings of the data as outlined above, it was likely that the relationships obtained in the regression might be unreliable. Some further analysis was necessary, therefore, to try to ascertain the extent to which the coefficients might be unreliable and to attempt to improve the model. The full explanation of the analysis carried out is to be found in Appendix 2; the results and some discussion are presented below.

(1) INTERACTION OF VARIABLES

Assume that a transformation, if necessary, can be found so that the erosion due to a variable can be expressed in the form

$$E_i = a_i + b_i X_i$$

where E_i is the erosion caused by the variable X_i and a_i and b_i are the regression coefficients. Then the erosion due to the variable X_j can be expressed similarly as

$$E_j = a_j + b_j X_j$$

If the two variables interact such that X_j modifies the effect of X_i then both a_i and b_i will be a function of X_j. Indeed it is possible to consider the erosion $E_{i,j}$ caused by both X_i and X_j acting together as having a relationship of the form

$$E_{i,j} = a_i(1 + a_j + b_j X_j) + b_i(1 + a_j + b_j X_j)X_i$$

which can be written more simply as

$$E_{i,j} = a_{i,j} + b_i' X_i + b_j' X_j + b_{i,j} X_i X_j$$

The logical extension of this model, assuming that all the relevent variables interact, is to a relationship of the form

$$E_{1,..,k} = a_{1,..,k} + b_i X_i + b_{i,j} X_i X_j + ... + b_{1,..,k} X_1 X_2 .. X_k$$

where k is the number of independent variables.

However, to attempt a regression analysis with all possible combinations of interactions would require 21 "independent" variables for path and bare ground, and 63 for maximum depth. Since the multicollinearity among the interaction variables would be very great, isolation of the relevant interactions would be virtually impossible. Thus it was necessary to consider each path variable in turn and suggest which interactions might be expected. This was possible because some variables would not have an interaction factor; for example, the effects of the two soil types on maximum depth, brown earth and podsol, were mutually exclusive. Also, the effect of cross slope and the path restriction factor were considered to be without interaction, since it was not possible to have an unrestricted path at the same time as a high cross slope, by definition of an unrestricted path (section 7.1.1).

The results of the attempt to produce interactions in the model were not very different, in terms of the proportions of the regression explained variance, from the simple additive model with the interaction of path slope and recreation pressure. The significance of the various interactions was assessed by using the value of R^2 and additions to R^2 as before. The results are given in table 7.13. The values of individual regression coefficients are different because the variation of the dependent variable is being allocated to different interaction factors. The interactive model is no real improvement on the first model, in terms of explanation, but it may be said to be more soundly based in logical terms. One of the reasons for the lack of success in fitting an interactive model may be that the data are so highly heteroscedastic, with very great variation for high values of the predicted dependent variable, such that specification of one model rather than another is not possible. One fact that emerged from the inclusion of interaction terms was that, the heteroscedasticity of the data was not reduced, and so it was not a consequence of the lack of interactive relationships, as might have been expected (Fergusson, 1977).

In conclusion, the interactive model may be preferred on

TABLE 7.13 Regression analysis of the first and second phase sampling data. Path variables in terms of the site variables and the interactions of site variables

	PATH SITE VARIABLE	BETA* COEFFICIENT	R^2
PATH WIDTH	X1X3	0.49	
	X3	0.33	
	X4	0.18	
	X2	-0.19	
	X5	0.09	
	X1X3X5	-0.13	
	X1X3X4X5	0.09	
			0.65
BARE GROUND	X1X3X6	0.59	
	X3	0.20	
	X6	0.11	
	X5	0.11	
	X1X3X6X7	-0.12	
			0.55
MAXIMUM DEPTH	X1	0.36	
	X3	0.16	
	X2	0.30	
	X8	-0.16	
	X9	0.16	
	X1X3	0.34	
	X1X3X7	-0.14	
			0.46

VARIABLE LIST

X1 path slope squared

X2 cross slope

X3 square root recreation pressure

X4 path, unrestricted

X5 *Calluna* veg. type

X6 altitude

X7 position on ridge

X8 brown earth soil type

X9 podsol soil type

* Beta coefficients (standardised regression coefficients) are used because of the size of the values produced in the multiplication of variables in the interaction factors, which necessitated the introduction of factors of 10 into the regression in order to maintain the necessary level of arithmetical precision.

logical grounds; however, in terms of explaining the variation of the path variables it adds little to a simple model with the interaction of the main slope and recreation variables only. Moreover, as a result of the multicollinearity produced by the interaction terms, the actual coefficients and the particular interactions which are significant may vary from one data set to another.

(2) MULTICOLLINEARITY

A full discussion of the tests for multicollinearity and a technique for its correction is given in Appendix 2. The technique used was that of ridge regression (Hoerl and Kennard, 1970; Jones, 1972; Mather, 1976).

Ridge regression operates by reducing each simple correlation coefficient between the different independent variables by a factor, which is allowed to increase for each trial regression. Because all the correlations are being reduced by the same factor, the multicollinearity is reduced at each successive trial. However, at the same time, the correlation between the dependent and each independent variable is being reduced, so that the overall regression explanation, R^2, also decreases at each trial. The effect of the technique is to stabilise the regression coefficients after a number of trial regressions, each increasing the reduction factor by a small amount, but the stability is at the expense of the value of R^2. The amount of reduction of the simple correlation coefficients and of R that is necessary before the regression coefficients stabilise is judged from the "ridge trace", the diagramatic representation of the coefficients' change with the reduction of the correlation coefficients.

In the example cited in the literature, the desired stability in the regression coefficients is achieved without too great a decrease in the value of R^2, Jones cites two examples, in which the value of R^2 decreases from 0.76 to 0.71 and from 0.65 to 0.61. The initial values of the path variable multiple correlation coefficients are generally lower than those above, and to obtain stable regression coefficients, it is necessary to accept reductions in R^2 from 0.66 to 0.46 for path width, from 0.52 to 0.37 for bare ground and from 0.46 to 0.31 for maximum depth.

The ridge regression estimates are given in table 7.14 together with the original coefficients for comparison. It can be seen that the only major changes occur for the path width equation. Path slope, as a separate variable from the interaction variable, ceases to be significant; there are considerable adjustments to the interaction variable and the recreation pressure variable, their coefficients being approximately halved and doubled, respectively. For all the other variables, the adjustments to their coefficients are fairly minor, suggesting that on the whole the regression relationships are quite stable.

For path width, the ridge regression relationship expresses the dependent variable in terms of recreation pressure and in terms of an interaction between recreation pressure and path slope, and of course in terms of the other relevent variables. This is consistent with the relationships between path width and slope for each path considered separately. Figures 7.2 and 7.3 demonstrates how the values of the regression constant and regression coefficient for path slope are related to recreation pressure. The relationships are not perfect because there are other variables involved for each path and the recreation pressure values are only estimates, but clearly both path size and the rate of increase

TABLE 7.14 Ridge regression: comparison of regression coefficients with those obtained from ordinary least squares regression

	INDEPENDENT VARIABLE	REGRESSION COEFFICIENTS OLS	RIDGE REGR.	R^2 OLS	RDG REG.
PATH WIDTH	Recreation press. (square root)	0.28	0.54		
	Path slope (squared)	-0.011	-0.0007*		
	Cross slope	-0.089	-0.078		
	Path, restricted	1.88	1.77		
	Calluna veg.type	0.90	0.72		
	Interaction,path slope/rec.press.	0.0027	0.0011		
				0.66	0.46
BARE GROUND	Recreation press. (square root)	15.70	15.77		
	Altitude	0.101	0.084		
	Calluna veg.type	79.92	66.20		
	Ridge position	-58.02	-42.14		
	Interaction,path slope/recreation	0.065	0.055		
				0.52	0.37
MAX. DEPTH	Cross slope	0.71	0.61		
	Brown earth soil	-8.80	-7.21		
	Podsol soil	9.49	7.49		
	Ridge position	-5.41	-5.03		
	Interaction,path slope/recreation	0.0079	0.0062		
				0.46	0.31

* variable no longer significant

FIGURE 7.2 Relationship between path slope regression coefficients and recreation pressure estimates

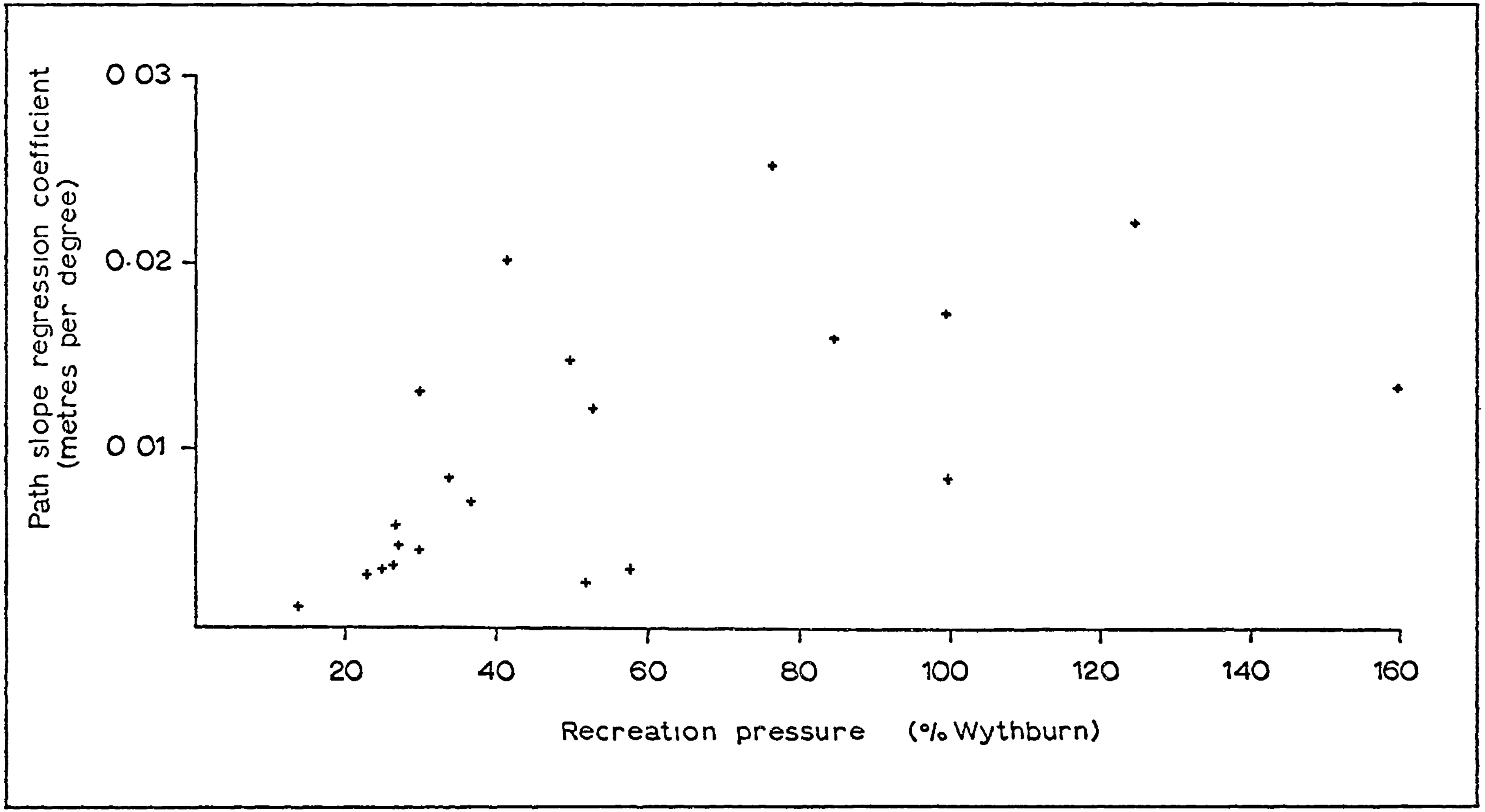
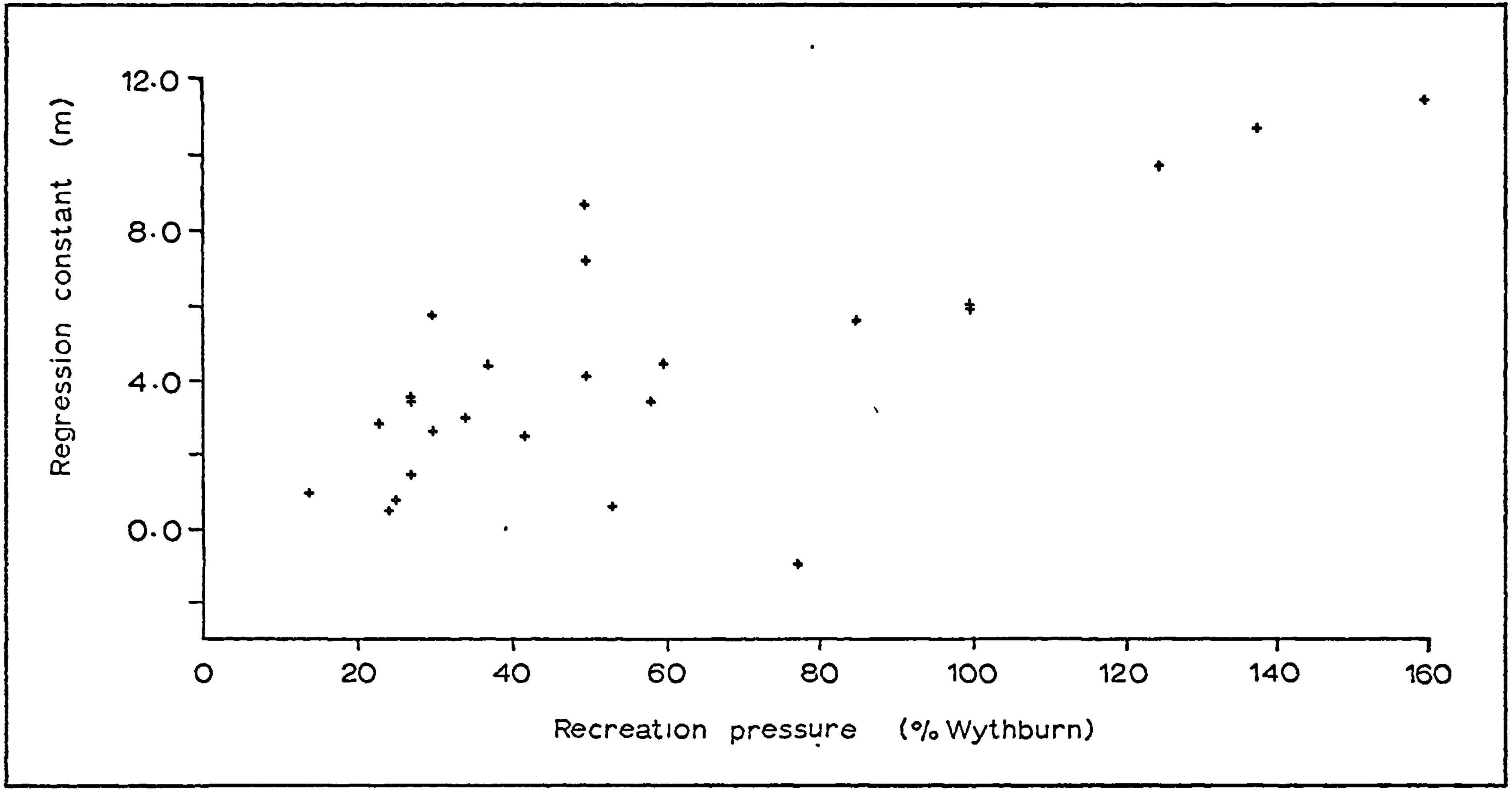


FIGURE 7.3 Relationship between path slope regression constants and recreation pressure estimates



of that size with slope are dependent on recreation pressure.

Thus, it has been possible to demonstrate that most of the variables established in the path regression are stable, in that their coefficients do not change markedly under the ridge regression modification of the correlation structure of the data. For the interactions between path slope, recreation pressure and the two variables considered separately, in the path width equation, some adjustments are indicated, and these are consistent with the relationships observed for each path separately.

The multicollinearity of the interaction model, discussed in the (1) above, was not considered. It was felt that such extensive interrelationships were built in to this model by definition that the technique would not be suitable.

(3) AUTOCORRELATION

Interdependence of the residuals was found in the form of positive spatial correlation among the path width and bare ground variables. A correction was applied in the form of an interactive procedure based on the Cochrane-Orcutt iterative process (Johnston, 1972, pp 262,263). The detailed account of this is given in Appendix 2, only a summary being presented here. The iterative procedure is based on a regression of the form

$$y' = b_0 + b_1X_1 + b_2X_2 + \dots\dots\dots$$

where y' is a transformation of the original dependent variable, y, such that

$$y' = y_i - ry_{i+1}, \qquad i = 1,\dots\dots\dots,n-1$$

and r is initially calculated from the correlation of the residual from each y_i with that from the successive value, y_{i+1}. The regression is repeated with successive values of r, obtained from the correlation of the residuals until there is no significant autocorrelation. The estimates obtained from the last regression enable coefficients to be calculated for the dependent variable in terms of the independent variables.

Use of this iterative procedure yields the coefficient estimates given in table 7.15. This indicates how the autocorrelation in the data (i) led to overestimates of the true levels of explanation, and (ii) produced variance estimates of some of the regression coefficients which were too small. The squared correlation coefficient is reduced from 0.66 to 0.58 and from 0.52 to 0.45 for the path width and the bare ground variables respectively. The most noticeable changes in the values of the standard errors occur for the variables Calluna, ridge position and recreation pressure. However, the changes in the standard errors are not sufficient to alter the significance of any of the regression coefficients; thus, all variables are still apparantly relevent.

Given the sampling interval, there was no reason to think that this autocorrelation was the product of some "lag" effect. Rather, it was thought that either some "explanatory" variable(s) had been left out, or that some might have been incorrectly estimated. An example of the latter is recreation pressure, a poor estimate of which would produce groups of sites with either positive or negative residuals. For the purpose of estimating the relative effect of the environmental variables measured, the autocorrelation was apparantly not too damaging, but its effect was to overestimate the regression explanation by more than 10%.

TABLE 7.15 A comparison of the regression parameters obtained before and after correction for autocorrelation in the variables, path width and bare ground

	VARIABLE	BEFORE CORRECTION REGRESSION COEFFICIENT	BEFORE CORRECTION STANDARD ERROR	AFTER CORRECTION REGRESSION COEFFICIENT	AFTER CORRECTION STANDARD ERROR
PATH WIDTH	Path slope	-0.0108	0.002	-0.0102	0.002
	Cross slope	-0.0885	0.017	-0.0934	0.017
	<u>Calluna</u>	0.9020	0.259	0.8009	0.328
	path, unrestricted	1.8784	0.259	1.3674	0.268
	rec. press. sq. root	0.2802	0.075	0.3040	0.093
	interaction	0.0027	0.00024	0.0026	0.00025
	constant term	0.7348		0.8689	
	R^2	0.66		0.58	
BARE GROUND	altitude	0.1012	0.013	0.1006	0.018
	<u>Calluna</u>	79.92	15.78	75.50	19.62
	ridge pos.	-58.02	18.03	-50.65	24.54
	rec. press.	15.70	3.06	15.05	4.44
	interaction	0.0650	0.0042	0.0676	0.0043
	constant term	-244.77		-243.74	
	R^2	0.52		0.45	

(4) CONCLUSIONS TO THE DISCUSSION OF THE ANALYSIS

Given the doubtful validity of the application of linear regression to this date, a final test was made of the stability of the different regression parameters. The data were divided into three groups, randomly, and the regression analysis was repeated for each group.

The results are given in table 7.16. Surprisingly, no new variables appear to contribute significantly, although some variables from the regression of the total data are not significant in all of the groups. The regression coefficients are extremely variable, as is the value of R^2. However, it is noticeable that the variables which are not consistently significant are, as might be expected, those which contribute least to the regression explanation. This, in many ways, salutary exercise underlies the caution with which the regression results should be interpreted.

If the shortcomings of the data are ignored, or considered self-cancelling, then the standard errors of the regression can be examined in the light of any possible predictions of the population that might be made from the sample. However, the standard error of an individual predicted value of the dependent variable at the "position" defined by the average value of each of the independent variables is large. The standard errors are 2.63m, 147.4cm and 14.5cm for path width, bare ground and maximum depth respectively. If predicting values of the dependent variables at values away from the average values of the independent variables,these standard errors are much greater, because of the effect of the errors of the various regression coefficients. Thus it can be seen that these data yield a poor model for prediction of individual values of the path variables from values of the environmental variables. The major factor involved in these

TABLE 7.16 Stability of the regression analysis for the total data: comparison of regression parameters for three randomly selected subgroups of the data

DEPENDENT VARIABLE	INDEPENDENT VARIABLES	REGRESSION COEFFICIENTS GROUP 1	GROUP 2	GROUP 3	TOTAL DATA
Path width	path slope, squared	-0.011	-0.004	-0.10	-0.011
	cross slope	-0.089	-0.109	-0.089	-0.089
	interaction	0.0027	0.0014	0.0041	0.0027
	recreation sq. rt.	0.19	0.40	0.38	0.28
	path, unrestricted	2.11	1.85	1.22	1.88
	<u>Calluna</u> veg.	-	0.98	1.42	0.98
	R^2	0.67	0.59	0.72	0.66
Bare Ground	interaction	0.062	0.049	0.079	0.065
	recreation sq. rt.	13.03	12.87	21.35	15.70
	altitude	0.101	0.081	0.111	0.101
	<u>Calluna</u> veg.	80.72	69.53	82.32	79.92
	position on ridge	-15.67	-77.75	-	-58.02
	R^2	0.55	0.40	0.61	0.52
Maximum depth	interaction	0.0079	0.0079	0.0105	0.0079
	cross slope	0.59	0.75	0.71	0.71
	podsol soil	10.15	5.79	19.36	9.49
	brown earth	-10.21	-	-8.62	-8.80
	position on ridge	4.17	6.11	5.68	-1.44
	R^2	0.40	0.32	0.59	0.46

large standard errors is probably the highly heteroscedastic nature of the data, which, it is suggested, is likely to be a consequence of the irregular nature of footpath development, both through time and in detail at any site. No satisfactory technique was found for taking this into account.

However, whatever the doubts expressed about the model as a predictive tool, it seems of some value for indicating the effects of easily measured environmental variables. It demonstrates the importance of gradient and levels of use in determining the morphological characteristics of a path; it indicates the rate at which path erosion increases, on average, with increases in gradient and recreation. It appears to indicate, moreover, that on the type of terrain generally experienced away from the valleys in the Lake District, other environmental characteristics are relatively unimportant. Some further conclusions are drawn in section 7.5 following this section on the regression analysis, but, using this level of detail in the collection of data, it is not likely that much further information could be obtained for explaining the way in which footpaths respond to their situation, whether environmental or recreational.

