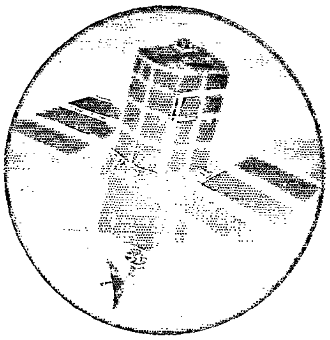
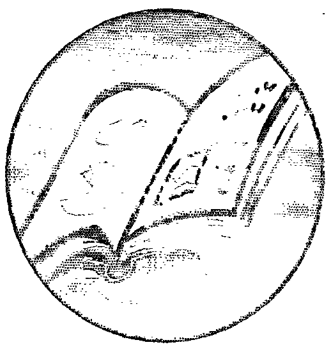
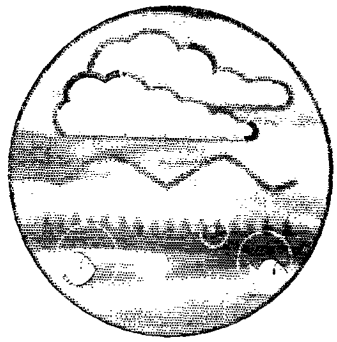
The Impact of Grazing and Upland Management on Erosion and Runoff: Additional Information

Research and Development

Project Record
P2/035/9

ENVIRONMENT AGENCY

The Impact of Grazing and Upland Management on Erosion and Runoff: Additional Information

R&D Project Record P2/035/9

M Johns

Research Contractor:
APEM

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FOREWORD

The Project Record is intended to provide a valuable source of reference for individuals who are involved in the management of the British Uplands. It was initiated as a result of interest raised by a paper written for the British Hydrological Society by Anne Sansom in 1996 entitled "Sheep and Floods".

Conclusions have been drawn about how different management systems affect erosion and runoff rates and indicates the range of potential impacts which can arise from high levels of erosion and runoff. In addition, recommendations are made for changes in management strategy and doctrine.

This project sets out to examine the scope of a future study which could quantify the relationships between grazing, erosion and runoff. It is not a panacea which can be used to solve upland erosion problems, that is the next task.

Many thanks are due to Anne Sansom, the Project Manager at the Environment Agency, without whom a great deal of valuable attention would not have been drawn to the importance of grazing and upland management. Throughout the period of time spent undertaking this R&D study she has been a source of inspiration and has provided much valuable information and evidence. She has provided an essential link between research, the Agency and the farming community, without which future progress would be hindered.

Thanks must also go to Dr. Stephen Boult of Intelisys Ltd, Manchester, for his significant contributions to this report. His understanding of catchment processes and climate systems was critical to providing a realistic evaluation of catchment management and physical system interactions.

In addition, Jim Loxham, Martin Price, Richard Spensley, Bob Evans, Jim Walker, David Sykes, Judy Palmer, Sue Rees, Liz Allen, and all the other individuals who have contributed to this study must be acknowledged as their inputs have ensured its relevance and applicability.

CONTENTS

List of Figures		v
Glossary		vii
Executive Summary		x
Key Words		xi
1.	**Introduction**	**1**
Part One	**Background**	
2.	**A Template of Interrelated Processes**	**6**
2.1	Introduction	6
2.2	Cycles of Change: Different Orders of Resolution	6
2.3	Erosion Mechanisms	8
2.4	The Sensitivity of Landscapes to Erosion	17
2.5	The Role of Vegetation	18
2.6	Agricultural Change in the Uplands	20
2.7	A Brief Review of Agricultural Policies Which May Direct Upland Farming	22
2.8	Trends in Upland Farming Practice	26
2.9	The Intensive Grazing/ Overgrazing Issue	27
2.10	Conclusions	29
Part Two		
3.	**A Review of Relevant Research and Information**	**32**
3.1	Introduction	32
3.2	The Impact of Livestock on Upland Erosion and Runoff Rates	32
3.3	The Impact of Burning on Upland Erosion and Runoff Rates	56
3.4	The Impact of the Control of Bracken on Upland Erosion and Runoff Rates	60
3.5	The Impact of Air Pollution on Upland Erosion and Runoff Rates	64
3.6	The Impact of Recreation on Upland Erosion and Runoff Rates	65
3.7	The Impact of Afforestation on Upland Erosion and Runoff Rates	68
3.8	The Impact of Land Drainage on Upland Erosion and Runoff Rates	70
3.9	The Underlying Control of Climate	73

Part Three

4.	**A Qualitative Assessment of the Local, Regional and National Extent of Upland Erosion in England and Wales**	**79**
4.1	Introduction	79
4.2	Case Studies of Upland Erosion in England and Wales	79
4.3	Erosion in the Uplands of England and Wales: A Critical Analysis	87