The complete analysis of the total data of 486 sites is given in table 7.17, namely, the regression coefficients and their standard erross, F ratio values, R^2, the standard errors of the mean value of the dependent variable and of the estimate[1], and relevent comments consequent to the investigations outlined in the sections above.

1 the standard error of prediction is ommitted because its value depends upon the "distance" of the values of the dependent variables from their mean value.

TABLE 7.17 Summary of the regression analysis for the data from the morphological survey

A. PATH WIDTH

Regression model	$Y1 = 0.735 + 0.28\,X1 - 0.108X2^2 - 0.089X3 + 1.878X4 + 0.902X5 + 0.00268\,X1X2^2$						
Standard errors	0.10	0.075	0.002	0.017	0.260	0.260	0.00024
F ratios		14.0	36.0	25.3	52.4	12.2	122.3
R^2	0.66		Correction for autocorrelation: $R^2 = 0.58$				
Standard error of estimate	2.53m		X5 not consistently significant in random subgroups of data. Ridge regression estimates for multicollinearity correction: $X2^2$ not sig.				

B. BARE GROUND

Regression model	$Y2 = -244.7 + 15.7\,X1 + 0.101X6 + 79.92X5 - 58.02X7 + 0.065\,X1X2^2$					
Standard errors	6.40	3.06	0.013	18.03	15.77	0.004
F ratios		26.4	62.3	10.4	25.7	242.4
R^2	0.52		Correction for autocorrelation: $R^2 = 0.45$			
Standard error of the estimate	141.0		X7 not consistently significant in random subgroups of the data.			

C. MAXIMUM DEPTH

Regression model	$Y3 = -1.44 + 0.709X3 - 8.80X8 + 9.49X9 - 5.41X7 + 0.0081\,X1X2^2$					
Standard errors	0.63	0.090	1.85	2.16	1.64	0.0004
F ratios		62.5	22.7	19.3	10.8	356.9
R^2	0.46		Correction for autocorrelation not applied.			
Standard error of the estimate	13.9		X8 not consistently significant in random subgroups of the data			

VARIABLES

Y1 Path width (m)
Y2 Bare ground (cm)
Y3 Maximum depth (cm)
X1 Recreation as percentage of estimated use of Wythburn path
X2 Path slope in degrees
X3 Cross slope in degrees
X4 1 if path width is unrestricted, 0 otherwise
X5 1 if vegetation type is <u>Calluna</u>, 0 otherwise
X6 Altitude in feet (100 ft = 30.5 m approx.)
X7 1 if path is on ridge, 0 otherwise
X8 1 if soil type is brown earth, 0 otherwise
X9 1 if soil type is podsol, 0 otherwise

7.5 ANALYSIS OF THE TOTAL DATA IN TERMS OF THE EROSION CATEGORY VARIABLE

The final part of the analysis for the total data involves the variable, erosion category, estimated for each site in terms of its erosion characteristics rather than the magnitude of path width, bare ground or depth of gullying. In an earlier section (7.3.1) it was found that sites could be grouped in terms of their erosion category and certain other variables, principally slope.

An attempt was made to find a discriminant function (Johnston, 1972, pp 336, 337) by which the two groups of sites, "eroding" and "not eroding", might be separated. However, the only variable identified as relevent to the separation of the groups was that of path slope, at a critical value of 17.5 degrees (Figures 7.4(a) and (b)). This result was very similar to that obtained by the classification attempt (section 7.3.1).

The various sites in the sample were examined, in the light of this potential "critical" angle, to investigate the efficiency of the separation of sites into "eroding and "not eroding" paths. Of the sites with path slope of 18 degrees or more, 130 were classified as "eroding", as would be predicted; 24 were unclassified and 45 were classified as "not eroding". These latter paths were termed type A paths. Of the sites with path slopes of 17 degrees or less, 232 were classified as "not eroding", as expected; 19 were unclassified and 36 were classified as "eroded". These latter sites were termed type B paths. Each site of the two groups, of type A and type B paths, was examined in turn, using field notes and data from the other variables. The following lists were made of the characteristics found for each type (Table 7.18).

It can be seen that many of the variables which could be

FIGURE 7.4 (a) Distribution of slope angles in the two erosion categories, "eroding" and "not eroding"

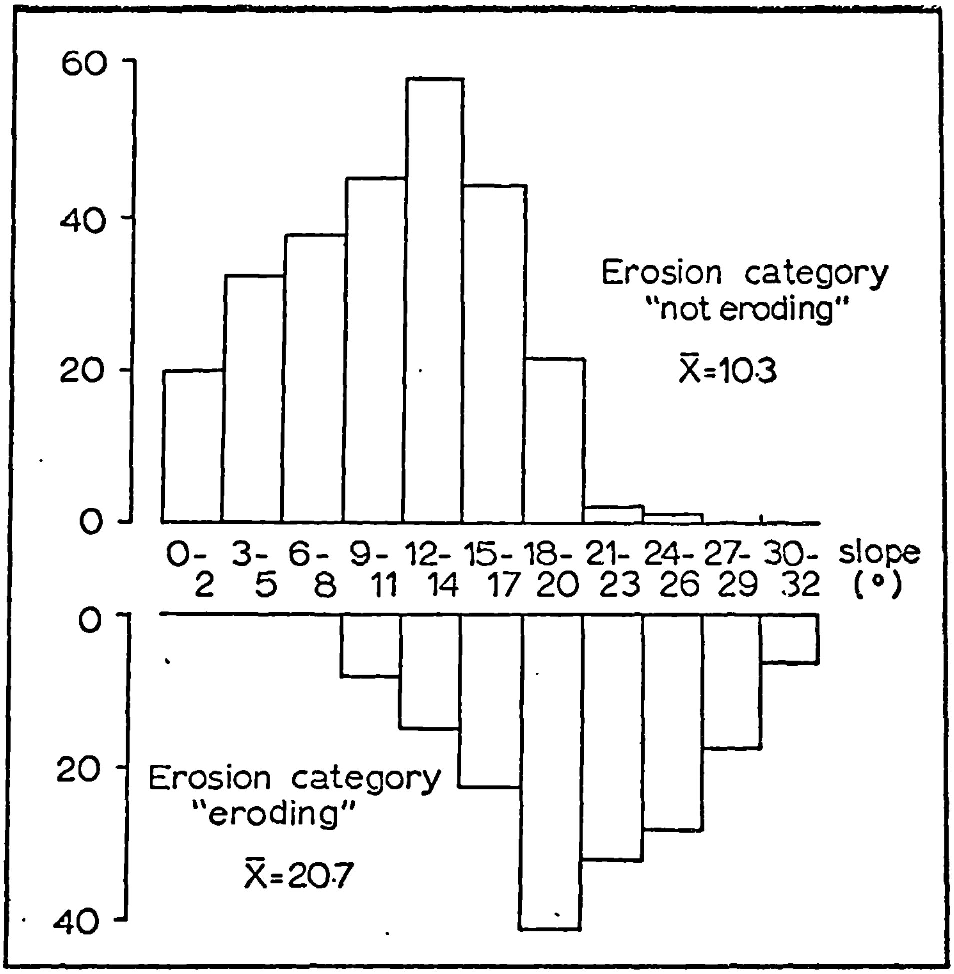


FIGURE 7.4(b) Detailed distribution of angles of (a) in the range 15-20 degress

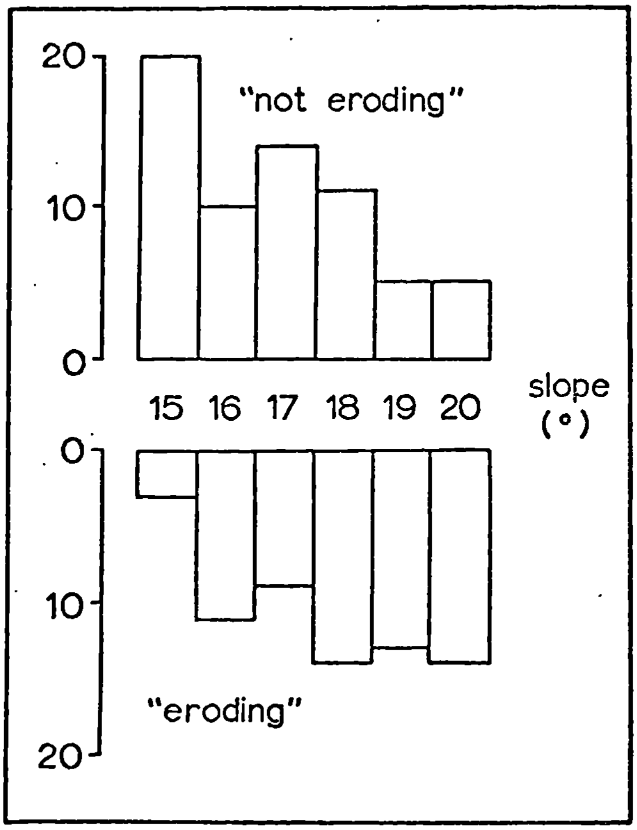


TABLE 7.18 Characteristics of sites which were not classified in the erosion category predicted by their slope angle. Type A sites are those for which it is predicted that they will be eroded, but they are not classified as such. Type B sites are those for which it is predicted that they will not be eroded, but they are classified as such.

I OBSERVED CHARACTERISTICS OF TYPE A PATHS

1. Many boulders at the surface to take path wear.
2. Very unrestricted - abundant area of grass at each side of the path
3. Very low recreation pressure.
4. Drainage at the side of the path - a small channel which drains away water so that the path tends to remain dry for long periods.
5. Low altitudes - sites with Pteridium growing on brown earths.
6. Path wear in the form of "steps" in the turf.
7. Subsoil of a fine gravel, or similar, producing an easy walking surface after erosion of vegetation and topsoil.
8. Ridge paths with bedrock near the surface.

II OBSERVED CHARACTERISTICS OF THE TYPE B PATHS

1. Very wet sites - associated often with seepage and peat deposits.
2. Sites collecting a noticeably large amount of run off, usually fed from a stream or intermittent spring.
3. Severe erosion adjacent to site, causing oversteepening of the slope and undercutting of the site.
4. Stone deposits from an eroding area of path above.
5. One site where a corner is being eroded by walkers taking a short cut.
6. Two sites with exceptionally steep cross slope, causing slumping and lateral erosion.

ALL of the sites in Types A and B groups had one or more of the characteristics from the relevent list.

predicted as relevent to erosion amounts do occur within one or other of the lists. It is also possible to see why amounts of erosion on paths are difficult to explain in a quantitative model such as linear regression. There are many factors which are relevent, but some of them may only operate intermittently in time; others may occur so infrequently over a range of sites that their effect is lost among the general variation; yet others may not operate at all, unless, or until, a certain threshold of erosion amount is achieved on a path.

In conclusion then, it was felt that the use of geomorphological and other criteria to decide whether path sites were eroding or not, had been validated by the results. The emergence of a critical angle not only suggested a useful, simple criterion for path management, but also substantiated a suggestion made by Barkham (1973) that all slopes of 15° or more might be subject to erosion.

7.6 GENERAL INFORMATION FROM THE MORPHOLOGICAL SURVEY

Although the aim of the morphological survey was to provide data for analysing the effects of various site and trampling factors, the results incidentally produced basic data for a statement of general path condition in the area.

Each path measured is listed in table 7.19 to show the approximate proportion of that path which, in 1976, (1) had bare ground width in the categories: 0 - 100 cm

101 - 300 cm
301 - 500 cm
> 500 cm

(2) had maximum depth of gullying in the categories:

0 - 10 cm
11 - 20 cm
21 - 50 cm
> 50 cm

TABLE 7.19 Proportions of the surveyed paths in different categories of "erosion state": amounts of bare ground, gullying and active erosion.

PROPORTION OF PATHS (*IN PERCENTAGES*)

PATH	Approximate width of bare ground (cm)				Approximate depth of maximum gullying (cm)				Erosion category
	0-100	101-300	301-500	>500	0-10	11-20	21-50	>50	"eroding"
A. HELVELLYN									
Browncove Crag	25	41	14	20	32	28	20	20	41
Fisher Gill	100				72	14	13		14
Dollywagon Pike	13	49	23	15	20	32	39	9	18
Helvellyn Gill	85	15			85	15			69
Swirral Edge	12	88			22	45	33		5
Striding Edge	22	42	11	25	19	40	25	16	25
Tongue Gill	27	58	6	9	15	18	55	12	51
White Stones	70	18	6	6	54	30	12	4	18
Wythburn	11	49	22	18	27	34	22	17	33
AVERAGE	41	40	9	10	38	28	24	9	30
B. NEWLANDS VALLEY									
Causey Pike	55	30	3	12	35	15	35	15	54
Causey Ridge	7	34	53	6	33	28	39		60
Grisedale Pike	66	16	16	2	73	24	3		15
Rowling End	68	28		4	28	36	28	8	44
Sail	25	53	24		14	45	40	1	53
Scar Crags	72	19	5	4	72	24	4		4
Skiddaw	13	39	31	17	13	43	33	11	56
AVERAGE	43	31	19	6	38	31	26	5	41

and (3) was deemed to be in the erosion category "eroded". The proportions are shown as percentages

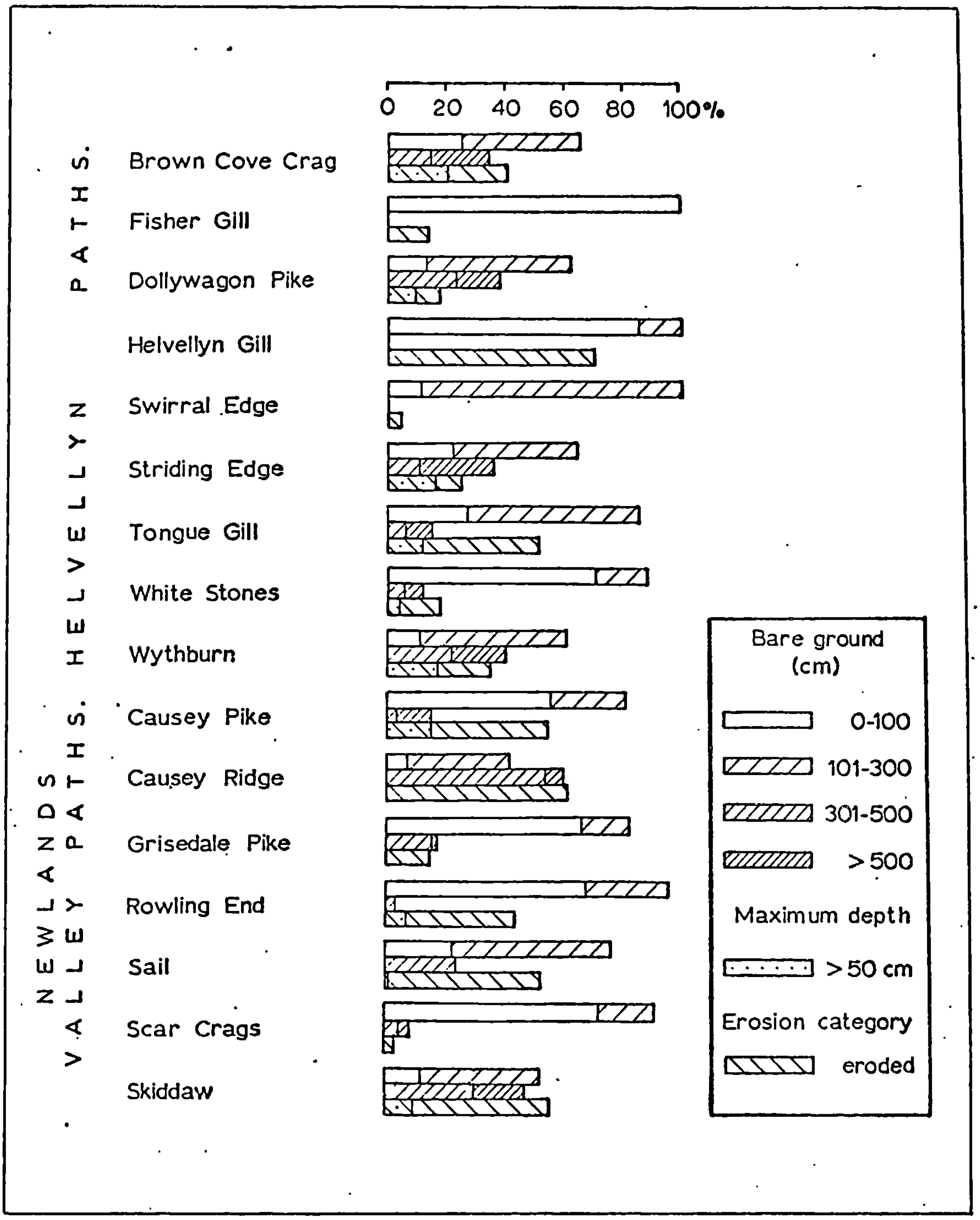
Figure 7.5 shows the main features that might be considered when identifying the "erosion state" of a path: the most important visual intrusion is possibly the width of bare ground and the pressure of severe gullying; the erosion category identifies the possible stability of a path, in terms of visual criteria for recent erosion or deposition.

Of the 16 paths, 15 have more than 50% of their length with a bare ground width of no more than 3 m, and 9 have 80% of their length in this state. On the other hand, 6 paths have more than 10% of their length with more than 5 m bare ground width and gullying deeper than 50 cm, 5 of these paths possessing both features. In terms of the proportion of the path length categorised as "eroding", 6 of the paths have more than 50% and 10 of them more than 25% categorised in this way.

It is not necessarily those paths with the greatest recreation pressure that have the highest proportion of "eroding" path; for example, Helvellyn Gill, with no part of the path with more than 3 m of bare ground, yet 69% in the "eroding" category, is not subject to heavy recreation pressure in comparison with the popular Helvellyn paths such as Striding Edge, Wythburn and Dollywagon Pike (Chapter Five, Table 5.6). Similarly it does not follow that a path with a large proportion of high values of path width also has a large proportion of the path in the "eroding" category; for example, Striding Edge has 25% of its length with a bare ground width of more than 5 m and 16% with gullying more than 50 cm deep, but, with 25% deemed to be "eroding", it is apparantly more stable than Helvellyn Gill.

It is noticeable that the less popular area of the Skiddaw

FIGURE 7.5 The erosion state of paths as measured in 1976 for the morphological survey



Slate mountains around the Newlands Valley, much of it heather moorland, appears to be more subject to eroding paths than Hellvellyn. On average, a path in this area will have 41% of its length classified as "eroding" compared with 30% on Helvellyn. Moreover, the average proportions of bare ground and gullying are not very different. Thus, possibly there is a little evidence to suggest that the Skiddaw Slates are more erodible than the Borrowdale Volcanics and that heather moorland is more susceptible to trampling than the grasslands on Helvellyn.

It is not possible to make judgements as to whether or not these figures represent badly eroded paths without making value judgements as to what constitutes an eroded path. However, it can be said that

(1) the extremes of erosion measured on these paths, that is bare ground width more than 5 m and depth of gullying more than 50 cm, are localised phenomena, averaging 9-10% of the path length in the area as a whole;

(2) erosion identified in terms of visible criteria as the presence of active processes is more widespread, averaging 35% of the path length in the area.

7.7 GENERAL CONCLUSION FROM THE FIRST TWO PHASES OF THE MORPHOLOGICAL SURVEY

Although in many ways the explanation of path erosion was incomplete, it was felt that the morphological survey had provided enough evidence, over a large number and range of site types, to demonstrate that the main differences among paths could be attributed to variation in gradient and recreation amounts from site to site. Moreover, the survey demonstrated that environmental conditions were at least as important as recreation pressure in determining the amount of erosion at a site.

Undoubtedly, factors other than path gradient and recreation were important, and the significance of the altitudinal and vegetation/soil variables demonstrated the importance of site resistance as a modifying factor on the effect of the primary forces. However, the data suggested that many of the site factors affecting the amount of erosion act intermittently, or only in conjunction with certain preconditions, and so these factors are harder to identify in any systematic analysis.

It was considered worthwhile to investigate some of the unexplained path variation in greater detail, to attempt to remove the effect of sone of the main variables and consider some of the other factors. Of greatest interest was the effect of differences in the materials comprising the soil and regolith horizons and this is discussed in chapter eight.

The data from the survey demonstrated that, as yet, the extremes of erosion found in the study area were localised, but that erosion processes were apparantly active on about a third of the total path length studied.

CHAPTER EIGHT

THE ANALYSIS OF PATH MATERIALS

8.1 PRELIMINARY SOIL SAMPLING

One factor which was expected to contribute to variation in path morphology, and which, so far, had not been considered in any detail, was the influence of soil and regolith materials on path erodibility. Prior to any survey to examine the materials as a factor, some field work was undertaken

(1) to investigate soil characteristics in the area, and to identify problems of measurement,

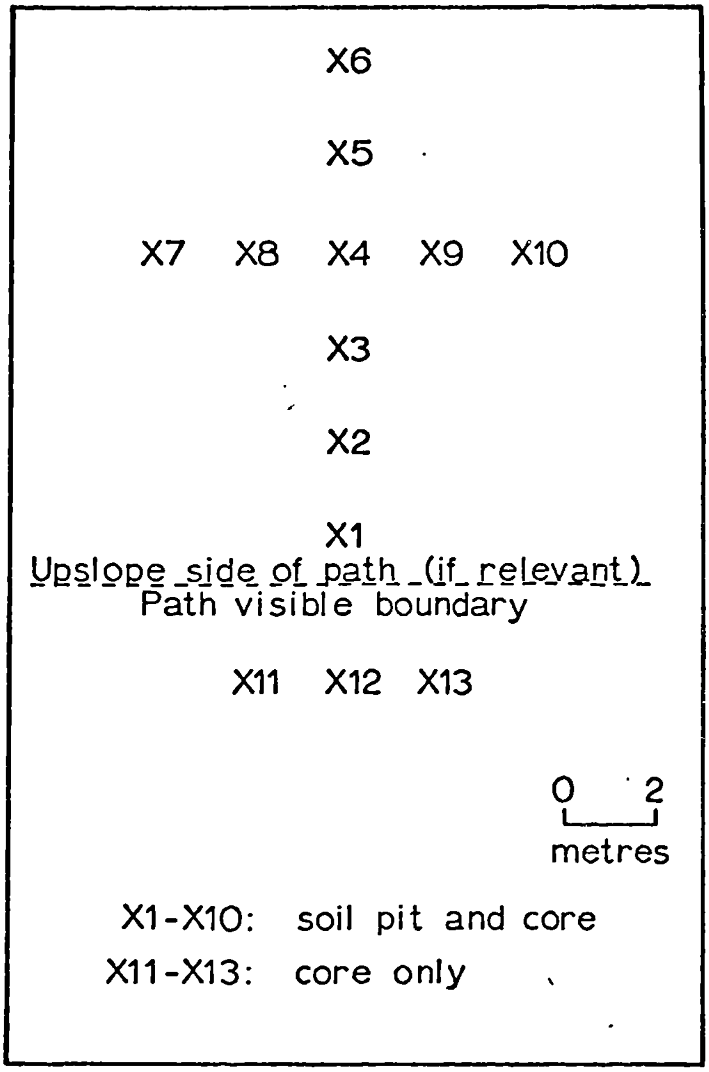
(2) to examine soil variability and the problem of predicting path materials from adjacent sites.

8.1.1 Methods of soil sampling and measurement

Four sites were investigated, reflecting the main soil types expected, namely brown earths, brown podsolic soils, podsols, and peat rankers. All of these soils were easily accessible on the Causey Pike path.

Core samples were taken from the top 12-15 cm of the mineral soil, and pits of approximately 1500 cm^2 area were dug to a depth of 30-40 cm, or the underlying rock, whichever was the lesser distance. Thirteen samples were taken, arranged as in figure 8.1 so that any systematic variation away from or parallel to the path might be identified. The four samples from and closely adjacent to the path were taken

FIGURE 8.1 Sampling in the preliminary soil analysis



as core samples only.

Properties measured in the field were:

1. dominant vegetation
2. depth of undecomposed litter/roots
3. depth of humus/peat
4. depth of humus surface to base of mineral A horizon
5. depth to base of mineral B horizon
6. depth of iron pan
7. presence of gleying

Properties measured in the laboratory were:

1. moisture content of top mineral soil horizon - moisture as a percentage of oven dried sample of fine earth (fraction less than 2mm)
2. organic content estimate - percentage reduction of fine earth by oxidation, using hydrogen peroxide.
3. dry bulk density - the ratio of the mass to the volume of the core sample
4. stone content of top mineral soil - fraction greater than 2mm dia.
5. percentage of silt and clay in fine earth fraction - that proportion passing sieve size 63 µm
6. percentage of fine sand, silt and clay - passing sieve size 250 µm
7. number of large stones - those with intermediate axis greater than or equal to 5 cm - expressed as the number per m^3

In addition, site slope, aspect, altitude and overall soil and vegetation type were recorded.

8.1.2 Results

The results (Tables 8.1 (a) - (d)) indicate that there is no systematic effect on soils either away or parallel to the paths measured. Moreover, the effect of the path not only

TABLE 8.1 (a) Preliminary soil sampling, site 1 (Site positions as in figure 8.1.)

SOIL PROPERTY	ON PATH			AWAY FROM PATH ⟶						PARALLEL TO PATH				
	11	12	13	1	2	3	4	5	6	7	8	4	9	10
Dominant Vegetation	Agrostis-Festuca			← - - - Pteridium - - - →						← - - Pteridium - - - →				
Litter/roots depth (cm)					3.0	3.0	3.0	3.5	3.0	3.0	2.5	3.0	3.5	3.5
Humus/peat depth (cm)					6.5	6.0	8.0	9.0	7.0	8.0	6.0	8.0	6.5	6.5
Mineral A horizon (cm)														
B horizon (cm)				← - - - Greater than 35 - - →						← - Greater than 35 - →				
Moisture % dry weight	61	89	68	110	104	99	100	93	182	117	124	100	107	100
organic %	2.0	1.7	1.9	2.3	2.5	2.4	2.2	2.6	2.2	2.5	2.7	2.2	2.2	2.2
Bulk density (g/cm^3)	2.4	2.2	1.4	1.7	0.9	1.1	1.8	1.6	1.5	1.5	1.3	1.7	2.1	1.2
% stones (topsoil)	47	71	52	42	59	44	59	52	43	65	65	59	61	48
% silt & clay (topsoil)	28	19	21	27	16	16	18	14	24	8	26	18	19	18
% fine sand, silt & clay (topsoil	47	31	35	47	30	32	32	27	34	24	36	32	34	33
Number of stones in subsoil ($no./m^3$)					1450	1030	1640	1375	1970	1970	1120	1640	2400	1150

<u>Other observations:</u>

Vegetation	*Pteridium* dominant, *Agrostis-Festuca*, occasional *Vaccinium*, mosses.
Soil type	acid brown earth, Pteridium roots deeper than 35cm.
Slope	21 degrees, diagonally across path.
Aspect	033 degrees.
Altitude	900 ft (275m).

TABLE 8.1 (b) Preliminary soil sampling, site 2 (Site position as in figure 8.1)

SOIL PROPERTY	SITES: ON PATH			AWAY FROM PATH ⟶						PARALLEL TO PATH				
	11	12	13	1	2	3	4	5	6	7	8	4	9	10
Dominant vegetation	Agrostis-Festuca			← – – – *Vaccinium* – – – – →						← – – *Vaccinium* – – – →				
Litter/roots (cm)					4	4	5	6	4	4	11	5	6	9
Humus/peat (cm)					10	10	10	13	11	10	16	10	9	12
Mineral A horizon (cm)					••	••	20	24	••	16	21	20	12	16
B horizon (cm)				← – – – Greater than 30 – →						← – Greater than 30 – →				
Iron Pan (cm)							25•	27•		18•	21•	25•		16•
Moisture % of dry	84	84	53	78	112	117	105	122	108	106	125	105	111	135
Organic %	2.1	1.9	1.9	2.0	2.0	1.9	1.9	2.4	1.9	1.7	2.3	1.9	1.8	2.2
Bulk Density (g/cm^3)	2.1	1.7	2.0	2.2	1.8	1.5	1.9	1.7	1.6	2.0	1.7	1.9	2.0	1.6
% stones (topsoil)	39	47	59	50	57	46	44	43	55	47	28	44	48	55
% silt/clay (topsoil)	62	57	70	52	46	70	45	73	74	57	63	45	60	65
% fine sand-clay (topsoil)	68	63	75	60	60	75	68	79	78	62	73	60	64	73
no. stones in subsoil (no. m^3)					1270	1100	1050	1550	2130	1820	980	1050	1340	1770

NOTE (1) •• not differentiated, (2) • discontinuous

Other observations:

Vegetation	*Vaccinium*, mosses.
Soil type	brown - occasional podsolic tendency, with elluviated mineral A horizon.
Slope	30 degrees, across path.
Aspect	035 degrees.
Altitude	1100 ft (335m).

TABLE 8.1 (c) Preliminary soil sampling, site 3 (Site position as in figure 8.1).

	SITES													
SOIL PROPERTY	ON PATH			AWAY FROM PATH ⟶						PARALLEL TO PATH				
	11	12	13	1	2	3	4	5	6	7	8	4	9	10
Dominant vegetation	A-F	A-F	A-F	V-C/A-F	V-C	V	V	C	V-C	C	C	V	C	S
Litter/roots (cm) Humus/peat (cm)	not clearly differentiated				12	13	15	10	12	16	13	15	12	13
Mineral A horizon (cm)					18	20	24	15	18	22	20	24	19	20
B Horizon (cm)					greater than 30			27	← — — greater than 30 — — — — →					
Iron pan (cm)								15	18	22	20			
Gleying								15-18 cm	20 cm					
Moisture %	55	80	79	76	93	62	69	56	61	79	74	69	63	61
Organic %	2.2	2.2	2.0	1.7	2.3	1.5	1.7	1.4	1.7	1.6	1.6	1.7	1.5	1.4
Bulk density (g/cm^3)	1.8	1.8	1.3	1.9	2.2	2.4	1.7	2.5	1.5	2.1	2.1	1.7	2.2	2.0
% stones (topsoil)	58	48	42	56	19	30	14	16	27	8	7	14	8	25
% silt/clay (topsoil)	77	66	73	80	90	77	85	79	83	84	83	85	73	85
% fine sand-clay (topsoil)	83	73	78	85	93	82	90	82	90	91	92	90	80	91
no. stones in subsoil					1780	1590	1280	1660	1060	950	1100	1280	1850	1270

V - Vaccinium

C - Calluna

S - Sphagnum

A-F - Agrostis-Festuca

Other observations:

Vegetation	Calluna dominant but also Vaccinium and Sphagnum spp.
Soil type	Podsolic with intermittant iron pan.
Slope	23 degrees, parallel to path.
Aspect	040 degrees.
Altitude	1250 ft (381 m).

TABLE 8.1 (d) · Preliminary soil sampling, site 4 (site positions as in figure 8.1)

SOIL PROPERTY	SITES													
	ON PATH			AWAY FROM PATH ⟶							PARALLEL TO PATH			
	11	12	13	1	2	3	4	5	6	7	8	4	9	10
Dominant vegetation	*Juncus squarrosus* throughout													
Litter/roots cm Humus/peat (cm)	Peat throughout				23	10	25	22	24	21	10	25	25	15
Mineral A horizon (cm) B horizon (cm)	Peat and stones throughout				25	25	28	24	28	26	25	28	25	30

Other observations:		
	Vegetation	*Juncus scuarrosus*, occassional *Nardus*, *Sphagnum*
	Soil type	Peaty ranker.
	Slope	14 degrees, down the path.
	Aspect	038 degrees.
	Altitude	1500 ft (457m).

appears to be small, but also does not seem to extend far beyond the visible limits of trampling. This agrees with the results obtained by Dale and Weaver (1974) who found little effect beyond 1-2 m on Rocky Mountain forest trails.

The most difficult problem encountered in taking the measurements was that of obtaining a core sample. The high stone content of all the soils meant that resistance of the soil to the entry of the corer was variable and often high. Consequently, compaction of the soil frequently occurred during core insertion and this may have been the cause of the consistently high values obtained for bulk density. If cores were to be used at all, it was evident that they would have to be large to minimise the resistance of the stones.

It appears that it is reasonable to assume that soils pre-dating the path would have similar characteristics to those about 2m or so beyond the present path boundaries, although, of course, there is no means of knowing whether the present soils have remained constant over the time of path development. It is also clear that for some variables there is a considerable range of values within the site.

8.2 SAMPLING AND VARIABLES FOR THE MATERIALS ANALYSIS

8.2.1 Sampling

In any consideration of the effect of differences in materials upon the amount of footpath erosion, it was thought that it was desirable to control for the effect of slope. It is evident, from the results of the morphological survey, that path slope is a crucial variable and that, for erosion to be extensive, a fairly high value of slope is required. Thus, if the erosion of different materials is to be studied, it would seem logical to standardise path slope as far as possible at a fairly high value, in order that any materials effect might become relevent. It was also desirable to standardise the paths studied with respect to recreation amounts, so that any analysis would not have to depend upon a variable so difficult to measure. However, this proved to be impossible because there was not a sufficient range of environmental conditions on any one path.

The remaining constraint put upon the sampling was that the path sections chosen should have zero or near zero cross slope. The reason for this criterion was that the effect of cross slope is to complicate the path morphology; for example, steep cross slopes affect the manner in which walkers use the path, they enhance the slumping effect of materials and they make the estimation of depths of erosion very difficult to carry out.

Although it was theoretically desirable to limit the range of other relevent environmental variables, this was not possible in practice, but an attempt was made to improve the estimates of such factors as the amount of water running down the path and to improve the sampling estimates of the amount of path erosion

The sites chosen for analysis were therefore taken from several paths, with the limiting criteria that

(1) path slope should be constant as possible, within the range of 20-25 degrees, and cross slope should be zero or near-zero;

(2) the path should have an existing estimate of recreation pressure from the morphological survey, and the estimate should be as reliable as possible;

(3) within each path, there should be three suitable sites so that at least a limited amount of "within path" comparison

could be possible.

These criteria proved to be difficult to satisfy, but nine suitable paths were obtained, yielding a total of twenty seven sites, which are listed in table 8.2.

8.2.2 Variables

Many of the variables measured were the same as those for the second phase of the morphological survey, but some improvements in either precision of measurements or accuracy of definitions were attempted. The variables and the method of their measurements are listed below.

(1) Recreation force and distribution

This was measured in the same way as in the main morphological survey (section 7.1.1 and table 7.3) but in addition, an estimate was made of average vegetation height at each site, since it was thought that vegetation height was an indication of the constraining effect of site vegetation, to encourage users to keep to the path. An average of ten readings at each site was used.

(2) Path morphology

At each site chosen, a central 10 m section was taken and divided into five 2 m sections. For each section, a transect across the path was located randomly and the parameters, path width, bare ground, maximum depth and the depth every 10 cm were measured, as in the morphological survey, but the results were averaged for each site.

(3) Geomorphological forces, soil and vegetation resistance

The variables measured in the morphological survey were used, but with one change and one set of additions. Water run off had been estimated in categories in earlier work, but for this stage, a change was made to a method which, it was hoped would give a more accurate estimate. The catchment area for

TABLE 8.2 Paths sampled for materials characteristics.
(three sites on each path)

PATH		GRID REFERENCE OF SITE
Brown Cove Crag	1	NY32751620
	2	NY32901595
	3	NY33051590
Causey Pike	1	NY22852105
	2	NY22452100
	3	NY22352090
Dollywagon Pike	1	NY34951250
	2	NY34801265
	3	NY34751275
Grisedale Pike	1	NY22752355
	2	NY22302350
	3	NY21102290
Helvellyn Gill	1	NY32101665
	2	NY32251660
	3	NY32351655
Rowling End	1	NY23152090
	2	NY23102075
	3	NY20002070
Skiddaw	1	NY28002625
	2	NY27902645
	3	NY27852660
Tongue Gill	1	NY34851090
	2	NY34801110
	3	NY34851120
Wythburn	1	NY33201360
	2	NY33651355
	3	NY33901375

water draining in to the site was estimated by assuming that it would be proportional to the distance from the nearest watershed. This watershed was identified in the field from the topography taking account of the fact that local concavities and convexities would divert drainage from the site even if it was situated near the bottom of a slope. The distances were measured using maps and air photographs for lengths greater than about 100 m. The contribution to site run off from further up the path was assumed to be partly proportional to the length of the path dnaining into the site. The distance up the path to a point at which drainage water was diverted down the hillside, rather than the path, was measured. The point at which water is diverted off the path can be identified by breaches in path sides, small channels down the hillside, deposits of earth and gravels, and differences in vegetation. The additional set of variables was that of the materials characteristics. The characteristics measured were far from comprehensive, but the nature of the terrain and that of the soils imposed severe restrictions on what might be carried out with the resources available. Two important limiting factors were the variability of the various soil characteristics expected within a site, which required a large number of soil samples for each site, if the results were to be at all representative, and the stoniness of the soil, which rendered core sampling difficult and hence also many of the soil measurements which depend upon core sampling. In the event a compromise was made between taking a large enough number of samples to cover the site area and thus the possible nature of the soils preceding the formation of the path, and the time factor that would have been involved in digging many soil pits. Ten samples were taken from auger holes and bulked for subsequent analysis. The ten samples were taken within the stratified random sampling framework used to obtain the path transects. One problem encountered in taking the soil samples was the decision that had to be made about the depth of sampling. For the peat rankers, soil depths are minimal, but for some of the brown earths, several metres of mineral material can be observed in exposures on, for example, stream banks, and it is difficult to define where the soil/regolith boundary lies; many of these soils are developed on fine materials deposited by periglacial processes (Boardman, 1977). Ideally, samples should probably be taken at different horizons, but the soils are very stony in their lower horizons and often consist of dense compacted and interlocking layers. It seemed reasonable, therefore, to concentrate on the upper horizon; the character of this horizon would determine the erodibility and the initial incision of the path, and almost certainly would be of lower bulk density than the lower compacted layers; hence it would affect the rate of throughflow through the soil From fieldwork so far, a depth of 20 cm appeared to be sufficient to establish the character of most top soil horizons, although there would obviously be problems with the thin rankers, which would have to be considered separately. Other research workers have shown that most of the rapid throughflow occurs in the upper horizons (Whipkey, 1965; Arnett, 1974), and that the depth through which this flow occurs depends upon the type of soil and the slope. The choice of 20 cm was therefore somewhat arbitrary, but it was thought to be reasonable in view of the steepness of the slopes being sampled and the depths of the A horizons of the podsols and podsolic brown soils, which were unlikely to be much greater than 20 cm at many sites.

In addition to the soil samples, the depth of the humus layer was recorded, and also the depth to which the soil could be augered, this being a measure of the amount of relatively stone-free, uncompacted soil. A cone penetrometer was used to try to measure soil resistance to compaction, but this proved to be inadequate because of the number of stones, which made it impossible to tell what the readings were really measuring. All measurements were taken at ten points and later averaged. On the path surface, a measure of the residual particle size was taken by recording the length of the intermediate axis of the ten largest particles along each transect. Where relevent, other soil properties which were observed were noted; for example, the presence of iron pans or gleying.

In the laboratory, the following soil parameters were measured:

(1) moisture content, as a percentage of the dry weight of the soil fraction less than 2 mm, was obtained by oven drying at 105°C;

(2) organic content was estimated by oxidation with hydrogen peroxide. (Although not very accurate, the method provided a means of analysing a larger sample at one time than would have been possible with the "loss on ignition" method. Moreover, it formed part of the preparation of the sample for particle size analysis);

(3) particle size analysis was carried out in four stages:

  (a) oxidation of organic material

  (b) dispersion of aggregates - by the addition of sodium hexametaphosphate and mechanical stirring

  (c) wet sieving - to separate stones, coarse, medium and fine sands, and finer fractions.

  (d) pipette analysis - to estimate proportions of medium and fine silt, and clay. Coarse silt fraction was obtained by subtraction of the other fractions from the total sample weight.

Thus the particle size distribution obtained was within the categories:

stones	greater than 2000 µm
coarse sand	2000 - 600 µm
medium sand	600 - 210 µm
fine sand	210 - 63 µm
coarse silt	63 - 20 µm
medium silt	20 - 6 µm
fine silt	6 - 2 µm
clay	less than 2 µm

A summary of all the variables measured in the field and laboratory is given in table 8.3

8.3 RESULTS AND ANALYSIS

8.3.1 Variable Groupings

Certain environmental groupings had emerged from the preceding analysis (Table 7.6). With the addition of some materials characteristics, it was hoped that potential groupings of variables might be identified using factor analytical techniques or simple linkage analysis of correlation coefficients (Gregory, 1976). It seemed possible that there might be three main factors, representing

(i) environment (soil, vegetation, climate)

(ii) geology

(iii) hydrology

In addition to this, it was hoped that the materials characteristics which had been measured might help to identify reasons for the significance of the soil types, brown earths and podsols, in the maximum depth of gullying found on paths (Table 7.17).

TABLE 8.3 Variables measured in the survey and analysis of materials characteristics

PATH MORPHOLOGY	path width bare ground maximum depth depth every 10 cm erosion category residual particle size
RECREATION PRESSURE	recreation counts path restriction* presence of boulders* presence of permanent wetness* vegetation height
GEOMORPHOLOGICAL PROCESS AND SOIL AND VEGETATION RESISTANCE	vegetation type* soil type* water run off of site and path altitude aspect organic horizon type* geology* peat/humus depth soil depth cone penetrometer index value soil moisture content soil organic content stone content particle size distribution
OTHER FACTORS	erosion category of path above and below path slope any other relevant site details

*variables recorded at the nominal scale

(a) Variable groups analysis This was investigated (for the variables measured on a continuous scale) using factor analysis, with and without rotations, and linkage analysis, with both product moment and rank correlation coefficients. The results of the groups were virtually the same, but disappointing in that neither factors nor groups were clearly distinct. In the factor analyses, most of the data variance was accounted for by the first factor; in the linkage analysis, most of the variables could be joined in one group. The following associations were consistently identified by whichever method was being used:

altitude, vegetation height, soil depth;
site run off and moisture content;
percentage coarse medium and fine sand;
percentage clay, fine and medium silt.

The association of these variables became significant for the regression analysis undertaken later, since not more than one out of each group was used at a time.

(b) Soil types It was possible that different soil types would be reflected in values of the materials parameters, and that the effect of geology might be significant. Average values were therefore calculated for the different groups (Table 8.4).

The effect of geology does not appear to be very marked except for the greater silt content of soils developed on the Skiddaw Slates. More important appears a certain difference between the soil types. Generally, as has already been noted, the soil types are altitudinally zoned and reflect both this and the materials on which they are developed. The brown earths are deeper and developed on relatively fine periglacial deposits. The augerable depth tends to be deeper and the residual particle size tends to be smaller than those of the

TABLE 8.4 Average values of the materials parameters for the different soil types and lithologies

VARIABLE	SKIDDAW SLATE	BORROW. VOLCANIC	BROWN EARTH	BROWN PODSOLIC	PODSOL	PEAT RANKER
% clay	16.3	21.2	15.5	24.0	12.1	23.9
% silt	62.6	40.5	50.6	47.2	53.7	50.6
% sand	21.1	38.3	33.9	28.8	34.2	25.5
% stones	25.8	20.1	29.8	19.9	15.6	19.8
residual particle size (mm)	40.3	48.9*	29.8	43.5	81.4	58.8**
% organic	2.6	4.3	3.0	2.7	3.9	4.8
% moisture	66.6	59.1	69.6	67.8	68.0	49.9
augerable soil depth (cm)	22.0	28.2*	34.6	22.0	21.5	17.7**
no. in group	12	11	8	7	2	6
		*15				**10

other soil types; there also is apparantly a similarity between the brown earths and the podsols in respect of the relative amounts of clay, silt and sand, both soil types being slightly coarser than the brown podsolic soils and the poorly developed peat rankers. The effect of these characteristics can only be surmised, but probably the brown earths allow more infiltration and so may generate less surface run off and near-surface throughflow; hence they would generally be expected to produce less water for erosion on the path. The infiltration characteristics of the brown earths are affected by their predominant vegetation as well as the soil; deep penetration of Pteridium rhizomes creates numerous channels down which water may infiltrate. Rhizomes can be observed at depths of a metre or even more and their effect has been suggested as important by Arnett (1974) from studies of throughflow in an upland area in Yorkshire.

Since there are only two podsol sites, the results of any of the soil parameters may not be at all representative of other podsols. However, the underlying iron pan, even if only intermittant, as was found under all the podsols observed in fieldwork in this area, would be expected to impede drainage at a level relatively near to the surface, and so would be expected to produce more run off than say a brown earth or brown podsolic soil. The peat rankers are a shallow group of soils and must also produce rapid run off, but these are developed on the upper slopes and so the water catchment area is relatively small.