Part Four

5.	**The Impacts of Upland Erosion and Runoff on the Environment Agency**	**98**

Part Five

6.	**Recommendations for Future Work**	**102**
6.1	Work Required	102
6.2	Work in Progress	102
6.3	General Recommendations	103

Part Six

7.	**Conclusions**	**106**
7.1	Introduction	106
7.2	Policy	107
7.3	Impacts of Upland Management	108
7.4	The Spatial Extent of the Problem	111
7.5	The Future	112

8. Bibliography	**113**
Appendix One: A Directory of Relevant Individuals and Organisations	**130**
Appendix Two: A Directory of Relevant Projects	**133**
Appendix Three: Comments From A Sheep Farmer	**136**
Appendix Four: Colour Figures	**137**

LIST OF FIGURES

1. The cycling of rock material in the upper crust.
2. The interrelationships between drainage basin systems.
3. The complexity of a catchment biogeochemical cycle.
4. Frost-shattered blocks of rock.
5. A classification of mass-movement processes on slopes.
6. The effect of rainsplash on slopes.
7. Surface runoff and puddling of water.
8. The relationship between erosion, transportation and sedimentation.
9. A Lake District river in spate.
10. Corrasion and cavitation forming potholes.
11. Greater numbers of sheep are overwintered and foddered in the uplands today than in the past.
12. A model of the effects of trampling and grazing on soil, herbage and animals.
13. Trampling and Puddling in a feeding area.
14. Effects of excluding stock from vegetation.
15. River bank erosion in non-fenced and fenced areas.
16. unoff and sheep numbers in a North Derwent catchment.
17. Burning as a management tool.
18. The risk of fire in the uplands.
19. The appearance of bracken dominated slopes.
20. Areas of bare ground are left after bracken has been cleared.
21. The effects of recreational erosion upon footpaths.
22. An eroding moorgrip.
23. The impact of free-range piggeries.
24. Rilling of slopes.
25. Runoff of water and soil into water courses.
26. Grazing on the Wiltshire Downs.
27. Recreation erosion on the Langdale Pikes.
28. Footpath erosion in Great Langdale.
29. Stable boulderfields on the slopes of Helvellyn.
30. Unstable eroding scree on the slopes of Helvellyn.
31. Material being transported down Dry Gill.
32. The impact of the movement of material along Dry Gill.
33. Full blown sheet erosion on Lingmell.
34. Longmoor common, not grazed.
35. Kinneside Common, Intensive grazing.
36. The Side, low levels of grazing resulting in robust vegetation and stability.
37. Side Wood.
38. Rabbit erosion in Littondale.
39. Erosion of river banks where grazing occurs.
40. An abandoned channel, the product of channel migration.
41. Differential grazing of heather in Swaledale.

42. The visual impact of excluding sheep from land.
43. Eroding peat.
44. Isolation of peat hags and the exposure of mineral soils.
45. Desiccation of peat bogs.
46. Incision of peat hags.
47. The effects of bracken control.
48. Footpath erosion in the North York Moors.
49. Vegetation recovering after bracken control.
50. Islands of vegetation.
51. Gully erosion along a long-distance footpath.
52. Grazed upland moors.
53. River bank erosion.
54. River bank erosion.
55. Sheep congregating at a ring feeder.
56. The National Parks of England and Wales.

GLOSSARY

Abrasion
The process by which solid rock is eroded by rock fragments transported by running water, glacier ice, wind and breaking waves.

Albedo
The proportion of the total solar radiation which is reflected by the Earth's surface.

Alluvium
Material deposited adjacent to a river channel, e.g. a floodplain.

Anastomosing
A term used for a stream in which numerous individual channels are continually separating and rejoining.

Attrition
The process whereby the load particles of rivers, glaciers, winds and waves are reduced in size as a result of continual impacts between individual particles.

Bedload
The solid rock particles which are transported along the floor of a river channel by rolling, sliding and saltation; an alternative term is traction load.

Carrying Capacity
The maximum number of 'users' which can be supported by a given resource or set of resources e.g. the greatest number of livestock which can be adequately fed on the output of a given area of pasture.

Cavitation
A process occurring within streams flowing at a very high velocity. Bubbles of air within the water implode, causing shock waves which hurl rock particles within the stream against the channel margins. This smooths, striates and erodes the channel.

Channel
The intrenched part of a valley floor occupied either temporarily or permanently, and either in part or full, by the flowing water of a river or stream.

Chemical Weathering
The decomposition of rock minerals by agents such as water, oxygen, carbon dioxide and organic acids.

Colluvium
Material in transport to channel and floodplain deposits.

Corrasion
The purely mechanical erosion of rock surfaces by the impact of debris being transported by streams.

Corrosion
The purely chemical erosion of rock surfaces by flowing water, as in limestone which is attacked by carbon dioxide dissolved in streams.