The finer materials (residual particle size) of the brown earths might be expected to render them more erodible, but observation of rapidly eroding gullied sites during the monitoring programme showed that during periods of high run off, sufficient water was generated to move most sizes of particles. It is therefore suggested that the observed differences in the morphological survey data, namely that depth of gullying on paths is less for brown earths and more for podsols, is more likely to be a result of different infiltration and run off characteristics than of the particle size distribution of either the fine earth fraction or the stones. Such suggestions are, however, only tentative.

8.3.2 The relation between erosion and site variables

Much of the potential problem in relating path erosion to site variables which were highly related was alleviated by the fact that relatively few of them proved useful for explaining path variation. In some cases this was because the variables proved to have little variation themselves, for example path restriction.

Analysis was by regression, in the manner used in chapter seven. From the variable groupings established, it was possible to ensure that highly intercorrelated variables were not used in any one regression analysis. Most of the variables were used as measured, but for the run off variable, an attempt was made to combine the potential catchment area with the length of path above draining into the site. This was done by using the product of the path length and the distance from the watershed, and was introduced because of the failure of either variable, on its own, to be relevant. In addition to regression trials using the variables measured at a ratio scale, variables defined in categories were introduced, using dummy variables.

The highest correlationswere obtained between path morphological measures and residual particle size. However, this poses some problems for interpretation. For most of the sites, the greater the erosion and hence the higher the values of path width, bare ground and depth of gullying the larger is the material remaining on the path surface. This results, at least in part, from the fact that as path erosion cuts through successive soil and regolith horizons, the materials generally become coarser. Thus, residual particle size is really only interesting when its value is small in the presence of extensive erosion, for then it may well have contributed to the erodibility of the lower horizons, or when its value is large for little eroded sites, when the converse applies.

Excluding residual particle size, the best explanation of the data variance was found in terms of variables similar to those of the morphological survey in chapter seven. Path width could be accounted for using recreation pressure and either vegetation height or vegetation type, with a marginal advantage with the latter. Since vegetation type is easier to record, and it can be recorded from air photographs, it is to be preferred.

Variation in amounts of bare ground was accounted for by the altitude variable; that in depth of gullying by the proportion of clay, in the top 20 cm of mineral soil, and by the soil type.

The regression relationships are given in table 8.5 from which it can be seen that, apart from path width, for which 76% of the variation is accounted, the levels of explanation are not very high - 47% and 43% respectively. The samples are not very large, but even so, the results are consistent with those of the main morphological survey.

It should be recalled that the main purpose of this small survey was to examine selected soil parameters. The only path variable for which any of the measured soil parameters was as relevant as the simple variable, soil type, was the

TABLE 8.5 Regression equation obtained from data gathered for the materials analysis

EQUATION	R^2	SAMPLE SIZE
$Y1 = 0.57 + 1.57\sqrt{X1} - 3.94X4 + 1.83\ X5$	0.76	27
$Y2 = 140.0 + 0.37\ X2$	0.47	27
$Y3 = 35.9 + 0.86\ X3 - 14.90\ X6 + 15.97\ X7$	0.43	23

VARIABLES

Y1 path width (m)

Y2 bare ground (cm)

Y3 maximum depth (cm)

X1 recreation pressure

X2 altitude (ft)

X3 percentage clay in first 20 cm of mineral soil

X4 = 1 if vegetation is *Pteridium*

0 otherwise

X5 = 1 if vegetation is *Calluna* dominated, with other heath types

0 otherwise

X5 = 1 if soil type is brown earth

0 otherwise

X6 = 1 if soil type is podsol or peat ranker

0 otherwise

maximum depth of gullying on a path. For this variable, the clay content of the top soil appeared to be useful in explanation, contributing 0.10 to a total value of R^2 to 0.40. The clay percentage acts positively in the equation; that is to say, greater depth of gullying occurs on paths with sites with higher percentages of clay in the topsoil. However, there is little real difference in particle size distribution among the soil samples; the results obtained in the regression may be due to chance.

It should also be noted that no relevant contribution was found from any of the path run off variables. Indeed, the relevant variables appear to suggest that infiltration rates and their concomitant run off and throughflow rates are more instrumental in determining the amount of water running down a path than hillside catchment area. This is similar to the findings of Arnett (1976).

Although the results of the materials analysis are rather negative, they do emphasise the difficulty encountered in trying to establish complete explanations of such a complex system. Footpaths develop and are eroded by a series of site characteristics which can be expressed theoretically, but which are difficult to identify or measure in the field over a large number of sites. Path run off is just one of these difficult factors; the real force generated by recreation is another. Given the fluctuations that occur due to variations in season, weather and the occasional catastrophic erosion event, it is probably unrealistic to expect more from the type of data which was obtained, and indeed that can be easily obtained. It seems likely that to procure more complete explanations of footpath development, controlled experiments are needed, in which inputs to the path system can be measured, rather than relying upon deductive inferences from survey data.

8.4 CONCLUSIONS TO THE NORPHOLOGICAL SURVEY

The results of the two phases of the main morphological survey and the survey of selected sites for materials analysis lead to the following conclusions:

(1) reasonable estimates of the probable size of the path and the extent to which it is gullied and unvegetated can be made from simple measures of recreation pressure and gradient. Additional and useful information may be obtained using simple environmental variables, altitude, vegetation and soil type;

(2) an approximation as to whether to not erosion is likely to be operating on a path may possibly be made using a threshold slope value, apparantly 17/18 degrees on the paths measured;

(3) many quasi-unique site factors appear to operate at some path sites, which makes comprehensive analytical explanations difficult to obtain;

(4) many theoretically important variables are difficult or impossible to define and/or measure precisely because

(a) the area is environmentally highly complex, and standardised sites for use in examining selected variables are not easily found,

(b) certain environmental variables require spatially intensive and, in the case of water flow, sometimes frequent sampling, but the terrain makes this exercise difficult and time consuming,

(c) the presence of the public in a popular recreation area restricts use of complex and expensive monitoring equipment, and itself as a variable is almost unmeasurable in terms of the real force exerted on the different parts of the footpath system.

These conclusions may justify the choice of a broad based approach, taking simple measurements and observations over a wide area rather than concentrating on a few sites. As noted by Bayfield (1973(a)), much of the criticism of research in recreation ecology stems from the lack of comparibility between sites studied. However, it is apparant that to undertake comparative analysis of many sites, such as in this study, complex ecological measurements would require a substantial committment of resources.

CHAPTER NINE
THE EXPERIMENTAL FOOTPATH AT BRADFIELD

9.1 THE FIELD EXPERIMENT

As already mentioned, without some control over the inputs and outputs of a system, it is difficult to establish the relative effects of the different processes which may be operating. In view of the impossibility of controlling the inputs to a public path, it was decided to create an experimental path, measure the inputs of rainfall and trampling, then compare these with collected outputs of water and sediment. The change in form of the path could be monitored by measuring successive profiles. Any such site had to be accessible at all times of the year, for daily visits if necessary, and so a site was obtained at Bradfield, north-west of Sheffield (Grid Reference: SK 276925).

9.1.1 Description of site and experimental paths

(a) The site was a south-west facing slope, with an average gradient of 17-18 degrees. The situation was just below the crest of the hill at the top of the valley slope which dropped 200 m in altitude to the valley floor, about 1200 m in distance. The land, used as rough grazing for cattle in the summer was covered with a mixture of moorland heath plants and grasses, with other flowering plants. The grass areas were compacted by grazing cattle and the soil was hard in summer; thus, in many ways, the surface resembled that of a well trampled path before the loss of any vegetation cover. The field was private with no public right of way. The soil at the site, investigated by taking five small cores at the end of the experimental period, was a sandy silt loam, with few stones, developed over gritstone blocks a metre or less below the surface. In respect of the soil, the site differed from the paths found in the Lake District, which were abundantly supplied with stones, and those soils varied from sandy silt loams to silty and silty clay loams.

(b) In June 1977, a small area was fenced to exclude cattle and two parallel paths were prepared. Path A was designed to represent the early stages of footpath development from grass to bare soil; path B was to represent a later stage with a small amount of incision. The incision was artificially created by digging out the grass and soil to a depth of 8-10 cm; the worn path was started by trampling and scraping the grass with climbing boots. Both the worn and incised path were allowed a period of just over two months, during which time trampling was maintained, in order that each might come to a state similar to that of natural paths. By September, the paths had reached the desired state (Plate 10) and measurements were commenced.

9.1.2 Measurement at the site

(a) Input The Department of Geography meteorological station was only a short distance away from the site, 500 m away at the top of the hill. It was therefore assumed that rain falling at the site would be similar to that recorded at the station. It was recorded automatically as the number of tenths of a millimetre falling per ten minute intervals. A funnel and container was kept on the ground near the two paths, collecting rain falling at the site, for comparison.

Trampling input was measured as the number of up and down passages. Trampling was carried out in blocks of 25 passages, 25 up and 25 down, with a minimum of zero and a maximum of 100, allocated on a random basis.

(b) Output Water and sediment were collected in Gerlach type troughs (Gerlach, 1967) at the end of the paths (Plate 9) each trough with a capacity of about 15 litres. However, it seemed likely that path run off might exceed this on many occasions and so the troughs were connected to overspill plastic containers giving a total capacity of approximately 24 litres for each trough.

(c) Profiles Profile measurements along and across each path were made from a framework running parallel to the paths (Plate 10). This framework was secured in position by a series of supports of angle iron, inserted into the ground at intervals of about a metre, the whole structure being bolted together to make a rigid support for the measuring bar. The metre long measuring bar was of box cross-section steel, along which a carrier could slide, holding a stainless steel rod. The position of both carrier and the rod could be locked in position by screws. The measuring technique was therefore very similar to that used in the bar transects. The distance from the bar to the top of the rod was measured and subtracted from the length of the rod, 0.5 m, to give the depth of the path below the bar.

Profile measurements were made across the path at fixed points, whose position was determined by a nut and bolt. Eight profiles were used on each path, each about a metre apart. Since the bar was fitted with a sliding carrier for the rod, any number of positions could be measured, but the bar was marked in 2 cm intervals and so most points were taken either 2 or 4 cm apart.

PLATE 9 Covered troughs to collect water and sediment from the Bradfield paths

.

P ATE 10 Angle iron framework from which profile changes were measured on the Bradfield paths

Profile measurements were made at approximately two monthly intervals after the beginning, September, 1977, but some were missed in the winter period because snow lay on the ground.

As far as possible, the troughs were emptied after each rainfall event, that is the passage of a front or a period of showers. A total of 52 events was monitored, from 8 September, 1977 to 2 September 1978, but these included some amalgamated storms when it had not been possible to visit the troughs at the site, and some long periods when the ground was snow covered.

9.2 RESULTS AND ANALYSIS

9.2.1 Effectiveness of monitoring

(a) Rainfall

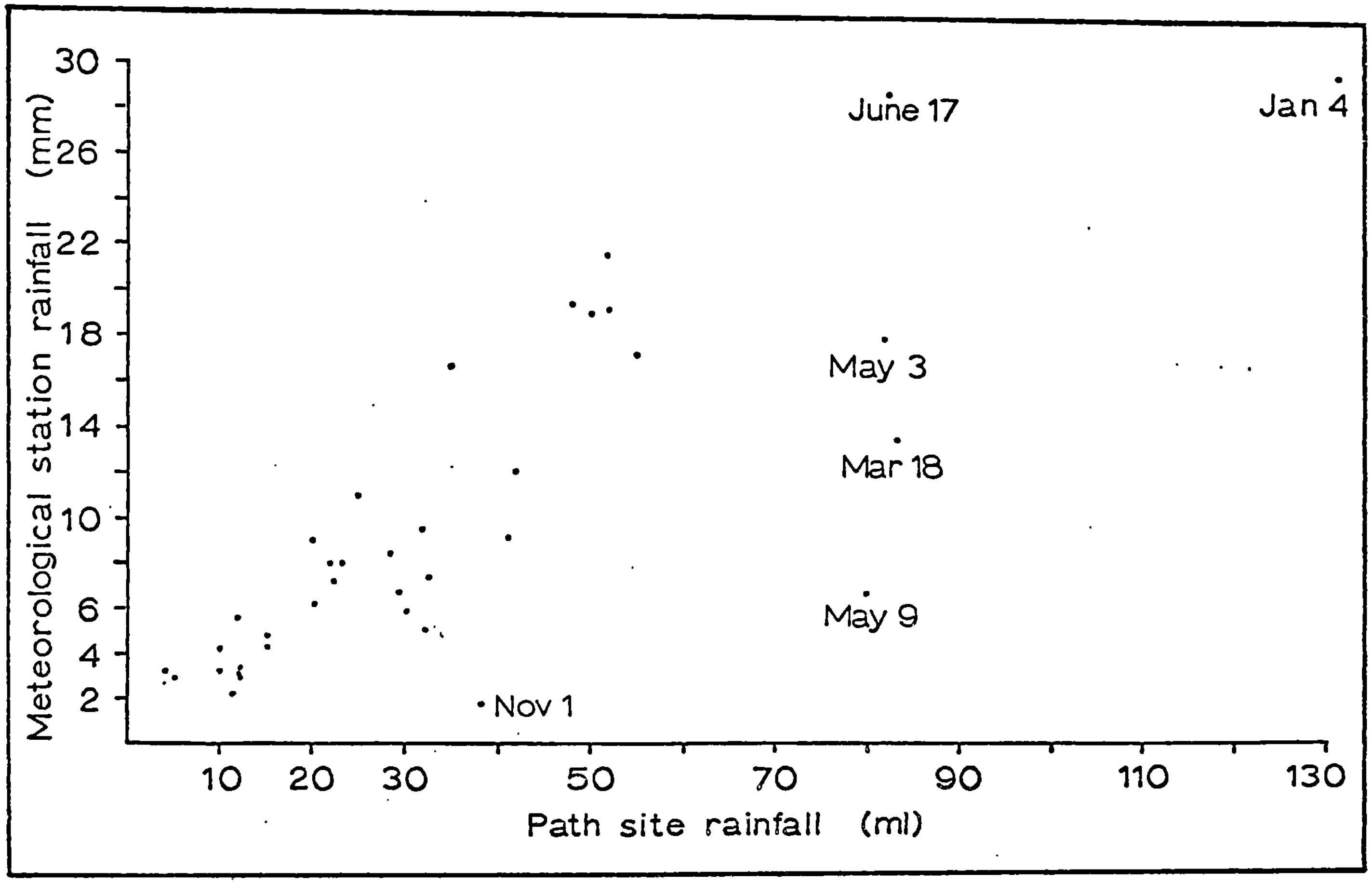
Of the 52 rainfall periods monitored, 17 had to be omitted from any rainfall-run off analysis because they were either unsuitable or lacking some data. The reasons for omission were one or more of

1) rainfall data missing because of non-operation of the rainfall recorder;
2) snow cover over the paths;
3) amalgamation of run off from more than one rainfall.

A total of 35 cases were left for analysis.

Rainfall as measured at the site related reasonably well to that recorded at the meteorological station at low values, less than about 60 mm, but above this figure the results were very disparate (figure 9.1). Certain characteristics of the path site may have acted to protect or expose it to rainfall;

FIGURE 9.1 Relationship between rainfall measured at the meteorological station and at the path sites



a wall ran downhill to the east and across the top to the north. Moreover, the local wind eddies may have acted to increase or decrease precipitation at the site, relative to the station at the top of the hill. Since the rain collected at the site was at the same ground level as the paths, it should have reflected the rainfall they were receiving. However, not being a standard rainguage, there may have been unknown errors and, particularly during the summer, the surrounding vegetation may have affected the gauge. It was considered reasonable to interpolate missing rainfall totals for low values, but not for high ones.

(b) Run off water and sediment

It was expected that the amount of collected sediment would be related to water run off (Morgan, 1977) and a sample of 52 cases was available to test this. Initially, there was some doubt as to the accuracy of the water collection at times of heavy rain, as it was thought that the receiving containers might be inadequate. It appeared that in most cases, all the water coming into the containers was held, but the possibility of some overflow in seven cases cannot be discounted. These were all times when both the trough and the overflow bottle were full. The overflow bottles were lower than the troughs, with the connecting tube entering the bottle near the base; thus, it was likely that all the sediment was trapped even if some of the water was lost. At all times the weight of sediment in the overflow bottle for path B was very small; most of the sediment settled out in the trough. The overflow bottle for path A was rarely used and never contained any significant sediment. Path B collected from two to six times the volume of run off from path A, depending upon the conditions.

Initially, the weight of sediment collected was estimated as follows. The run off, brought back from the site in containers of approximate capacity 9×10^{-3} m^3, was thoroughly mixed and 0.2×10^{-3} m^3 was removed as a sample. The sample was poured through 250 and 63 µm sieves, and that passing the 63 µm sieve was oven dried and weighed. The remaining volume of the run off was measured and passed through the same sieves, but that passing the 63 µm sieve was discarded. All the sediment of size greater than 63 µm was oven dried and weighed. The contribution of the silt and clay, the sediment less than 63 µm, was estimated for the total volume using the weight per 0.2×10^{-3} m^3 calculated for the sample.

After January 4, 1978, enough collecting containers were ssembled to allow time for each to stand for two days. At he end of this time, most of the water could be siphoned off, leaving the total amount of sediment in a sufficiently small volume of water that it could be oven dried and weighed without sampling.

In March and April, three series of run off contributions were given both treatments to see whether the sampling method had been very inaccurate. Errors arise in calculating the amount of silt and clay in the sample; material can be lost in sieving and possibly retained with that of larger size through inadequate rinsing of the sand. Any error is then multiplied in the subsequent exrapolation to the total run off; moreover, an error in calculating the volume of the total run off will produce an inaccurate multiplication factor.

In the three sets of measurements tested, the errors were quite large, but not consistently in one direction, as can be seen in table 9.1.

TABLE 9.1 Accuracy of the sampling method to estimate the quantity of sediment collected; comparison of this with total sediment collected after siphoning off water

DATE	VOLUME OF WATER ($10^{-3}m^3$)	TOTAL SEDIMENT COLLECTED (kg)	TOTAL SEDIMENT ESTIMATED FROM SAMPLE (kg)
18 March	14.2	0.141	0.167
12 April	16.0	0.015	0.016
28 April	24.0	0.235	0.212

It is likely that the silt and clay may be underestimated in the sample, but this may be partly balanced by any retention of silt and clay in the sand that was retained on the sieves. Errors in measuring the volume of water may occur in either direction. Clearly, the estimates of total sediment using the sampling technique may have included large errors, particularly for high values of the total run off.

(c) Other factors

The trampling factor was controlled, hence raised no problems, beyond the fact that trampling near the collecting trough may have been distorted since it was the point at which the trampler had to turn round and walk back uphill. The top of the path presented no problems because it was possible to walk beyond the end, a solution which could not be applied at the bottom because of the presence of the trough.

Frost heave was expected to influence the amount of sediment in the run off both by the production of material from the sides of the path and by disturbing the path surface. In the event however, there was little evidence of frost heave at the sides and, although some occurred on the path, the effect was often masked by the effect of snow or trampling.

The other factor noticed was that in dry weather large cracks spread in a network over the path surface. It seemed probable that run off would be subsequently diverted into these cracks and that any sediment might be trapped. Trampling when applied, counteracted the effect by breaking up the cracks and filling the gaps with kicked sediment.

9.2.2 Results

The complete results for each path, water and sediment yield, and rainfall, both as measured on the site and recorded at the meteorological station, are given in Appendix 3.

Path A (worn grass)

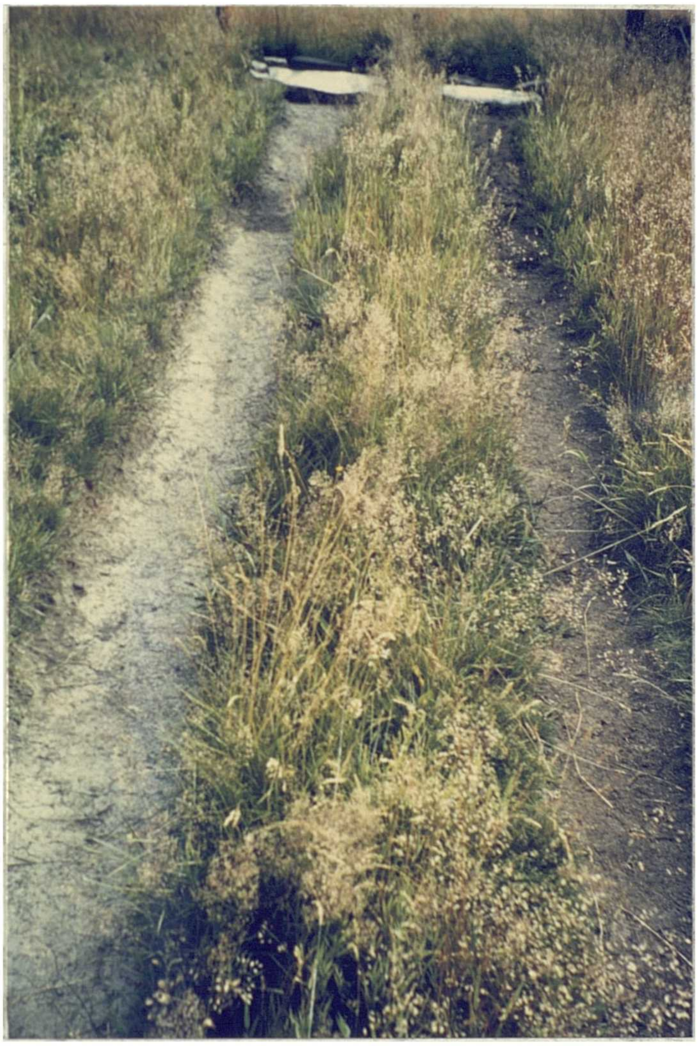
0.19 kg of material was collected in the trough at the bottom of path A over the one year period, much of the sediment being organic and only a little mineral soil. The trampling destroyed surface parts of the vegetation, but only in a few places was the underlying soil exposed. In between trampling, there was some new growth of grass on this path in the summer.

The greatest wear on the grass occurred when the soil became wet in the autumn. Not only was vegetation growth declining at that time of year, but material from the most worn parts became smeared over other leaves; the wetness also rendered the boot more likely to skid, which scraped and tore both surface vegetation and the organic parts, roots and litter, below.

The changes in profiles on path A were very small. Apart from a few points where footmarks developed to expose the mineral soil, the measured changes were only a few millimetres. In most cases, the changes were in the direction of surface lowering, either by erosion or compaction, but two profiles, one near the bottom and one at the top of the path appeared to show an opposite effect. This may have been caused by some slight slumping and rotation in the soil, particularly if the trampling tended to occur in a similar position at each passage. Although the profile changes were small, the definition of the path, after 2700 tramples up and the same number down, became much clearer as can be seen by comparing plate 10 with plate 11.