Erosion
The sculpturing action of running water, sliding ice, breaking waves and winds armed with rock fragments.

Fluvial
A term applied to the action of rivers and streams.

Geomorphology
The science of landform study.

Infiltration
The movement of water, derived from water or melting snow, into the soil at a rate depending on soil porosity, the degree of compaction of the soil surface, the presence of plant roots, and the degree to which soil moisture is already present (the antecedent conditions of the soil).

Infiltration Capacity
The constant rate at which water can enter the soil in a particular case.

Intensive Grazing Pressure
This is a term which is applied where the impacts of grazing animals (the removal of vegetation and trampling) are concentrated into a restricted space. This can occur wherever the numbers of sheep exceed a stocking density suitable for a particular terrestrial environment. This can develop from a number of causes including: the elevated numbers of stocked animals in too small an area; where vegetation (e.g. bracken) encroaches onto viable land; or where livestock are concentrated around honey-pots (e.g feeding troughs). This should be used instead of **Overgrazing**.

Load
The material (dissolved or solid) being transported by a river. The load may be carried in solution, as suspended sediment or as traction load dragged, rolled or bounced along the river bed.

Mechanical Weathering
The disintegration of rocks into fragments by entirely mechanical means such as expansion and

contraction.

Morphology
The 'study of form' in the context of geomorphology, a principal aim of which is to study the shape, size and origin of landforms.

Overgrazing
A level of grazing which has negative impacts on the soil and sward. Agricultural overgrazing refers to the removal of vegetation at a rate or density that the stock cannot sustain itself without alternative feeds. Ecological overgrazing refers to the removal of vegetation at a rate or density which has direct impact on floral or faunal survival and diversity. Overgrazing can occur at a level where soil becomes eroded an transported. This term should be avoided and **Intensive Grazing Pressure** should be used instead. Overgrazing implies mismanagement and has a negative implications for graziers.

Poaching
A descriptive term for the effect hooves have on soil (compaction and shearing), often found around feeding troughs and river banks.

Porosity
The possession by a soil or rock of pore spaces (interstices) between the individual constituents such as pebbles, sand-grains or clay particles.

Rill Erosion
The formation of small, sub-parallel channels on a slope as sheetwash begins to become concentrated.

Runoff
The surface discharge of water, derived mainly from rainfall but also from melting snow and ice, in the form of sheetwash and rivulets on slopes. Runoff is generated where rainfall intensity exceeds the infiltration capacity of the soil, leading to the build-up of a surface layer of water.

Saltation
A process of transportation in rivers, involving the continual 'jumping' of small particles (usually sand grains)along the channel floor.

Solution
The removal by rainwater and percolating groundwater of dissolved minerals and the products of other weathering processes.

Weathering
The breakdown and decay of rocks *in situ*, giving rise to a mantle of waste or loose debris which may be removed by the processes of transport. Weathering is divided into two main types, chemical weathering and mechanical weathering.

Upland Sheet Erosion
A combination of impacts from the activities of animals, rain, wind and frost affecting large areas of slopes, causing exposure and erosion of soil and rock.

EXECUTIVE SUMMARY

The fundamental conclusion of this project is that the enhanced removal of vegetation, erosion of soil and rock and the consequential increased runoff of water is a widespread problem in the British uplands. Where academic study has failed to yield evidence of this, anecdotal and photographic evidence has managed to do so. The net effects of this enhanced erosion have severe impacts on the functions of the Environment Agency and the wider economy.

It would appear that the impact of intensive grazing pressure forms a large component of the cause of the problem. However, other mechanisms do cause soil erosion in the uplands. The creation of bare soil from the effects of agents such as fire, bracken control and forestry exacerbates the impacts of other erosion mechanisms. The presence of grazing animals on such areas of bare soil increases the erosion rates and retards the return of vegetation (which has the potential to reduce erosion and runoff).

In general, agriculture has become more intensive, especially in lowland areas, in that stocking densities and the numbers of sheep reared have risen in some locations. However, upland farming could also be considered as extensive, in terms of mass reductions in labour. This has direct consequences for management which has effectively decreased, resulting in a lack of shepherding (pre-war ratio's of shepherds to sheep were 1:2-300, today the ratio can be as large as 1:12-1500; Spensley, pers. Comm.). Therefore, uncontrolled livestock cause hotspots of grazing pressure and impacts from hooves.

In the past, the management of the uplands and grazing animals was a sustainable symbiotic relationship. The numbers of sheep grazed was controlled by the amount of fodder produced by the land and the ability of the farmer to transport feed to remote moortops. Today, artificial feeds are used to sustain large flocks, and All Terrain Vehicles can transport the feeds to remote areas, promoting year round grazing. Winter grazing is particularly damaging as the vegetation is not growing during this period. In addition, stressed vegetation is more susceptible to extreme environmental conditions (e.g. drought, freezing cold) and the creation or enhancement of bare soil is more likely when such conditions occur.

The problems caused by grazing pressures and trampling may not simply be due to the higher densities of sheep on the hills, but due to a combination of high densities of sheep and the low numbers of shepherds who can reduce concentrations of livestock and spread the impact of grazing and trampling.

All agencies concerned with this issue should focus on the wider aspects of the catchment, not just discrete areas (e.g. moorlands, ESAs, SSSIs, LFAs).

Long-term data sets are required to quantify the problem; these are currently unavailable. However, the areas affected by erosion and high runoff (e.g. Swaledale) do have people living and working in them and they could be considered as "laboratories" which have had long-term experiments running in them. It is therefore worthwhile remembering these people and using their knowledge and experiences to gain a qualitative understanding of the problems. However, this type of information should not be used as a basis for remediation strategies, qualitative datasets are also required.

It is apparent from the review of literature conducted in Part Two of this report that the academic community has a full variety of conclusions on the subject of grazing, erosion and runoff which are often at odds with each other. The variety of findings from the study of the subject can be attributed to the scale at which the problem or process is viewed. Generally, experimental catchments are small and therefore tend to be non-representative. An overall model is required as different effects occur at different scales. To achieve this, long-term studies need to be initiated in a variety of different catchments.

A final consideration involves the timescale over which erosion problems are viewed. For example, there will be another glaciation in the future, the effects of which will mask the impacts of grazing induced erosion seen today. Alternatively, if a long return-period flood event occurs, such as that seen in Eastern Europe during July 1997, the impacts on the landscape will negate the physical scars of grazing induced erosion.

However, while the effects of current upland erosion may be regarded as small-scale when compared to events such as glaciations, they are obviously of great significance to current ecological and socio-economic systems. Everyone who has become involved in the uplands in any way (for example, farmers, conservationists, and walkers) has a responsibility for their physical and biological well-being. The actions of humans in the uplands will also affect other ecological and socio-economic systems in the lowlands. Instead of being fatalistic about the impact of large scale physical events, we should be positive about the natural importance of these areas and promote their longevity as part of an overall strategy of sustainable development.

KEY WORDS

Erosion, runoff, grazing, sheep, impact, upland, management.

1. INTRODUCTION

Erosion has occurred throughout geological time and involves the breakdown of rock and soil *in situ* (**weathering**) and the transportation of this material which can be broken down further (**attrition**) whilst in transit. Natural rates of **erosion** can be thought of as a balance, with the removal of material being supplemented by new material replacing it from higher up a catchment or slope. These rates attempt to conform to a "quasi-equilibrium". However, if the rate of removal is greater than renewal and there is a net loss, then **erosion** can be thought of as being "accelerated". In this manner, the balance or quasi-equilibrium state is disturbed to a point at which catastrophic events may occur (such as landslides in uplands, bank failure in **fluvial** systems or **rilling** of fields and loss of soil in the lowlands).

An increase in the stocking densities of livestock (due largely to an increase in sheep subsidy payments) may have direct links to an increase in the level of riverbank and slope **erosion** (there is much anecdotal evidence to support this). Sheep numbers have increased by an average of 34% in Britain since 1982 and from 12 million in the 1940s to approximately 43 million sheep today (Wildlife Trusts, 1996). In many locations, the numbers of sheep grazing a particular area of land are too high for the vegetation cover to be able to maintain itself (intensive grazing/**overgrazing**). Natural regeneration may be totally halted if grazing animals are present. In these circumstances, the vegetation may be lost altogether, exposing soil and rock which then becomes poached and compacted by livestock moving over it. Once exposed, natural **erosion** processes can rapidly enhance the degradation process.

Uplands, especially blanket bogs, have been subject to drainage ('moorgripping') aimed at improving grazing and have also suffered the impacts of polluted air and acid rain, which have direct impacts on the stability and diversity of the vegetation cover and the rate at which water runs-off these areas. An increase in the incidence of accidental and deliberate moorland fires, which can also drastically affect the vegetation, has compounded this problem. In addition, any change in climate will have an underlying and effective control over physical and biological systems. Vegetation stressed by grazing activity is much more likely to succumb to climatic stresses (e.g. drought) than healthy vegetation.

River systems (especially in upland regions) are subject to an influx of sediment, ranging in size from silt (from peat moors and alluvial plains) to cobbles and boulders (from mountain slopes and reworked glacial or **fluvial** deposits). Where accelerated **erosion** is occurring, a "choking" of **channels** with a range of sediments can occur, which may have a wide range of detrimental impacts upon the aquatic environment. In addition, an apparent increase in the occurrence of high magnitude precipitation events coupled with increased **runoff** rates (causes of this include the loss of vegetation cover and land drainage) facilitates an increase in the **erosion** of river banks, the reworking of **channel** deposits, flooding and the deposition of large amounts of coarse **fluvial** deposits upon the floodplain.