Many times this path produced little or no run off during rain, and at all times any run off obtained was much less than that from path B. However, the ratio of one to the other was not contant; it clearly depended upon the particular

PLATE 11 Bradfield footpaths after 2700 tramples



rainfall characteristics.

Path B (incised soil)

Changes on this path were much greater than on path A. Many times run off was produced, and with it, much soil. The path collected throughflow and surface flow because of its incision. Not only would it act as a natural collection channel, but also the removal of the surface vegetation, organic layers and some of the top soil may have created a stong water pressure gradient along which flow would migrate because of the easy escape into the path. Early in the path development, the roots of the path edge vegetation became washed clean by water trickling down them.

The total sediment washed down the path was 5.72 kg, 2.68 kg in the winter and 3.04 kg in the summer - May to September. This is to be compared with 1.69 kg of soil trampled down the path onto the trough lip by 100 tramples up and down when the soil was extremely wet after a period of snow - January and February - and another 0.07 kg trampled down after April snow with 25 tramples. In addition, when the soil was damp it adhered to the soles of the boots, and two "bootsful" of soil amounted to almost 0.05 kg. It was noticeable, however, that run off produced primarily by snow melting on the path produced little sediment; for example, 13 and 25 January, 2 March and 12 April produced sediment at the rate of less than 1 g per litre whereas most other comparable cases produced sediment at 2-30 g per litre.

The number of tramples seemed to have less effect upon the amount of sediment produced in the run off than the incidence of trampling. Once the surface was well disturbed, which took about 15-20 tramples, the trampling pushed the soil back into the path as well as lifting it up - unless the soil was saturated in which case trampling pushed large amounts down the path. The trampling disturbance effect was marked; rain on undisturbed soil forms a skin with the surface particles and this is broken up by trampling, which provides many loose particles for easy dislodgement by rain splash. Twice the trampling was carried out whilst it was raining, but if any effect was significant it was that trampling tended to interfere with the small trickles of water travelling down the path, In contrast to this, on paths which have a large volume of water moving down, such as may be seen on some Lake District paths, trampling moves sediment into the water flow and thus aids erosion processes.

The profile changes in the year are shown in figures 9.2 - 9.4. For the most part, erosion dominates the changes, but in a few places deposition has occurred. Deposition on path surface is most evident at the lowest profile (P8 in figure 9.3). This material was mostly pushed down by trampling, on one side particularly, and the pattern, once established, tended to be self perpetuating because the run off was diverted to the other side. Deposition at the path sides was apparantly caused partly by the path banks slipping or bulging, a not unexpected occurrence in view of the way in which the path was dug out. However, this type of adjustment to vertical or nearly vertical incision can be seen on "natural" paths. For example, the deep water incision on Causey Pike, recorded at site 1 (Chapter four, figure 4.1) craated nearly vertical sided gullies, but these were subsequently modified to more stable, angled slopes.

Even after heavy rain, there was little sign of water incision in path B. This suggested that there was not sufficient water run off to erode the path by corrasion to any noticeable effect. Thus, much of the sediment load was probably derived from particles displaced by rain splash.

FIGURE 9.2 Profile changes across path B at Bradfield:
P1 (top) to P4

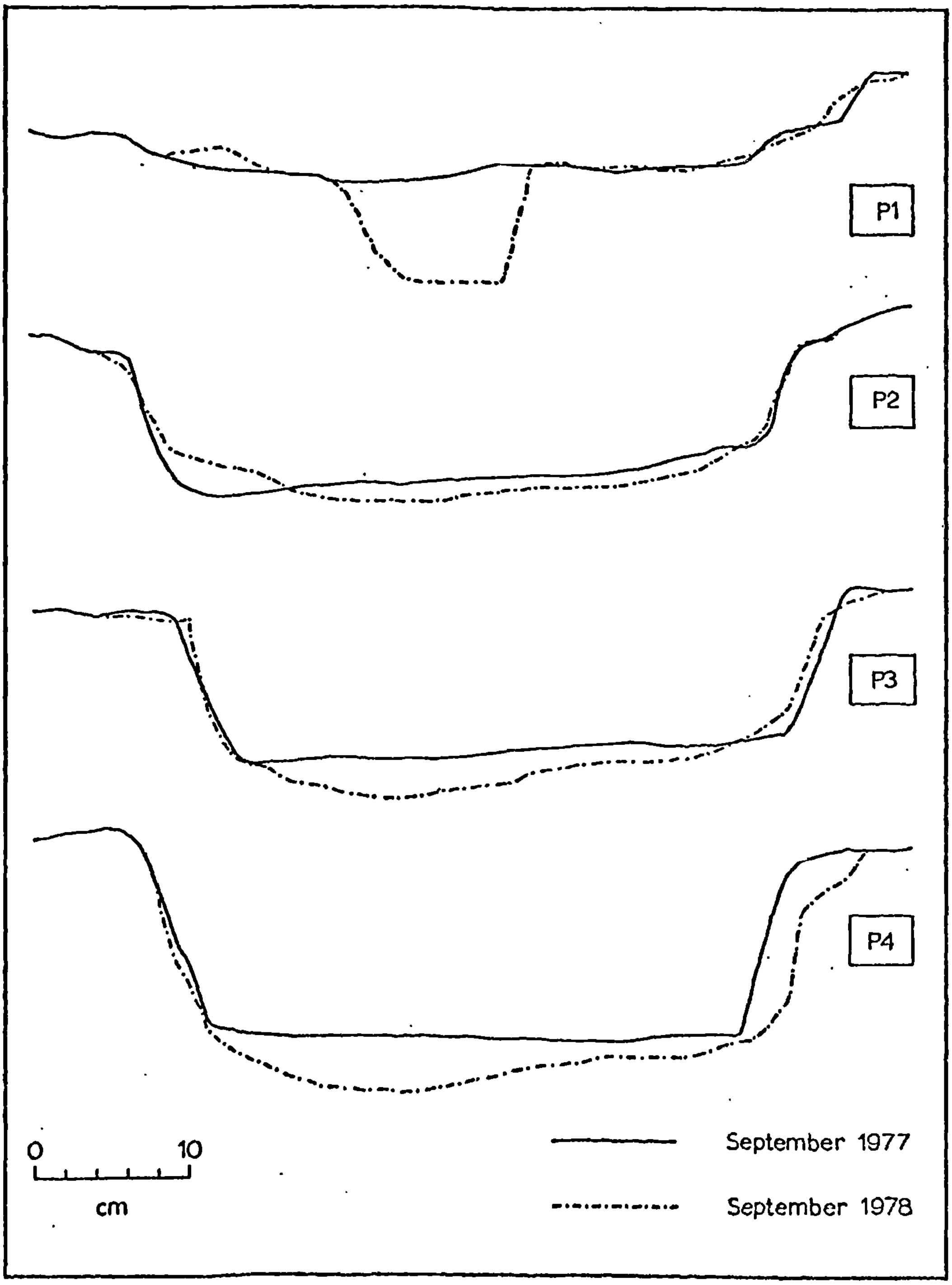


FIGURE 9.3 Profile changes across path B at Bradfield: P5 to P8 (bottom)

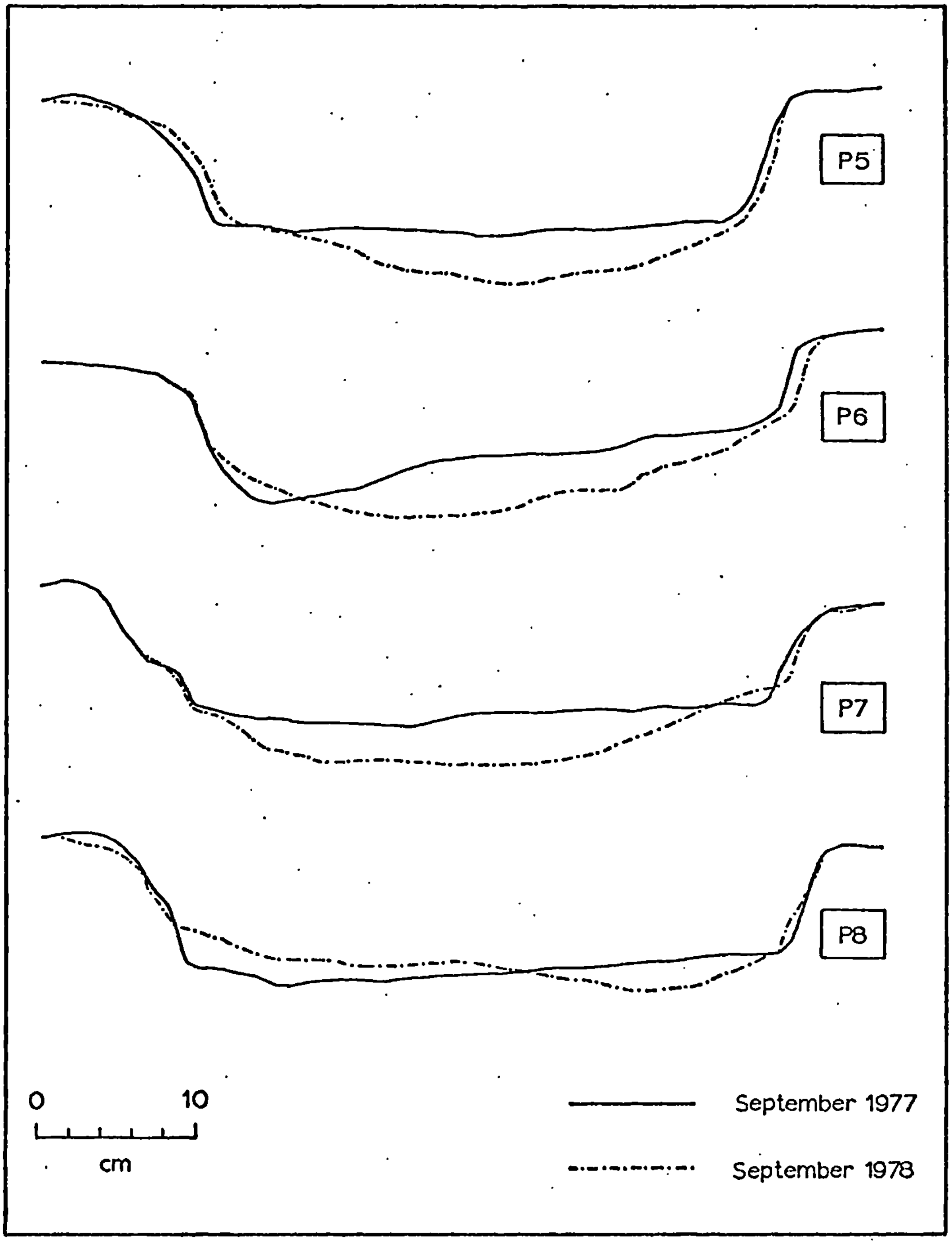
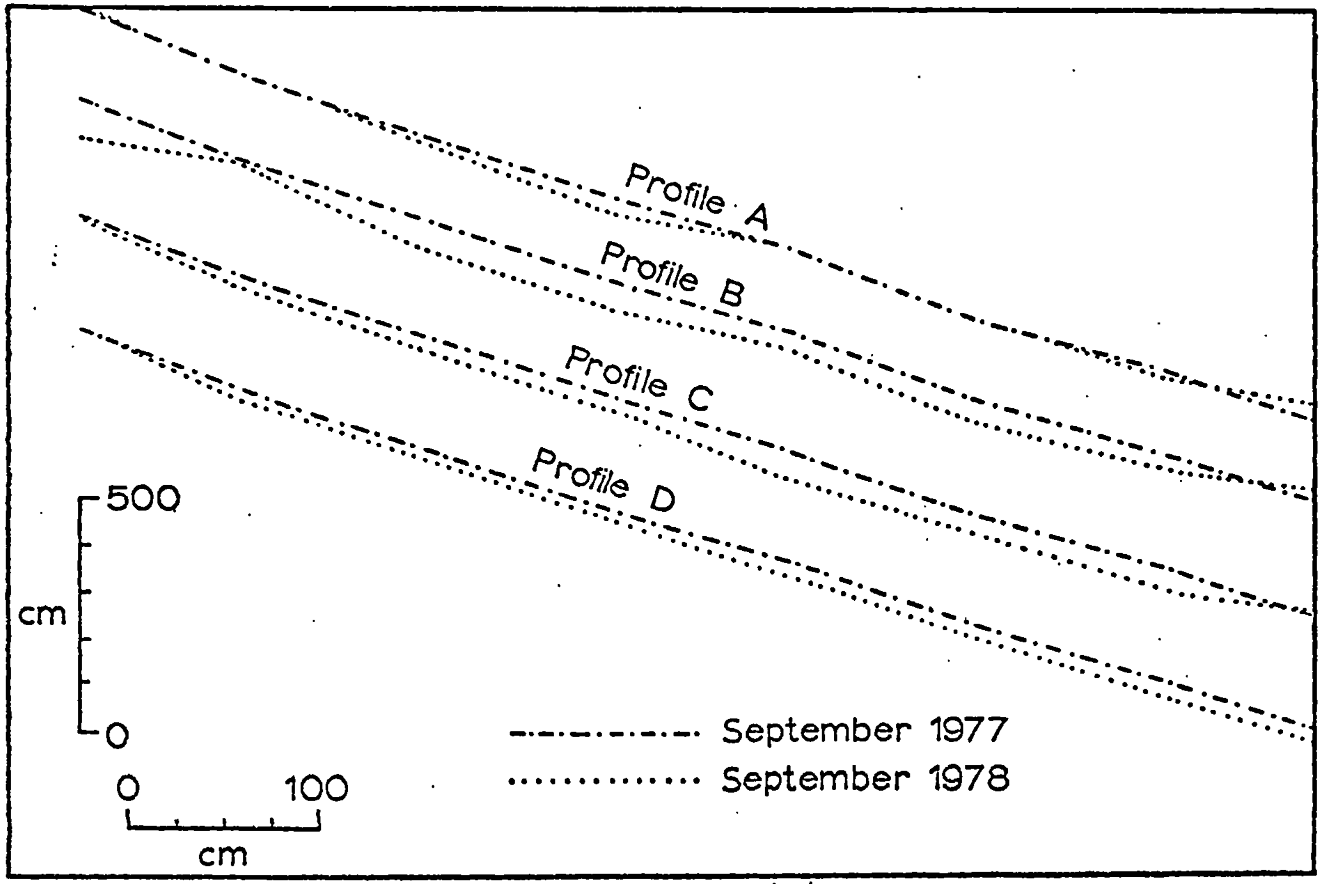


FIGURE 9.4 Longitudinal profile changes down path B
(Profiles A to D: LHS to RHS in figures 9.2, 9.3)



This suggestion is at least partly substantiated by the results from analysing sediment load and rainfall parameters (section 9.2.3) which identified rainfall intensity rather than rainfall amount as the more useful variable to "explain" the amount of sediment collected. The most probable reason for the lack of incision capability in the run off was the fact that there was no path section above the feed water in, as there often would be in "natural" paths.

In considering the erosion at certain points of the profiles in a downslope sequence (Figure 9.4) it can be seen that the least amount of surface lowering has taken place at the top of the path, where there was less water to remove sediment, and at the bottom of the path, where trampled down sediment collected at the trough. At the top profile, P1, the line of the bar was originally across the "back wall" of the path. In time, parts of the collapsed; hence there is a large change in depth recorded at parts of this profile (Figure 9.2). Changes in the area of the profile cross-section are given in table 9.2, demonstrating the downslope variation in erosion.

An approximation to the amount of material apparently eroded can be obtained from the profiles, using the change in area of cross-section as an average for each portion of the path, and assuming that the dry bulk density is the same as that of the adjacent grassy areas - an average of 1.5 g cm^{-3} for 5 small cores. This produces a figure of about 50 kg, representing an approximate average of 10 mm per year of surface lowering. The amount of sediment collected in the trough and by trampling - including an estimated 2 kg removed on the soles of boots - was just under 10 kg, representing an approximate average of 2mm per year of erosion. In addition, a small amount of material was kicked off the path

TABLE 9.2 Changes in the area of cross section of each profile on path B, September 1977-8

PROFILE NUMBER	INCREASE IN AREA OF CROSS SECTION (cm^2)
P1	57.4
P2	9.1
P3	40.0
P4	94.9
P5	62.4
P6	59.2
P7	67.1
P8	-8.1

and lost, but clearly there is a great discrepancy between the two estimates, suggesting that much of the surface lowering is due to compaction and/or a significant amount of material was being lost underneath or around the sides of the trough.

Compaction was recorded on path B on two occasions, measuring before and after 50 tramples. The first occasion was 22 November, when the soil was damp after rain, and the second was 7 August, when the soil was drier, but not hard and dusty. In November, 58 out of 64 points registered surface lowering, with an average of 1.1 mm; in August, 47 points registered surface lowering and 13 showed no change; the remaining points all demonstrated the way in which soil could be raised by trampling. In August the overall average lowering was 0.8 mm. With 2700 tramples, even if these rates of compaction were generally valid, only about half the surface lowering might be contributable to compaction. Repeated profiles, at short time intervals of about two months, all indicate steady surface lowering, suggesting that the errors may lie in the sediment collection if the discrepancy is not due to compaction, nor wind, nor any other form of loss. Observing run off during rain, there was no sign that significant amounts were being lost, but the possibility could not be tested without disturbing the trough. Leopold and Emmett (1967) suggest that this is the major problem in any construction of this type.

The rates of change of the surface profiles are compatible with those measured on the Lake District footpaths.

9.2.3 Analysis

(a) Variables for Regression Analysis

The main purpose of creating the artificial path at

Bradfield was to try to relate the sediment collected to various meteorological and trampling factors. This was not possible for path A because there were too few cases when run off was produced. For path B there were plenty of data.

Hudson (1971) suggests that the erosivity of rainfall may be related to the kinetic energy of the raindrops, which breaks up aggregates and disturbs particles, and may affect the turbulence of any surface flow. If rain splash is instrumental in initiating particle motion, then surface run off is required to transport the particles down the path. Surface run off is dependent upon the total rainfall, but also on the intensity of this rainfall and its comparison with the infiltration capacity. Infiltration is affected by antecedant moisture conditions as well as those of the falling rain.

Morgan (1977) in his study of soil erosion on sandy soils on a slope in Bedfordshire, found that the various rainfall parameters he tested were poorly related to sediment collected from run off. Kinetic energy, total rain and storm duration were found to be significant, but not all at each of the sites. Morgan considered that the low magnitude storms were misleading in these relationships; he found that 99% of collected sediment was from 10 out of 50 storms and that the relationships were better for these alone.

In the analysis of the Bradfield data, the kinetic energy was taken to be proportional to rainfall intensity (Wischmeier et al, 1958). Low intensity rainfall appears not to be erosive (Hudson, 1971) but the necessary threshold for the site would depend on the erodibility for the soil. At Bradfield the maximum intensity recorded in any one ten minute period was 2.7 mm, or 16.2 mm and hour, but most values were very much less. Thus different values of a possible "intensity threshold" were tried, based on the spread of values experienced at the meteorological station: 0.5, 1.0 and 1.5 mm per ten minute period. Wischmeier (1972) suggests a formula for kinetic energy, of the form

$$KE = 210.3 + 89 \log_{10} I$$

where K.E. is the kinetic energy in metric-ton metres per hectare per centimetre of rain, and I is the intensity in cm per hour. Thus it is possible to express the total kinetic energy of any one storm as a function of the sum of the logarithms of the intensity values for any values greater than the threshold adopted, for the time periods available.

In addition to the kinetic energy variables, other rainfall parameters were considered, namely intensity, duration, total rainfall and antecedent moisture. Rainfall intensity parameters used were the maximum 10 minute intensity, the maximum 30 minute and 60 minute intensity. Antecedent conditions were estimated using two different surrogates indices: rainfall totals in the previous 24 hours and an index suggested by Papadakis and Preul (1973), used by Morgan (1977). The index is given an arbitrary value - 10 mm for these data - at the start of the period; on each day with rain, the total fall is added to the index; on each dry day, the index is reduced by 10%. There arose the problem of snow cover. An arbitrary solution was adopted (a) of increasing the index by 10% for every day of snow cover and (b) increasing the index by 5%.

Total rainfall figures were available (a) from the meteorological station and (b) from the rain collected at the site. The complete list of rainfall parameters considered in the analysis of the factors affecting the sediment yield at path B is given in table 9.3.

In addition to the rainfall oarameters, the trampling effect and the amount of water run off were used in the

TABLE 9.3 Rainfall parameters considered in the analysis of sediment yield from path B, 1977-8.