A paper was released in 1996 (Sansom, 1996) which asked the question "Floods and Sheep, Is There a Link?". The paper described a wide range of negative impacts occurring in the Yorkshire Dales which were potentially attributable to the rise in sheep numbers and intensive grazing regimes. This paper (and a follow-up "Drought and Sheep-is There a Link"; Sansom, 1997) raised interest in the subject within the Environment Agency and promoted concern about the potential wide-ranging impacts upon the functions of the Environment Agency. In turn this led to the precipitation of this Research and Development (R&D) study.

The phenomena described above have the potential to affect all functions of the Environment Agency (Flood Defence, Water Resources and Quality, Fisheries and Conservation and Waste Management). The "off-farm" cost involved in rectifying or preventing some of the negative impacts described in this report are characteristically greater than the "on-farm cost". Some of the potential impacts are listed below:

- A greater rate of **runoff** can promote spate events; this has an obvious effect upon current flood defence strategies and the risk of property damage. Where river banks are eroding into public highways or properties, a reactionary approach is usually undertaken instead of a proactive one. For example, river banks are repaired using blockstones, riprap, revetments, gabions, reprofiling and revegetation (in many cases with little or no long-term success). Where livestock graze adjacent to eroding banks, fences may be erected to prevent further **poaching** of the banks.

- The interception of rainfall by a high biomass of vegetation can increase the ability of soils to allow the easy percolation of rain and snowmelt into ground-water systems, and increase evapotranspiration losses. Therefore, a high biomass of vegetation can reduce the risk of spates. A loss of such vegetation (through grazing pressure, fires etc.) and reduction in soil **infiltration capacity** (due to trampling, saturation and drought) will result in the majority of precipitation moving rapidly over the surface of the land to receiving water courses. This may increase the risk of flooding and exacerbate summer drought conditions. There may be serious implications for water resources, unless this rapid discharge of water can be intercepted in storage reservoirs.

- Increased **loads** of transported sediments may be reaching receiving watercourses or storage reservoirs. Where the **load**ing of fine material is increased, there may be a negative impact on water quality, increasing the need for de-silting and further treatment. The silts may also contain materials hazardous to human health or detrimental to water quality (e.g. metals, pesticides, pathogens, nutrients).

- Degraded and denuded environments lose much of their aesthetic appeal. This can be due to discoloration of waters by suspended solids or the loss of riparian habitat and physical burial of the **channel** (choking) by coarse sediments. These undoubtedly have a serious implication for the conservation of invertebrates, fish, birds and mammals. In turn, this will have a knock on effect to the recreational users of rivers (canoeists, anglers etc.).

- Other land use practices associated with the uplands may also have serious implications. These include the impacts of accidental or deliberate fires, the control of bracken, and the increased use of synthetic pyrethroid sheep dips in the vicinity of watercourses.

- In many upland sites, coarse gravels, cobbles and boulders are remobilised from glacial deposits as a result of rapid overland flow of water and spate flows. These act as a destructive tool when the river is in flood. Sands and gravels abrade anything in their path (riparian vegetation, fish, structures) whilst cobbles and boulders impact against banks and structures as well as exacerbating the lateral and vertical **erosion** of river **channels**. Intensive grazing along river banks weakens a river's ability to withstand these pressures, further exacerbating the problem.

- Removal of soil or rock at a rate greater than that of natural renewal promotes a change or loss in the biological and physical conservation value of the uplands. In some cases this process is already irreversible and active scree slopes are forming from previously well vegetated hillslopes.

As far back as 1971, Dr Bob Evans of Cambridge University, undertaking research into soil **erosion**, called for schemes to monitor **erosion**. His work led to the attention of some organisations (e.g. the Peak District National Park Authority and the National Trust) to focus upon issues surrounding upland **erosion** and the impacts of grazing. Subsequently, a wide range of research has been undertaken into many aspects of upland **erosion** and management.

The Wildlife and Countryside Link (WCL) in their 1997 report "Farming the Uplands in the Next Millenium" (written on behalf of members including the Council for National Parks, National Trust, The Wildlife Trusts, Wildfowl and Wetlands Trust, WWF-UK, RSPB, and CPRE) clearly state that recent agricultural changes (e.g elevated grazing pressures) have affected the natural environment in numerous ways including the loss of habitats such as heather moorlands, associated flora and fauna, the creation of bare soil and its subsequent erosion.

Projects have been commissioned which address many of the associated impacts. For example, the National Rivers Authority's (Environment Agency) R+D Note 409 looked at the "Effects of Agricultural **Erosion** on Water Courses", Project 113 assessed the "Impacts of Diffuse Pollution on Receiving Water Courses" and R+D Note 87 identified how buffer zones could be used for the conservation of river and banksides. In 1995, the NRA produced a document which promoted "Understanding Riverbank **Erosion**" in uplands and lowlands. In addition The Ministry of Agriculture, Fisheries and Foods (MAFF) has produced two "Codes of Good Agricultural Practice" for the protection of soil and water.

Consistent academic research into specific aspects of upland **erosion** and **runoff**, coupled with anecdotal evidence of their wider impacts, has created the urgent need to draw together information on this subject and to approach the topic of upland **erosion** in a more systematic and holistic manner.

The loss of vegetation biomass removes the insulating properties of vegetation which protects against freeze-thaw activity and frost-heave during the winter and dehydration and desiccation in the summer. This type of soil disturbance prevents revegetation and therefore, may promote further **erosion**.

Therefore, this report will attempt to assess the potential cause(s) of accelerated upland **erosion** and **runoff** and will investigate the direct and indirect environmental and socio-economic impacts. However, it is recognised that the scale of the task is large and future work will be needed. This project is primarily a scoping study, with one of its tasks being to identify areas where information is lacking and to make recommendations on the focus of future work.

The overall objective of this project is to examine the scope of study required to determine the extent that impacts of grazing pressures in upland areas are responsible for the increased **runoff** rates and soil **erosion** observed.

To achieve this prime objective, specific actions will be undertaken:

1. A review of related research and information (Part Two).

2. To examine whether policy/guidance/legislation already exists on sheep grazing densities, including its effectiveness or whether this is causing some of the problems (Part Two).

3. To examine the validity of the theories postulated with alternative explanations (Part Two).

4. To determine whether similar problems are occurring in upland areas nationally (Part Three).

5. To make recommendations for action and further research (Part Five).

PART ONE

BACKGROUND

2. A TEMPLATE OF INTERRELATED PROCESSES

2.1 Introduction

There is a vast array of interlinking relationships between different physical and biological "systems" and evolving landforms, including climatic, hydrological, **weathering**, **erosion**al, vegetational and anthropogenic systems. In addition, each of these has its own set of processes and interrelationships.

When addressing the evolution of landforms, geomorphological principles often adopt the uniformitarian view that "the present is the key to the past" (as long as climatic conditions are comparable); this decrees that landforms should be explained only in terms of processes observable at the present time. When putting current trends in landscape evolution into context this obviously creates difficulties. For example, the landscape of southern England has been fashioned to some degree by periglacial conditions existing in the Quaternary. However, periglacial processes occurring in the Arctic today may not be comparable to those which occurred in the Quaternary in England. In addition there are relatively few, if any, areas of chalk landscape currently experiencing periglacial conditions. Therefore, any attempt to evaluate how the landscape of Southern England has developed can only be tentative.

Other areas of Britain have been transformed during former glacial periods. Since the last de-glaciation, when ice caps and glaciers retreated and disappeared from Britain, the development of the landscape by biogeochemical agents of **erosion**, deposition and transport has been set against a template of form created by the last ice-age. In addition, evidence for historical rates of geomorphological change can be destroyed by the very processes which shape landforms.

Therefore, it is sometimes difficult to both put present-day landform development and process activity into context with a geological timeframe, and to define whether or not perceived patterns of change can be classified as being accelerated, when compared to past and future rates of **erosion**.

2.2 Cycles of Change: Different Orders of Resolution

In order to achieve some sense of structure and relativity when addressing problems of upland **erosion**, it is vital that the large-scale cycles of change which affect the Earth are addressed. It is hoped that by creating a theoretical template which incorporates large scale solar cycles, earth cycles and catchment based cycles, and then superimposing the effects of upland management, the factors influencing accelerated upland **erosion** and its impacts can be logically addressed in context.

The following show a range of cycles which impose major effects upon the British uplands. These are addressed from the largest order of resolution (solar cycles) to smaller orders of resolution (drainage basin cycles).

- **Solar Cycles....Large Scale Climatic Change.**

The Earth rotates at an angle on its axis in an elliptical orbit around the sun. With time the path of this orbit causes the earth to be relatively closer or further away from the sun. This pattern of change in distance from the sun has implications for long-term fluctuations in the earth's climate (e.g. the "Milankovich hypothesis"). Once this astronomical mechanism leads to a reduction in temperature, the effects can be modified by positive feedback processes (for example, promoting the onset of a new glaciation).

- **Earth Cycles.... Tectonism and Climate.**

The concept of a rock cycle can illustrate the relationships between crustal and surface processes (Figure 1).