Total rainfall:	(a) site		
	(b) meteorological station		
Duration of rainfall			
Intensity of rainfall:	(a) maximum 60 minutes		
	(b) maximum 30 minutes		
	(c) maximum 10 minutes		
Antecedent moisture:	(a) rainfall total in previous 24 hours		
	(b) index (Papadakis and Preul) modified for snow cover -	(a) + 5% for each day	
		(b) + 10% for each day	
Kinetic energy total:	intensity	(a) 0.5 mm per hour	
		(b) 1.0 mm per hour	
		(c) 1.5 mm per hour	

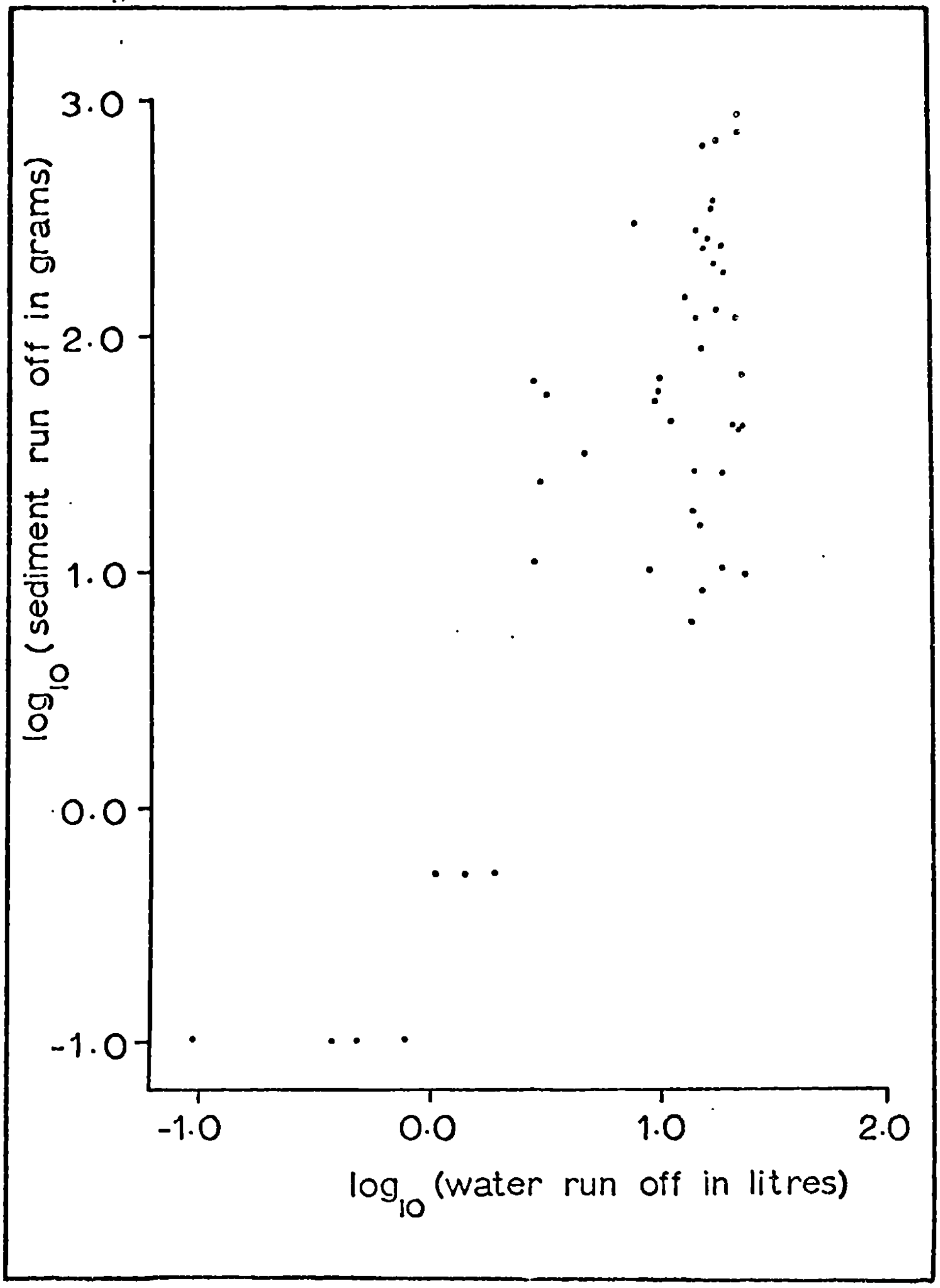
analysis. Thirty five cases were available for analysis if the antecedent moisture was not to be considered. If it was to be included, then the number of cases had to be reduced because some data were lacking for the period of time before the measurements: a small amount of data was discarded for September and October; a total for December 7 was interpolated for the meteorological station so that the antecedent index could be calculated, this being justified on the grounds that the rainfall was slight that day.

(b) Results

It had been expected that the yield of water and sediment would be related, as found by Morgan (1977), but, as can be seen in figure 9.5 this is not so. A pseudo-correlation exists in the form of two clusters of points, one for low values and the other for high values of the data. One reason for the lack of association between the two variables is that the trampling factor is not taken into account. The separation of the points into two groups suggested that to analyse the data as one might be misleading. Yair and Klein (1973) identified a threshold value of 3 mm of rain a day before there was any slope run off, but no simple threshold presents itself for these data. One of the problems is that the incised nature of the path allows water to flow into it long after the rain has stopped and this flow depends upon the type of throughflow operating on the slope at the time as well as any rainfall total and surface flow. Thus, the situation is rather complex.

It was decided to remove the nine cases in which run off was insignificant: 24 October, 2, 7 and 22 December, 6 March, 19 May, 5 and 28 June, and 7 August. This was done because the main interest lay in identifying the relative effects of rainfall and trampling in cases when there was soil erosion.

FIGURE 9.5 Relationship between water and sediment yields from path B



The best "explanation" of the variation in the amount of sediment collected was given by the following variables:

maximum 10 minute rainfall intensity

antecedent moisture index (adding 10% for each snow cover day)

incidence of trampling (but not its intensity)

total rainfall (both site gauge and meteorological station gave similar results but the latter is preferred, since the records are required for the other rainfall parameters)

The exact relationships are given below, with the cumulative values of R^2 in parenthesis.

$$X_0 = 0.392\ X_1^{1.49}\ X_2^{0.717}\ X_3\ X_4^{0.582}$$

where X_0 = sediment yield in grams

X_1 = maximum 10 minute intensity in mm ($R^2 = 0.42$)

X_2 = antecedent moisture in mm, initial value 10 mm ($R^2 = 0.50$)

X_3 = 3.01 if trampling is applied
1.0 otherwise ($R^2 = 0.57$)

X_4 = total rainfall in mm ($R^2 = 0.64$)

Hudson found that, in splash cups experiments, the amount of sand splash was related to the kinetic energy of the rain falling at intensities of more than 1 inch per hour (25.4 mm per hour). This is equivalent to approximately 4.2 mm per 10 minute period, a rate never reached at the Bradfield site. However, it does suggest that, at lower rates, the maximum intensity may have the greatest effect upon sediment disturbance as was found in these data. Young and Wiersma (1973) also demonstrated the importance of rainfall impact, since when the raindrop energy was dissipated by screens, without reducing the amount of rainfall, the sediment losses decreased by 90% or more.

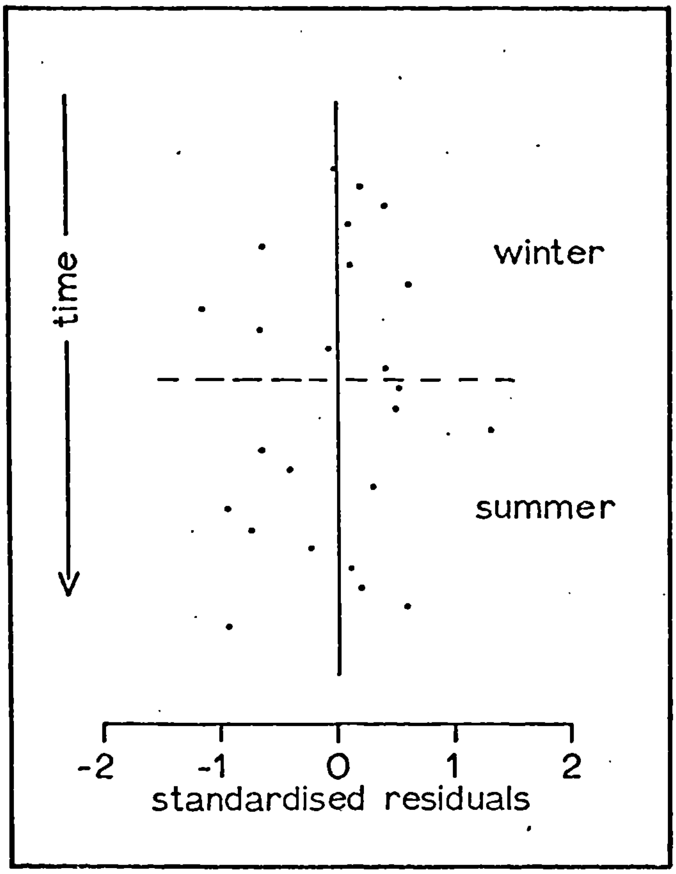
The effect of antecedent moisture, trampling and total rainfall are secondary to the rainfall intensity in terms of accounting for the variation of the data, but nevertheless significant. Perhaps surprisingly, the intensity of trampling was not important. Once disturbed, the soil was not rendered more erodible by more trampling. On average, for this path, three times as much sediment is collected after trampling as that collected if the ground is not disturbed. This data set is small and only obtained over a period of one year; it may not be very representative. However, it suggests that the soil disturbance factor is significant and that in an area with frequent trampling and rain, much of it heavy, as in the mountaineous north west, soil losses as a consequence of recreation may be considerable.

The residuals from the regression show no temporal grouping (Figure 9.6) and so no indication that the relationship is affected by winter or summer conditions, other than the snow cover factor already included. The effect of frost heave, which was expected to be relevent, was probably masked at times by trampling and inhibited by snow cover. There is another possibility; unless the high intensity rainfall occurs near the beginning of a period of rain, it is probable that the surface will be partly stabilised by gentle drizzle, with little erosive potential. There was no indication in the residuals that the different method used to calculate the sediment yield before 4 January had any significant effect.

9.3 CONCLUSIONS

The information from the Bradfield footpath indicated the importance of the trampling factor as a disturbance effect

FIGURE 9.6 Residuals from the sediment regression relationship



upon the soil, in that three times as much sediment was collected from run off following trampling as from run off following no trampling. Moreover, when the soil was wet enough to be plastic, after saturation under a snow cover, the equivalent of almost one third of the year's total of sediment collected from run off was trampled down the path into the collecting trough by 100 passages up and down.

The comparison of the approximate amount of soil erosion, as measured by the changes in profile, with the sediment collected in the trough suggested that some, at least, of the surface lowering might be due to compaction of the subsoil.

The rainfall data demonstrated the importance of high intensity storms as erosive agents; it also showed that moist soils are vulnerable.

The incised path experienced many times the amount of water run off obtained from the path wearing in the grass, even with a limited contribution area. At the end of the year of measurements, the incised path had lost much sediment and had undergone noticeable changes in its profile; the path in the grass was only beginning to be eroded into the mineral soil layer and the amount of sediment collected was small.

If such results were to be extrapolated to mountain footpaths in general, they would suggest that trampling frequency is as important as trampling intensity unless the surface of the path is such that trampling is primarily kicking or rolling stones down the path. Particularly in the early stages of path erosion, trampling appears to facilitate the removal of small particles of the sizes that would be affected by rainsplash, in other words the top soil. The results also demonstrate the vulnerability of footpaths that are used in winter, both because of the heavy rain that is often experienced in the mountainous north west in the winter and the trampling of snow-saturated soils. Footpaths which become incised as a result of local water collection for any reason become a self perpetuating system of erosion because of their form; they are instrumental in accelerating erosion since, without water concentration, much of the disturbed sediment affected by rainsplash may merely be transferred randomly from one part of the path to the other.

CHAPTER TEN

RECAPITULATION, SUMMARY AND CONCLUSIONS

10.1 RECONSIDERATION OF QUESTIONS RAISED IN CHAPTER ONE

At the conclusion of this study, the questions posed at the start must be reconsidered, in the light of the research. These questions were summarised as:

Q1 Is footpath erosion a problem?

Q2 What are its main causes?

Q3 What are the implications for management?

They were then subdivided into more specific problems:

Q1.1 Are present amounts of footpath erosion
- (a) visually intrusive
- (b) dangerous underfoot
- (c) harmful to agriculture or nature conservation?

Q1.2 Is excessive footpath erosion a widespread phenomenon?

Q1.3 What are current rates of footpath erosion?

Q2.1 What are the main site conditions likely to result in serious erosion?

Q2.2 How do numbers of people affect rates of erosion?

Q2.3 What is the relative importance of numbers of people and site conditions?

Q2.4 How are factors affected by differences in weather or season?

Q3.1 Is it possible to predict the course of erosion on a path if its site conditions are known?

Q3.2 Will increasing the numbers of users by a certain amount increase the erosion by the same amount?

Q3.3 Is some eventual equilibrium reached, albeit after a large amount of degradation?

The research was designed to provide some contribution to answering these questions. In these concluding pages it may be possible to judge how far the research has supplied answers.

Question 1.1

This question lay beyond the scope of this research for the most part. However, the results of interviews on Helvellyn and Causey Pike suggested that walkers are aware of footpath erosion as a problem in some parts of the Lake District.

Question 1.2

This question is concerned with the existing state of paths and cannot really be answered without defining the term "excessive", which is considered to be beyond the scope of this research. However, some statements can be made about the extremes of erosion encountered on Helvellyn and the hills around the Newlands Valley.

The very extensive paths, sometimes as wide as 30 m, are usually accompanied by much bare ground and frequently by gullying. Any precise description of "extreme" is arbitrary, but bare ground widths of more than 5 m and gullying deeper than 0.5 m were thought to be reasonable criteria; they certainly represent a large amount of path erosion.

Using this definition, 12 out of the 16 paths measured for length of the different path sections had areas with bare ground width greater than 5m, and 10 paths had sections with gullying deeper than 0.5 m; only 3 out of the 16 had neither attribute. On the other hand, the proportion of these paths with this amount of erosion only averaged 9-10%

of the path length in the area as a whole.

Thus it could be said that the extremes of footpath erosion are, at present, localised on any one path, but, in terms of the area as a whole, they occur on most paths.

Signs of active processes of erosion were observed on approximately one third of the paths measured; thus, it is fair to deduce that path modification of one sort or another is widespread. This view is reinforced by measurements taken at six monthly intervals, over two years, during which time more than a third of the sites showed measurable changes of either bare ground width or depth of gullying.

This selection of paths is typical of many areas of the Lake District; the statements above could possibly be applied to the whole of the area popular with walkers, from the eastern High Street range, through the central Scafell massif to the ridges running westward onto the West Cumbrian plain.

Question 1.3

This is concerned with rates of erosion. In the area studied, rates of erosion - mostly changes measured at six monthly intervals - were high at some sites. The type of path site identified as vulnerable was

1) that at which the original path progressed by a well graded zig-zag, but the modern path tends to take a straight up and down line, usually consisting of many alternatives;
2) that at which the path collects large quantities of run off water, often due to local concentration of throughflow in the hillside.

At paths of type one, vegetation on new routes became eroded at rates varying from 30-150 cm in the two year period; at paths of type two, gullies became deeper by 8-19 cm.

However, as already stated, this degree of erosion is localised and many of the sites measured were stable, or changed only a little.

Rates of change over so short a time period as two years may be atypical. They were put into perspective by referring to air photographs of the area taken 20-30 years before. These demonstrated that, whilst it cannot be denied that vulnerable sites have become considerably more eroded and that idefinite paths have become more clearly defined, localised areas of wide paths and soil erosion existed as long ago as 1947.

More detailed measurements of current rates of change suggested that the creation of new routes, to avoid bouldery sections of old paths, is progressing many times faster than any natural regeneration process of the vegetation. Hence it can only be concluded that, if the measured rates were not atypical, certain path areas will spread rapidly across the hillside until stopped by some physical limit.

Question 2

Question 2 is generally concerned with the factors that affect footpath erosion. The morphological survey of the paths showed that, for the area considered much of the variation in general path morphology can be accounted for by differences in slope on or across the path, the number of walkers, and the altitude, which in turn affects a number of factors, climate, soil and vegetation.

Certain minor factors are useful in a small amount of additional explanation, These factors include whether a path has any physical restriction, whether it traverses a ridge, whether it passes through Calluna moorland, is on the deep, well drained brown earth soils or the shallow poorly drained podsols.

In terms of changes in path morphology as a response to changes in the various factors, by far the most influential are path slope, recreation and altitude. The slope and altitude can be measured from maps and air photographs, and so vulnerable sites are easily identified.

Detailed measurements of changes at a few sites showed that probably different process were predominant at different seasons. Lateral erosion of path vegetation generally dominated the period from Easter to October, when recreation pressure is greatest; gullying in bare ground occurred mostly, although not entirely, in winter, when run off is greatest. The exception to this was on steep sites where trampling was instrumental in surface lowering, this therefore occurring mostly in the main recreation period.

Experimental work suggested that the effect of trampling on a stony path is to move stones down the path at a rate depending on the slope of the path. However, in the earlier stages of path development - and in new development at the side of an old path - when there is still a surface of fine soil, the effect of trampling primarily appears to be that of soil disturbance so that particles are put in a favourable position for erosive action by raindrop impact. Thus, trampling in this case is likely to be most erosive during periods of wet weather.

At times when the soil is saturated, particularly as the winter snow cover melts, trampling may produce a downslope flow of soil. This occurred with 100 up and down tramples on the experimental path, at a rate equal to nearly one third of the material washed down by runoff in the whole year.

The relative importance of recreation and site conditions is difficult to assess, since of necessity they act interactively. From the survey data, it can be seen that even paths which are relatively little used may have localised areas of deep gullying or extensive lateral soil erosion if site conditions render the path vulnerable. For the experimental path, on fine soil, the effect of trampling was, on average, to increase the amount of soil collected from the path after rain by a factor of three. However, on another slope, or with coarse material on the surface, the results might be quite different.

Question 3

Question 3 is concerned with possible path management. Comparing path size and recreation pressure, it was found that the relationship between them was not linear; indeed the simplest relationships was that path morphology was proportional to the square root of the recreation pressure. If generally true, this would indicate that increasing recreation pressure does not necessarily increase erosion in the same proportion.

There was little evidence to suggest that the most eroded sites would eventually stabilize, since the stony, steep nature of these paths continually tempts walkers to create new tracks on the easier vegetation at the side. Even when bedrock is reached walkers may prefer to walk on grass rather than in a gully. This is exemplified by the most eroded site on the Helvellyn Striding Edge path, one branch of which is gullied to bedrock, the other branch being an eroding path through peaty humus and soil, with a potential third branch becoming visible on the vegetation in between. Walkers noticeably avoid the original, now rock-floored path in favour of one or other of the two alternatives. It is difficult to visualise a limit to path width development of this type, other than a physical limit placed by the nature of the mountainside.

The type of relationships found for the study area provides a guide to the possible morphology of a path, for a given set of site conditions, but the variable nature of footpath erosion, and no doubt the inadequacy of some of the factors measured, render the relationships too imprecise to be used for more than general predictions. The precision of the estimates varies with the degree of erosion; prediction for low erosion sites will be quite reliable in comparison with high erosion sites.

The area studied is typical of much of the Lake District and probably the results could be extrapolated to other areas. Alternatively, it would clearly be simple to produce similar relationships for other areas with a new set of data.

10.2 CONCLUSIONS

The field measurements have reinforced some of the hypotheses that were suggested, based upon theoretical considerations of the footpath system and previous research. The results can be summarised as follows.

1) Soil erosion on footpaths, although not merely a phenomenon of the last few years, has in that time produced many paths which are wide and deeply gullied for at least part of their length. Extensive areas and depths of erosion are localised, but at such places, erosion processes appear to be active, and faster than any vegetation regeneration.

2) The most reliable environmental pointers to a site's vulnerability are its slope, altitude and the presence of certain vegetation and soil types. Eroded sites are generally found to occur on steep slopes and at higher altitudes; *Calluna* moorland and podsolised soils are particularly vulnerable. There appears to be a critical slope at 17-18 degrees, above which erosion processes are noticeably active.

Recreation pressure alone is not enough to cause widespread erosion on any path; on even the most popular routes, some sections of the path are quite narrow and appear stable. However, where environmental conditions are such that trampling does lead to much soil erosion, the vegetation and soil loss is affected by the amount of recreation pressure, although at less than a simple proportional rate.

3) Footpaths seem to be particularly vulnerable when trampling and rainfall alternate; This is because trampling disturbs the soil cover, rendering particles more easily moved by raindrop impact. Saturation after snow may leave the soil in a plastic state so that it flows downhill under foot pressure. Thus, autumn, winter and early spring are times when much soil erosion might be expected. Experimental work on one type of path with a moderate slope produced a trampling factor of three times the amount of rainfall erosion that occurred on undisturbed soil. Trampling can, without help from the weather, cause considerable erosion as feet kick, roll and push stones downhill, both when walkers are ascending and descending.

There are several conclusions that might be drawn from this work. In many ways the explanation of processes is far from complete. However, to elicit further detail seems impossible without further control of the system and its inputs and outputs. To do this for a comprehensive range of environmental site types would require experimental work on a large scale. It might be difficult to justify this in view of the overiding importance of simple variables such as slope.

It is tentatively suggested that the combination of slope and recreation has most effect on the course of footpath development, and that other factors do no more than modify this effect. The most powerful modification is the erosivity of large quantities of water if collected and channeled down a path.

In footpath management there are three alternative decisions that might be made:

1) to reduce the numbers of walkers to a point at which the paths ceased to erode further;

2) to increase the capacity of paths to carry large numbers of people without extensions of path erosion;

3) to do nothing and allow events to take their course.

The possibility of reducing the numbers of walkers seems remote in the forseeable future. If footpath managers wish to increase capacity by re-routing, reconstruction or conservation of existing paths, then they are faced with the difficult task of

a) persuading walkers to use a well graded zig-zag route in preference to an erosive straight up and down path;

b) constructing and maintaining enough culverts to drain all path sections which collect a large volume of water after rain, such as those traversing the lower parts of long slopes or those into which spring waters flow.

Work such as this has been undertaken on Snowdon, North Wales, demonstrating that solutions are possible even at high altitudes (J.E. Roberts, head warden, pers. comm.). At the time of writing, such path repair as has been done in the Lake District has been only at low altitudes, mostly in valleys adjacent to a road.

It is important that footpath managers do not ignore the opinions and reactions of footpath users. At present there is much goodwill and concern expressed by the average fell walker. This spirit of co-operation should be fostered, for, if hill paths are to be managed, it can only be with the co-operation of the thousands that use them. The foregoing thoughts are, however, those from an ideal viewpoint. In reality, economics of National Park planning may preclude conservation of all but a few places. In a discussion of the perception of wilderness damage in the United States Forest Parks, Barker (1974) pointed out that man is a very adaptable species. This is, perhaps, fortunate. No doubt, whatever the condition of the footpaths, future visitors to the mountains will echo the thoughts of Wordsworth:

> "For the power of hills is on thee
> As was witnessed through thine eyes
> Then, when old Helvellyn won thee
> To confess their majesty!"

(To -
on her first ascent to the summit
of Helvellyn, Wordsworth, 1816).

APPENDIX 1

CHANGES RECORDED AT THE SITES MONITORED BY A CORD STRETCHED BETWEEN FIXED POINTS

PATH EROSION CATEGORIES (as deduced from site appearance at the time of transect establishment)

CATEGORY A little or no erosion

CATEGORY B moderate erosion

CATEGORY C rapid erosion

A. WYTHBURN

Site 1 (mainly category B)

This site consisted of a series of alternative routes, some parallel and some at an angle to avoid corners. Most of the changes were quite small apart from the collapse of vegetation dividing two closely adjacent path sections. There was a tendency for erosion and deposition to alternate.

Site 2 (mainly category A)

Changes at this site were very small except for the central transect, which suffered extensive gullying in the storms of October, 1977. However, by the time that the profile was measured in the following spring, much of this gullying had been filled in with loose debris from other parts of the path.