The cycle proceeds from left to right; **erosion** of the uplands starts with **weathering** of exposed material and its subsequent transport downslope. Sedimentation occurs in troughs, followed by diagenisis (physical and chemical change). The troughs become folded and depressed in the crust under the weight of overlying material whereupon they melt. The molten material (magma) reaches the surface again via volcanoes and fractures in the earth's crust. This accumulation of material, together with tectonic uplift, presents fresh upland surfaces to **erosion** processes and thus, the continuation of the cycle.

Climate is the other major control over the physical environment (refer to Section 3.9 of this report), affecting soils, vegetation, animals and the operation of geomorphological agents such as ice and wind. The energy source which drives these processes is solar energy from the sun (Goudie, 1984). In the last 20,000 years, there has been a reduction in the surface area of the earth covered with ice to one third of its maximum extent. Meltwaters have raised the level of the oceans by over 100m; terrestrial regions have risen in height (and continue to rise); vegetation belts have shifted; areas of permafrost and tundra have diminished in size; rainforests have expanded; deserts have advanced and retreated and lakes have flooded and shrunk.

These changes are all influenced by short-term climatic cycles such as the North Atlantic Oscillation and El Nino (ENSO).

The processes of **erosion**, transport and deposition operate throughout these cycles of change in different ways and in varying intensities. Against this background of longer-term change, we can now begin to look at what is occurring in the current window of time at the drainage basin or landscape level.

- **Drainage Basin Biogeochemical Cycles**

A drainage basin is the fundamental unit of the Earth's surface. Within the watershed of a drainage basin, all precipitation falling will find its way to the major arterial watercourse. Physical features existing within it will not only define the drainage basin, but also the characteristics of any watercourses found within.

The interactions between compartments of a drainage basin are varied and complex (Figure 2). Essentially, the structural, geological and **erosional** history will determine the topography, shape, size and relief of the basin, which in turn effect how much precipitation is captured and the subsequent rate and volume of water movement through the system. The lithology, **weathering** and **erosional** processes will influence the type, formation, transport and deposition of sediment, soils and solutes, which will then promote or limit the type of vegetation which is present (Figure 3).

2.3 Erosion Mechanisms

2.3.1 Introduction

The complex template which has been outlined in the previous Section has described a range of cycles and processes which influence the uplands, from very-large scale cycles of change to more intricate interrelationships that occur in comparatively localised areas of land. In all of these, physical, biological and chemical systems interact with one another. The processes associated with **erosion** will now be discussed in some detail to provide the non-geomorphologist with a concise summary of these processes which are continually affecting landscapes. Such processes should be taken into account when assessing the impact of land uses such as grazing, bracken control, burning and drainage. They are discussed here to avoid repetition elsewhere in the report.

2.3.2 The definition of erosion

The term **erosion** has been assigned many definitions, including "the wearing away of rocks"; "a general term for all the processes of loosening, breaking up, physical and chemical disintegration, and **solution** of rocks"; and "a combined term for **weathering** and **corrasion**" (Challinor, 1967). It is often used in a wider sense as well to include transport of materials (as is the case in this report).

Holy (1980) defines **erosion** as follows: "**Erosion** (from the latin *erodere*) is manifested in the deterioration of the soil surface effected by exogenous forces, especially water, ice, wind and man. The disturbance of the land surface is accompanied by the removal of the detached soil particles by the kinetic energy of some of the **erosion** agents, namely water and wind, and the deposition of this matter with a decrease in this".

Gilbert (1876) defined the "three agents of **erosion**", in their "natural order" as being;

a) **weathering**,
b) transportation, and
c) **corrasion**.

"The rocks of the general surface of the land are disintegrated by **weathering**. The material thus loosened is transported by streams to the oceans or other receptacle. In transit it helps to corrade from the **channels** of the streams other material, which joins with it to be transported to the same goal".

2.3.3 The agents of erosion

Small and Witherick (1986) describe **erosion** as the sculpturing action of running water, sliding ice, breaking waves and winds armed with rock fragments. In this context, the various agents and mechanisms of **erosion** can be classified into six major categories.

- **Rainsplash Erosion**

The impact of raindrops impinging on the soil surface will cause the breakdown of soil aggregates and detach soil particles, splashing them short distances. The extent of this **erosion** is dependent on the intensity and kinetic energy of the rainfall, the characteristics of the soil, vegetation cover and slope angle (please refer to Section 2.3.5 of this report).

Continued precipitation can lead to runoff & overland flow (surface wash/ sheet **erosion**) and raindrops impacting on this create turbulence, increasing the ability of the flow to transport material.

- **Wind Erosion**

Wind **erosion** is the removal of soil particles by the force of the kinetic energy of the wind. These soil particles are transported and deposited when the energy of the wind drops. This type of **erosion** is particularly effective on dry, light soils where there is little vegetative cover (e.g. fine glacial deposits often found on limestones).