Site 3

This site was eroded and bouldery. It was subject to a considerable amount of walking on the grass at the side of the rough parts, particularly by walkers going down. During the monitoring period, a strip of grass was eroded and a portion of the turf side collapsed, undermined by water, frost heave and vibration from trampling. The path section which might have received the eroded material, transect 3.1, did not in fact do so since most of the downhill walkers took a short cut at this point, thus trampling in a different direction from the main path, and, at times of heavy rain, water also ran off at an angle to the main path, having burst through the main path "side".

Site 4 (category C)

This site is a short cut up a steep covered knoll, topped by bare rock and the original path. The knoll was formerly bypassed by a carefully graded zig-zag route, now rarely used. Erosion was rapid at the top transect during the monitoring period and approximately 3 m of new grass was added to the trampled width, parts of which were becoming very worn (Figure A1.1). Erosion further down was less evident. The deposition area at the bottom of this site received most of its debris during the winter, and this was trampled down the path during the summer. It proved to be one of the sites at which markers were lost; so many stones were scattered over a large area, and the surface was continuously being re-worked by trampling.

Site 5 (category C)

The original path at this site is deeply incised and bouldery, with frequent erosion of the sides as walkers try to avoid its difficult surface (Figure A1.2). Changes at the site were considerable over the two years, not only in erosion of the main path, but in the various alternatives developing at the site.

Site 6 (category A)

Site 7 (category A)

Both these sites are very stable and changed scarcely at all.

Site 8 (category B)

This path is the latest in a series of short cuts through a wide zig-zag, the original Victorian pony track. Each route developed has cut the corner a little more so that, in turn, the paths have been neglected for the newest track. The present path is wide and direct, but the surface is reasonable for walking, consisting of small stones. Nevertheless, some walkers do utilise the grass at the side and the path has obviously grown by the erosion of a parallel track, followed by the collapse of the strip of intervening vegetation. One such collapse occurred during the monitoring period, but overall the path was relatively stable in comparison with some of the rapid erosion occurring further downhill at sites 4 and 5.

B. CAUSEY PIKE

Site 1 (mainly category C)

This site underwent the most spectacular of the changes measured. The cause of the erosion was water gullying in the winter period, the source of the water apparantly being a series of spring-like concentrations of throughflow, which were captured by the incised path, and channelled, as in a gutter, across the hillside, before spilling downslope leaving a long trail of stones. The period of very heavy rain in October 1977 had a particularly catastrophic effect, but the gullying had been evident in previous winters, as illustrated in chapter four (Figure 4.1).

Site 2 (mainly category B)

This site was a bifurcated path, with one track deeply gullied and the other partly eroded and partly grass. Changes at this site were not very marked except for further incision and some collapse of the side in the old gully, which tended to channel most of the water from the path above. The non-gullied track is not evident in the 1957 air photos, but has developed as a more direct route across a corner.

Site 3 (mainly category B)

This site suffered a small amount of local gullying in its lower sections and also received debris from the path above in its top section. However, the overall effect was small.

Site 4 (category B)

The changes in this site were small, but distinctly pointed to ultimate path widening, and illustrated the way in which the path was developing. A narrow path is in the process of developing, parallel to the main, rather stony path. Erosion of the *Calluna*, peaty humus and some of the topsoil occurred during the monitoring period and this patently would lead to incision, followed by collapse of the intervening vegetated strip, as was occurring elsewhere on the site (Figure A1.3).

Site 5 (category C)

This wide stony site had been subject to considerable gullying in a summer storm in 1975, before measurements began. Much of the site subsequently became the deposition area for debris eroded from the top section. Widening of the path appeared to be inevitable as a result of trampling of the *Calluna* on one side; the species is intolerant of trampling and was clearly being eroded, (Figure A1.4).

Site 6 and 7 (category A)

These are two stable sites with only small changes observed: there was a small amount of vegetation erosion on the main path area.

C. HAWSE END

Site 1 (category A)

There was no significant change at this site.

Site 2 (category B)

This site maintained its overall width, but a small amount of soil erosion was recorded, mainly in the winter.

Site 3 (category B)

This part of the path had developed as a series of steps. During the period of measurement, some of these collapsed and started to form small gullies.

Site 4 (category A)

This path site has a steep cross slope which appears to restrict walkers. The surface vegetation was eroded at the start of measurements, but the site appeared to be very stable and no real change was observed.

Site 5 (category C)

This site, like site 3, developed as a series of steps eroded in the grass. Considerable collapse and amalgamation of the steps occurred to form a continuous gully through the centre of the path. During the measurement period, further erosion occurred (Figure A1.5).

FIGURE A1.1 Wythburn site 4

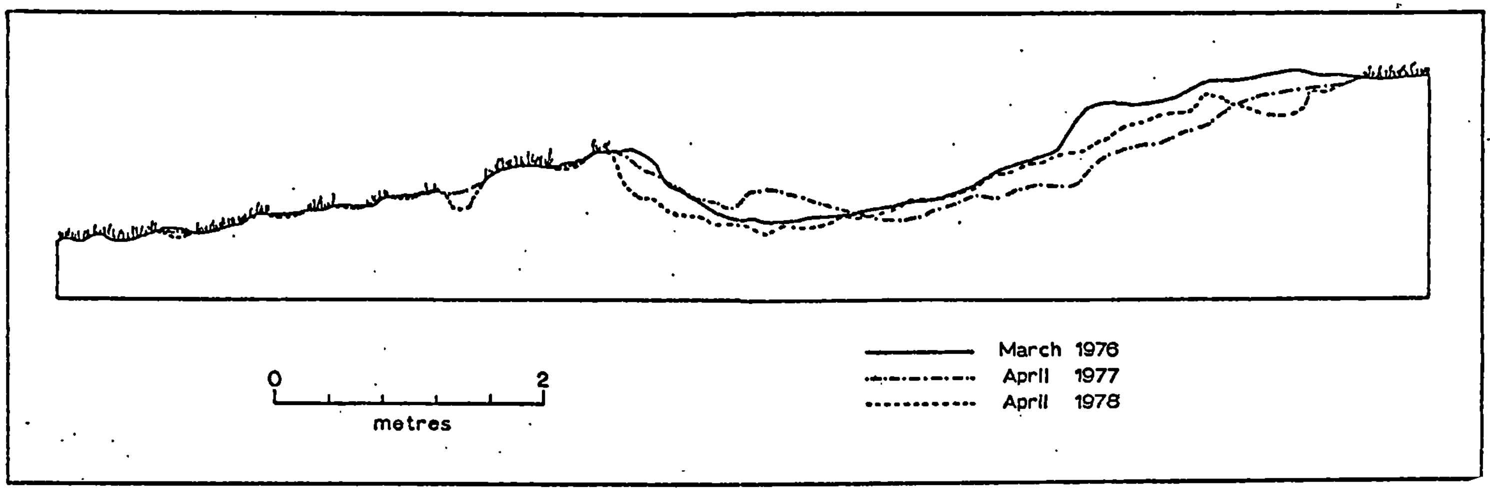


FIGURE A1.2 Wythburn site 5

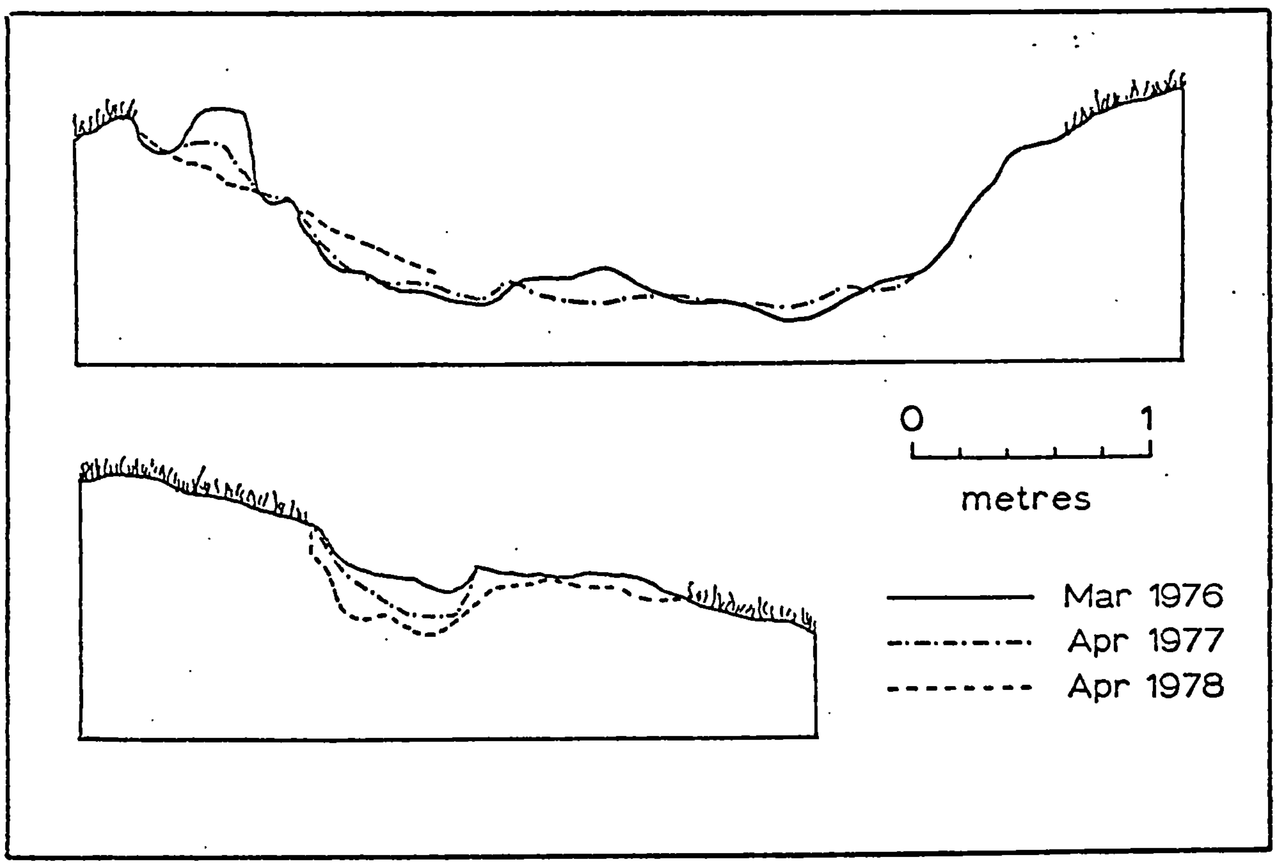


FIGURE A1.3 Causey Pike site 4

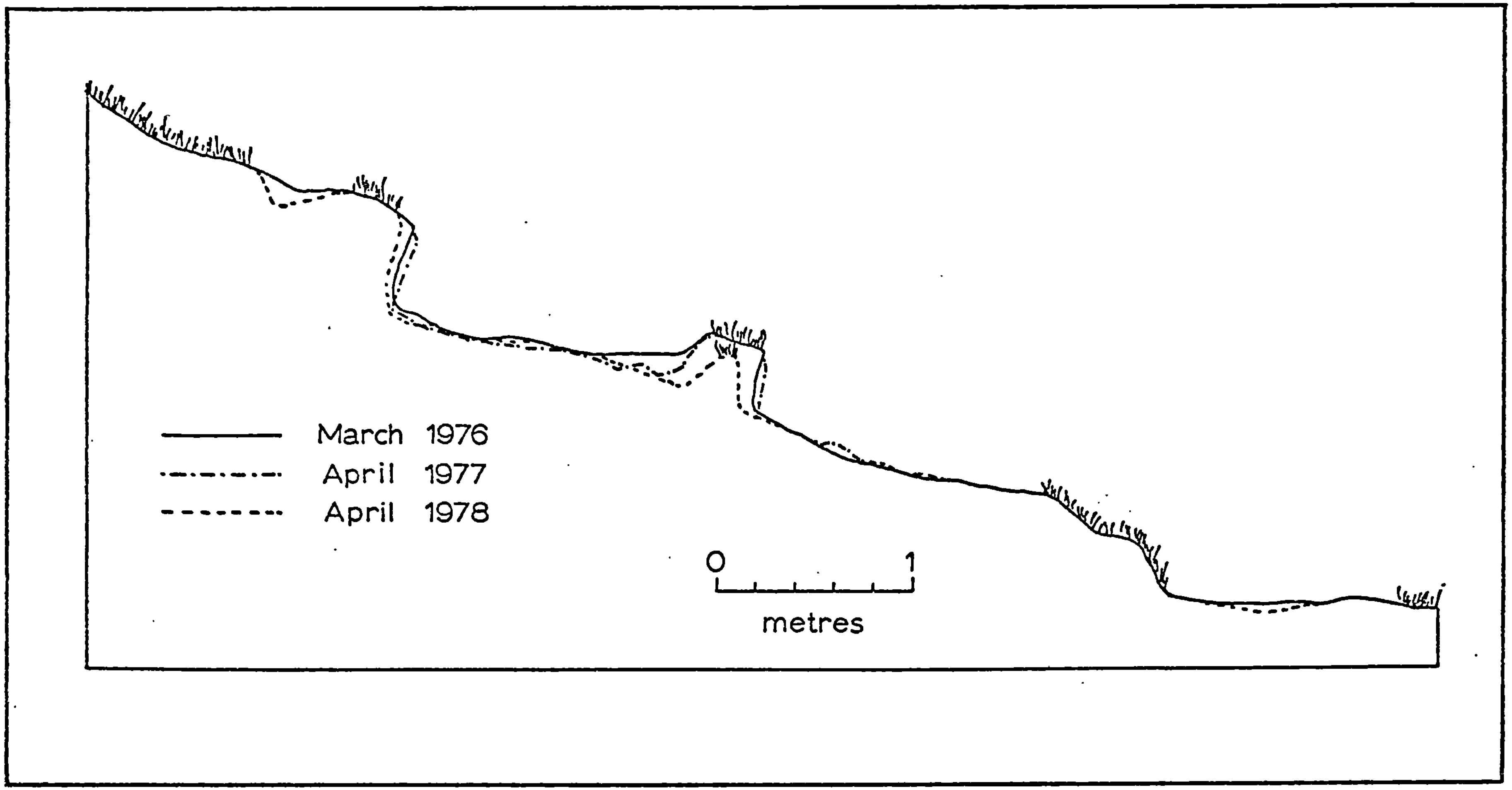


FIGURE A1.4 Causey Pike site 5

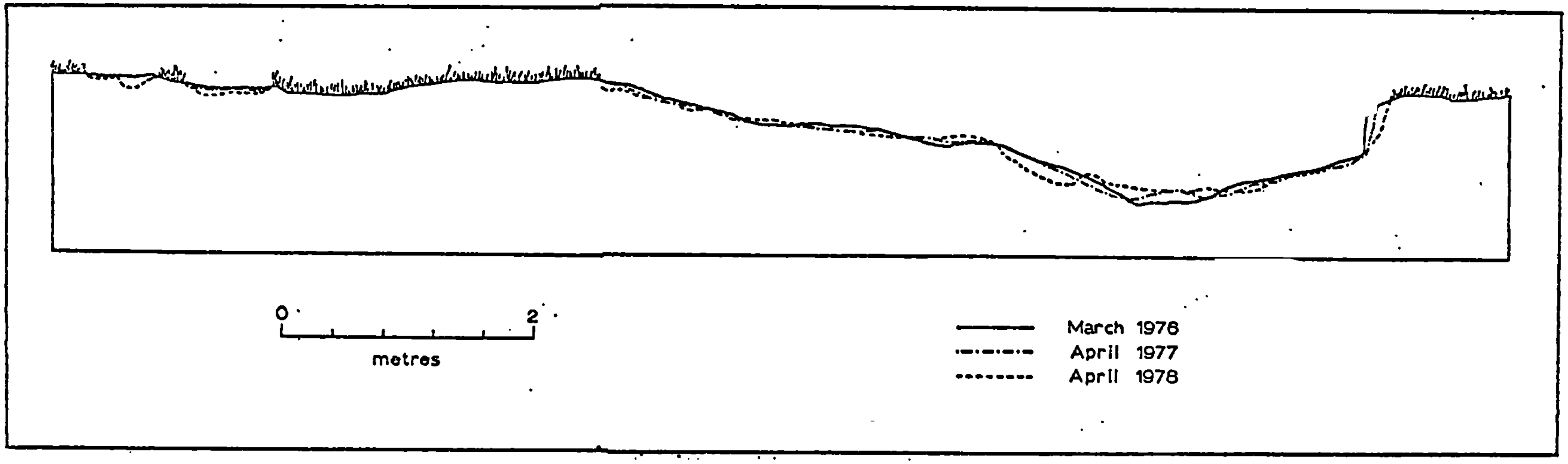
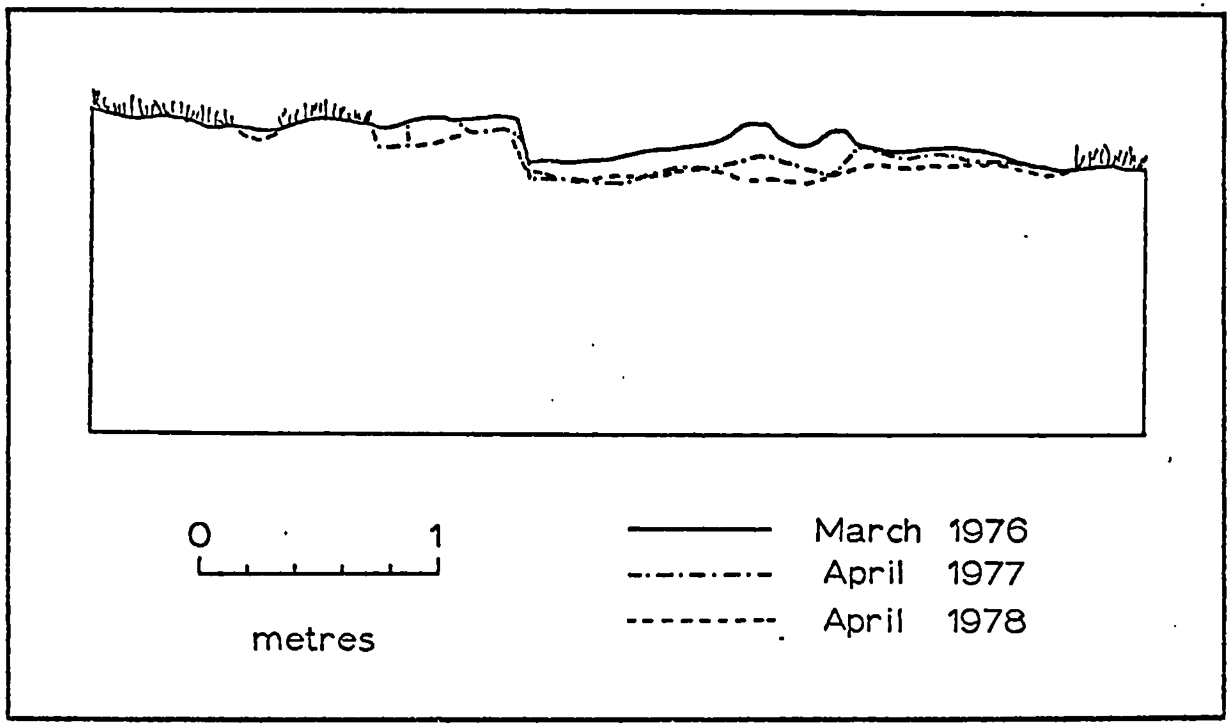


FIGURE A1.5 Hawse End site 5



APPENDIX 2A

AUTOCORRELATION IN THE MORPHOLOGICAL SURVEY DATA

Spatially correlated variables and residuals may produce misleading relationships using Ordinary Least Squares (OLS) regression because both the variance of the regression coefficients and the residual variance may be underestimated (Johnston, 1972; Martin, 1974).

If the spatial correlation can be expressed in the form of a simple linear autoregressive model, a simple technique exists for eliminating the problem approximately (Martin, 1974). The method is that of "first difference". For a sample of N points, with k independent variables, a relationship of the form

$$y'_i = \beta'_o + \sum_{i=1}^{k} \beta_j \, x'_{ji}$$

where $y'_i = y_i - y_{i+1}$

for $i = 1,2,......,N-1$

$x'_{ji} = x_{ji} - x_{ji+1}$

is calculated, using OLS regression for x' and y'.

A better approximation is obtained by using an iterative process to estimate the autoregressive structure (Johnston, 1972). OLS is used to estimate the regression parameters and then an estimate of the autocorrelation coefficient, r_1 is computed from the residuals of this first regression, transformation is then applied to the data of the form

$y'_i = y_i - r_1 y_{i+1}$

for $i = 1,2,......,N-1$

$x'_{ji} = x_{ji} - r_1 x_{ji+1}$

OLS is carried out again, using the transformed variables y' and x', producing new estimates of the regression parameters, and the autocorrelation coefficient, r_2, from the residuals of this second regression. At each stage, the autocorrelation of the residuals can be tested using the Durban Watson "d" statistic (Durban and Watson, 1950, 1951). If autocorrelation is still present after the first transformation of the data, a second transformation is applied, using the second value of the autocorrelation coefficient, r_2.

The process is iterated until there is no significant correlation between successive residuals, at which point the relationship between the original variables, x and y, can be expressed in terms of the final regression parameters.

For the morphological survey data in question, one transformation was sufficient to eliminate the autocorrelation present in the data for path width and bare ground. The values of maximum depth were not autocorrelated. The transformed model was of the form

$$y_i - r_1 y_{i+1} = \beta_o(1-r_1) + \sum_{j=1}^{k} \beta_j(x_{ji} - r_1 x_{ji+1})$$

and so the final regression parameters were those of the transformed OLS with the OLS intercept divided by a factor of $(1 - r_1)$.

Comparison of the two sets of regression parameters (Table A2.1) shows that the differences are small. However, the proportion of the variation in the dependent variable attributed to the regression is reduced, from 66% to 58% for path width, and from 52% to 45% for bare ground.

TABLE A2.1 Comparison of regression parameters between untransformed data and data transformed to accommodate spatial correlation of the residuals

	VARIABLES	Regression coefficient	Standard error	Regression coefficient	Standard error
PATH WIDTH[1] (m)	Path slope squared	-0.0108	0.002	-0.0102	0.002
	Cross slope	-0.0885	0.017	-0.0934	0.017
	Calluna	0.9020	0.259	0.8009	0.328
	Width un-restricted	1.8784	0.259	1.3674	0.268
	Sq. root. rec. pressure	0.2802	0.075	0.3040	0.093
	Interaction slope/rec. pressure	0.0027	0.00024	0.0026	0.00025
	Regression constant	0.7348		0.8687	
	Multiple correlation coefficient	0.81		0.76	
BARE GROUND[2] (cm)	Altitude	0.1012	0.013	0.1006	0.018
	Calluna	79.916	15.767	75.501	19.615
	Ridge Position	-58.024	18.028	-50.653	24.535
	Rec. press. sq. root	15.7009	3.058	15.0499	4.444
	Interaction slope rec. press.	0.0650	0.00417	0.0676	0.00429
	Regression constant	-244.77		-243.73	
	Multiple correlation coefficient	0.72		0.67	

1 autocorrelation coefficient = 0.4005

2 autocorrelation coefficient = 0.3991

APPENDIX 2B

MULTICOLLINEARITY IN THE MORPHOLOGICAL SURVEY DATA

The consequences of multicollinearity in the data are that

1) the relative effect of the different variables may be difficult to separate using OLS, and
2) the coefficient in the regression may be sensitive to certain data sets (Johnston, 1972).

In the morphological survey data, the key variables chosen in the regression by OLS were tested for multicollinearity using an "F" statistic (Johnston, 1972, p 164).

$$F_i = \frac{R_i^2/(k-1)}{(1-R_i^2)/(n-k)} \qquad i = 1,2,3,\ldots\ldots,k \quad k = 10 \quad n = 486$$

where R_i^2 = the square of the coefficient of multiple correlation between each variable, X_i and the remaining k-1 variables. The F statistic is tested with k-1 and n-k degrees of freedom respectively.

The table A2.2 shows the main variables contributing to the value of R_i^2 in each case. Between some variables there is a high degree of interdependence, which may have created instability among the regression estimates of the coefficients. The table emphasises the interrelationships between most of the variables in the regression analysis. The covariance of path slope, recreation pressure and the interaction factor is built into the data by definition (interaction factor = square root of recreation pressure x square of path slope), and other relationships could be predicted logically: cross slope path restriction and position on a ridge are related; altitude and the two soil types are related.

A solution to this problem has been proposed by Hoerl

TABLE A2.2 Tests for multicollinearity in the morphological survey data

VARIABLE	F_i VALUE	VARIABLES CONTRIBUTING MOST TO VALUES OF R_i
Square of path slope	565.2	Recreation pressure, interaction factor
Cross slope	27.4	Path restriction, position on ridge
Altitude	31.3	Soil type brown earth, recreation pressure
Vegetation *Calluna*	20.2	Position on ridge, recreation pressure
Soil type brown earth	27.8	Altitude, soil type podsol, position on ridge
Soil type podsol	7.1	Soil type brown earth, position on ridge, recreation pressure
Path restriction	19.7	Cross slope, position on ridge
Position on ridge	29.4	*Calluna*, path restriction, cross slope, brown earth, podsol
Recreation pressure	89.6	Interaction factor, square of path slope, altitude, podsol, *Calluna*
Interaction factor	591.3	Square of path slope, recreation pressure, position on ridge

Kennard (1970). They suggest a method of estimating the regression coefficients for the case of nonorthogonal independent variables. This "Ridge Regression" technique accepts an error sum of squares larger than the minimum obtained using OLS, but ensures that estimates of the regression coefficients are closer to their true values.

The Ridge Regression Method

Consider a series of standardised vectors $\underline{X}_i = \begin{bmatrix} x_{i1} \\ x_{i2} \\ \vdots \\ x_{in} \end{bmatrix}$,
where i = 0,1,....,p and n = no. of cases

$\underline{X}_0$ = the dependent variable

$\underline{X}_j$ = the independent variables, j = 1,2,....,p

and $\underline{X}$ denotes the matrix of the vectors $\underline{X}_1, \underline{X}_2, \ldots, \underline{X}_p$

Using the method of Hoerl and Kennard, estimates - ridge estimates - of the regression coefficients can be obtained from

$$\beta^* = \left[\underline{X}'\underline{X} + k\mathbf{I}\right]^{-1}\underline{X}'\underline{X}_0$$

where β^* is the vector of regression coefficient estimates.

An alternative form of β^* is

$$\beta^* = \left[\underline{X}'\underline{X} - \mathbf{I} + (1+k)\mathbf{I}\right]^{-1}\underline{X}'\underline{X}_0$$

$$= \left[(1+k)^{-1}(1+k)(\underline{X}'\underline{X} - \mathbf{I}) + (1+k)\mathbf{I}\right]^{-1}\underline{X}'\underline{X}_0$$

$$= \left[(1+k)^{-1}(\underline{X}'\underline{X} - \mathbf{I}) + \mathbf{I}\right]^{-1} (1+k)^{-1}\underline{X}'\underline{X}_0$$

Thus, $\beta^* = \underline{A}^{-1}\beta$, where $\underline{A}$ is equivalent to the correlation matrix of the variables with each of the off-diagonal elements multiplied by $(1+k)^{-1}$; β is the correlation vector between the dependent variable and its independent variables, also multiplied by (k+1).

The standard least squares regression estimate for regression coefficients, β, is of the form

$$\beta = (\underline{X}'X)^{-1}\underline{X}'\underline{X}_0$$

where $\underline{X}'\underline{X}$ is the symmetrical matrix of all correlation coefficients between the variables and $\underline{X}'\underline{X}_0$ is the vector of correlation coefficients between the dependent and its independent variables.

Hence it is possible to calculate values for $\underline{\beta}^*$ using the SPSS package for regression, which requires an input matrix in the form of all the correlations between the $\underline{X}_i$, i = 0,1,2.....,p. The ridge regression estimates can be obtained by constructing a series of modifications to the input matrix, namely, multiplication of each off-diagonal element by $(1+k)^{-1}$ as outlined above, for a series of k values from 0 to 1. The resulting series of regression coefficients are then successive estimates of the "ridge" coefficients, for corresponding k values.

These ridge estimates are then graphed against the values of k to produce a "ridge trace". A decision about the value of k to be chosen for specifying the estimates is made from the ridge trace, by identifying the value of k at which the values of the regression estimates appear to stabilise.

The technique not only provides a way in which more reliable estimates can be obtained, it can also be used as as sorting mechanism for deciding which variables are significant (Hoerl and Kennard, 1970; Jones, 1972). In the case of the Lake District data being studied, thirteen "independent" variables were being considered originally; those listed in table A2.2 plus three more soil and vegetation factors which, using OLS, were apparently not significant. There was no reason not to include them in the analysis, since the ridge technique might offer alternative variable selections to those provided by OLS.

The ridge trace for each dependent variable, for the three dependent variables path width, bare ground and maximum depth, are shown in figures A2.1 - A2.3. Each ridge trace shows the way in which the beta coefficients of the regression change with values of k, and the extent to which corresponding values of the multiple correlation coefficient are reduced -

KEY TO VARIABLES (Figures A2.1-A2.3)

X1 (Recreation pressure)$^{\frac{1}{2}}$

X2 (Path slope)^{2}

X3 X1.X2

X4 Cross slope

X5 Altitude

X6 Path restriction factor

X7 Ridge position factor

X8 *Calluna* vegetation type

X9 *Pteridium* vegetation type

X10 *Nardus* vegetation type

X11 Brown earth soil type

X12 Podsol soil type

X13 Thin rankers soil type

FIGURE A2.1 Ridge trace for the path width relationship

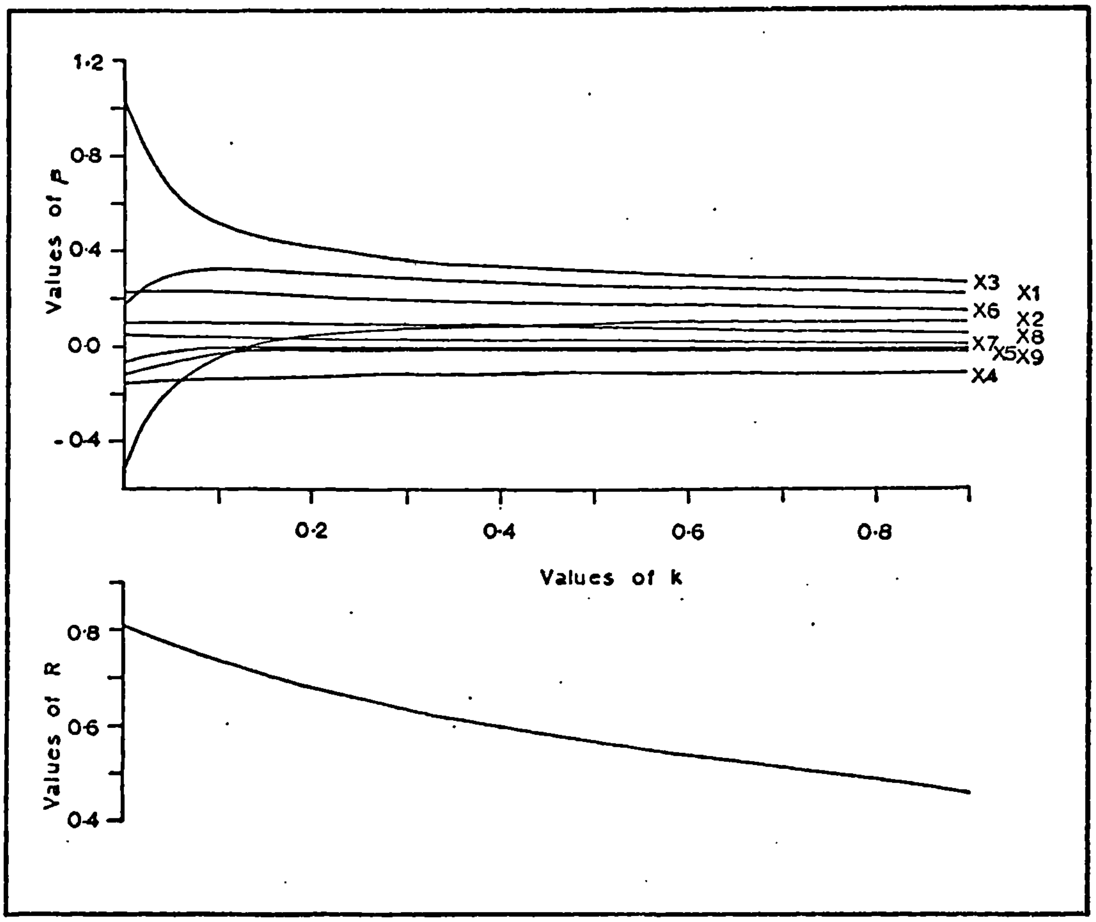


FIGURE A2.2 Ridge trace for the bare ground relationship

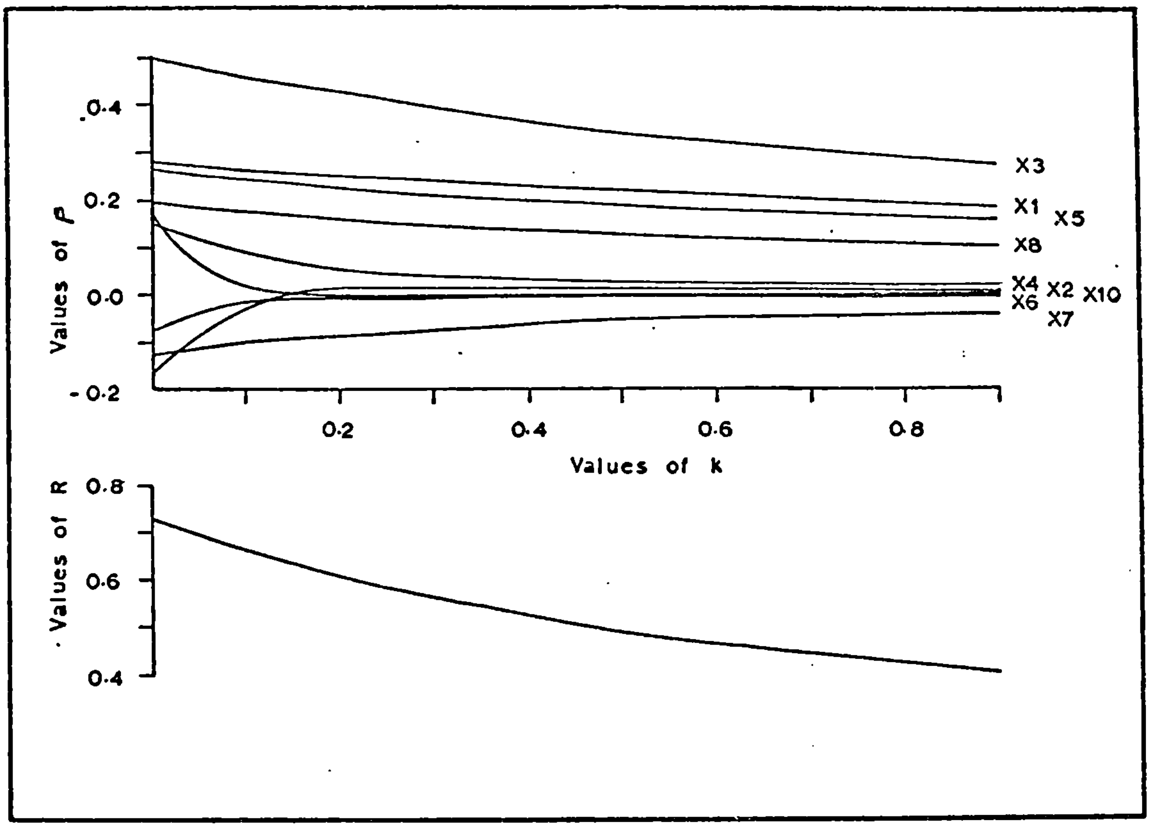
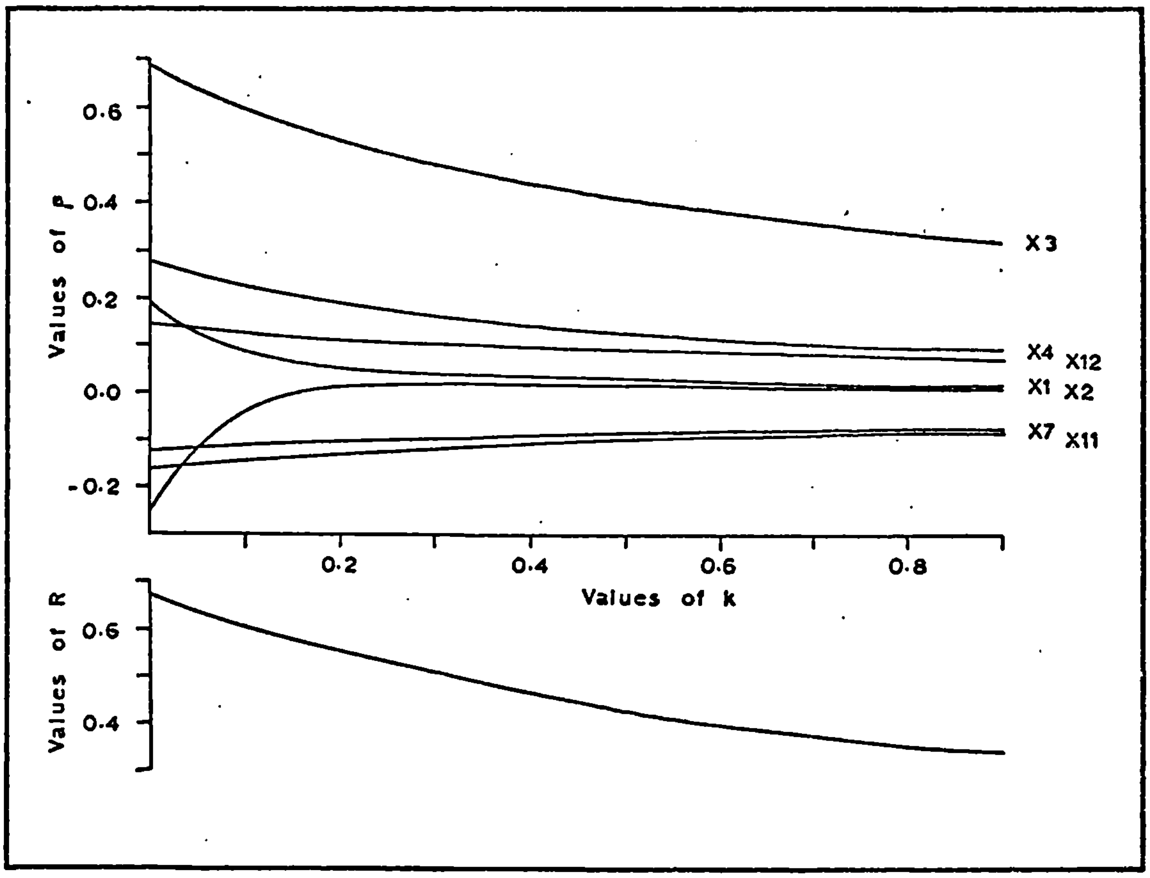


FIGURE A2.3 Ridge trace for the maximum depth relationship



representing the increase in the error sum of squares.

Path Width For this variable, the greatest changes occur, as might be expected, for the independent variables recreation pressure, path slope and the interaction factor of these two variables. The other coefficients, in spite of multicollinearity among them, maintain their stability. The coefficients maintaining a value greater than 0.05 are path slope, recreation pressure, the interaction factor, path restriction, cross slope and, barely, *Calluna* vegetation type. (Any contribution less than 0.05 is too small to be relevant.) Thus, apart from an adjustment that could be made to the relative effects of recreation, slope and their interaction, the factors relevant to the relationship between path width and site variables are not changed.

If an adjustment were to be made, then an appropriate value of k would be 0.2, which would provide more stable estimates of the regression coefficients, but at the expense of an increase in the error sum of squares from 34% to 54% of the dependent variable variation.

Bare Ground The most unstable coefficients are those for Nardus vegetation type, path restriction and path slope, none of which appear as significant in the OLS regression. The coefficients maintaining a value greater than 0.05 are recreation pressure, the interaction factor, altitude and *Calluna* vegetation type; the ridge factor almost maintains the value 0.05. Hence the OLS factors are retained in the ridge regression, with the possible exception of the ridge position factor.

Maximum Depth For this variable, the coefficients of path slope and recreation pressure are unstable and converge to a value near zero. The coefficients maintaining their stability and values greater than 0.05 are the interaction factor, cross slope, podsol soil type, brown earth soil type and the ridge position factor. In other words the ridge regression confirms the results of the OLS.

In conclusion, it appears that in spite of quite a high degree of multicollinearity in these data, the coefficients obtained from OLS are reasonably stable. The large sample size may have been instrumental in providing this stability.

APPENDIX 3

COMPLETE RESULTS FROM THE EXPERIMENTAL FOOTPATH AT BRADFIELD

DATE	RAINFALL PATH SITE (ml)	RAINFALL MET. STA. (mm)	TROUGH COLLECTIONS PATH A WATER (1)	TROUGH COLLECTIONS PATH A SEDIMENT (g)	TROUGH COLLECTIONS PATH B WATER (1)	TROUGH COLLECTIONS PATH B SEDIMENT (g)	TRAMPLING NO.
1977							
Sept 8	15	NA	4.8	8.6	8.6	308.2	1
10	10	3.1	0.3	TR	3.2	23.5	4
13	4	3.1	0.1	TR	3.0	10.8	4
24	60	NA	3.2	TR	14.5	30.1	2
29	24	NA	0.1	TR	2.8	14.3	5
Oct 7	84	NA	4.7	TR	20.8	70.0	4
11	28	NA	2.6	TR	19.5	369.6	4
13	12	3.0	TR	TR	3.0	63.7	5
20	23	9.9	TR	TR	10.3	51.7	5
21	11	2.0	TR	TR	3.4	54.4	3
22	5	2.8	TR	TR	5.0	31.0	1
24	15	4.2	TR	TR	1.5	TR	5
Nov 1	38	11.6	TR	TR	19.4	198.3	4
17	198	91.3	9.5	52.5	24.0	733.1	2
22	52	21.6	TR	TR	16.8	250.0	1
24	52	19.2	4.1	11.7	16.0	268.3	1
Dec 2	12	3.1	0.0	0.0	0.0	0.0	3
7	5*	NA	TR	0.0	TR	0.0	5
8	35	16.6	4.0	10.0	15.2	17.5	1
12	50	19.0	0.2	TR	15.4	115.2	1
19	32	9.4	0.0	0.0	16.3	88.1	5
22	10	4.0	0.0	0.0	0.0	0.0	2

* includes some snowmelt.

Trampling numbers: 1- 0
2-25
3-50 tramples up and down
4-75
5-100

NA Rainfall data not available

TR Trace only - less than 1.0 g sediment
less than 0.1 l water

DATE	RAINFALL PATH SITE (ml)	MET. STA. (mm)	TROUGH COLLECTIONS PATH A WATER (1)	SEDIMENT (g)	PATH B WATER (1)	SEDIMENT (g)	TRAMPLING NO.
1978							
Jan 4	135	29.5	0.0	0.0	18.5	336.6	2
13	27*	NA	0.0	0.0	14.5	5.9	4
25	90*	NA	4.0	TR	16.2	8.1	1
31	96*	NA	0.0	0.0	11.5	55.8	2
Feb 3	70*	NA	0.3	0.0	15.5	25.8	1
Mar 2	165*	NA	5.0	0.0	20.0	9.1	4
6	11	NA	0.0	0.0	0.0	0.0	5
18	83	13.5	0.0	14.2	14.2	141.2	3
Apr 12	180*	NA	0.2	0.0	16.0	15.1	5
28	92*	NA	2.0	TR	24.0	234.8	5
May 3	82	18.0	0.0	0.0	24.0	178.3	2
9	80	6.7	0.0	0.0	10.8	64.8	5
19	22	7.1	0.0	0.0	0.8	0.0	5
June 5	20	6.0	10.5	TR	1.8	0.0	3
17	85	28.7	15.0	30.4	17.2	633.8	3
22	28	8.2	10.8	11.5	17.5	227.6	5
28	15	4.6	0.2	TR	1.1	TR	2
30	41	9.0	15.1	1.9	24.0	9.6	3
July 3	42	12.2	14.8	3.7	19.8	25.9	2
5	29	6.5	4.0	TR	9.8	10.1	4
27	48	19.3	15.0	TR	20.1	9.7	5
29	12	5.4	5.0	TR	12.0	41.5	4
31	25	10.9	15.0	TR	24.0	64.8	1
Aug 2	22	7.9	6.5	TR	24.0	40.9	3
4	35	7.3	8.0	58.6	24.0	862.7	4
7	12	3.8	0.0	0.0	0.4	TR	5
11	55	17.1	3.0	1.8	19.4	123.0	3
15	20	8.9	0.0	0.0	5.0	TR	3
30	30	5.7	0.0	0.0	3.0	TR	4
Sept 2	32	4.9	0.0	0.0	5.1	3.6	2

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