- **Glacial Erosion**

The erosive action of ice, its meltwater and the debris it transports is limited to discrete regions defined by altitude and latitude. This process has played a very important role in the shaping of the UK landscape and the creation of many of the drift deposits and silty soils present in the uplands (especially on limestones). These deposits are currently being re-worked by other agents of **erosion**. Glacial **erosion** itself is not occurring in the UK.

- **Snow (Nival) Erosion**

This is caused by the movement of snow (in the form of avalanches) where **erosion** occurs at high pressure and velocity. Nival **erosion** may also be caused by the slow movement of a layer of snow along an unfrozen soil surface during a spring thaw.

- **Fluvial Erosion**

Erosion in rivers is undertaken by the processes of **corrosion**, **corrasion** and **cavitation** and is achieved both through the direct impact of the water itself and by the **load** which it transports. These processes are defined in Section 2.3.5)

- **Anthropogenic Erosion**

The activities of man can cause and exacerbate **erosion**. Mechanisms include livestock, vehicle movement, walking, burning, and clearance of vegetation. These issues will be discussed fully in Part Two of this report.

The breakdown of rocks is arguably the most fundamental of all geomorphological processes. In the absence of **erosion**, landforms created by structural movements, such as anticlines, fault-scarps and rift valleys, would undergo little subsequent modification (Small, 1970). The processes described by Gilbert (1876) can be seen in action today, from moor and mountaintop, right down to river **channels**.

The effectiveness of **erosion**al agents such as water, wind and ice depends on them being fed a steady diet of coarse particles of rock, often supplied in large quantities by **weathering**. However, **weathering** is dependent on the operation of other processes. If the transportion of freshly weathered material does not occur and there is no continual re-exposure of fresh rock, **weathering** may well be slowed down and potentially halted if a protective mantle of weathered detritus builds up. **Erosion**al processes can produce expanses of bare rock which can be attacked by **weathering**. In this way, the processes of **weathering**, transport and **erosion** are interdependent.

2.3.4 Weathering

Weathering can be defined as the breakdown or decay of rock *in situ* (Small, 1970). There are two main forms of **weathering**, mechanical and chemical.

i) Mechanical weathering

Mechanical (physical) **weathering** leads to the disintegration of rock into blocks or boulders and smaller particles such as grains. Most products of **weathering** are coarse grained and angular. In this way large blocks of rock can be reduced to a "sand" composed of individual mineral grains.

Mechanical weathering is induced by two main processes:

- **Heating and cooling** caused by insolation and radiation which, by causing the expansion and contraction of minerals, creates stresses within the micro-fabric of the rock. Freeze-thaw cycles in soil can also loosen and transport material, especially when needle ice forms.

- **Frost shattering** caused by the growth of ice bodies within pores and fissures in the rock which exert pressures which are generally higher than the tensile strength of the rock, or by the development of ice crystals due to fine particles of rock or soil acting as nuclei for growth (Figure 4).

ii) Chemical weathering

Chemical weathering causes the decomposition of rock minerals as a result of the action of agents such as water, oxygen, carbon dioxide and organic acids. Processes involved in **chemical weathering** include:

- **Solution**; some rocks (e.g. limestone and chalk) can literally dissolve. For example, calcium carbonate dissolves in the presence of water and carbon dioxide.

$$CaCO_3 + CO_2 + H_2O \rightarrow Ca^{2+} + 2HCO_3^-$$

- **Hydrolysis**; common rock-forming minerals weather in the presence of H and OH ions forming a by-product that is very different in character to that of the original rock (e.g. the **weathering** of orthoclase feldspar to kaolinite clay).

- **Hydration**; when minerals incorporate water into their molecular structure, a progressive expansion or swelling of the minerals can occur.

- **Oxidation**; some rocks, especially those containing iron bearing minerals, can degrade (rust) in the presence of oxygen and moisture. This is only really effective above the water table.

The end products of **chemical weathering** are typically finer than those from **mechanical weathering** and include "residual" decomposition products (such as clays) and "soluble" decomposition products (for example sodium bicarbonate) which are ultimately transported by water into rivers. Concentrated **chemical weathering** on susceptible rocks or along joints or fractures can lead to a physical degradation of the rock and the production of detritus similar to mechanical **erosion**.

The predominance of one form of **weathering** over another can have potential impacts on receiving watercourses. In an area where **mechanical weathering** dominates, water courses will have a coarser **bedload** to transport and **corrasion** can be a dominant process. Where **chemical weathering** dominates, the river will transport a suspended or **solution load**. However, **chemical weathering** can sometimes produce coarse debris (e.g. cobbles and boulders).

iii) Factors that influence weathering

There are many factors which control the type and rate of **weathering**, including:

- **Rock Hardness**; this can slow down insolation and frost **weathering**. However, all hard rocks possess weaknesses which can be exploited by **chemical weathering**.
- **Chemical Composition**; this influences a rock's resistance to decay and has some influence on **mechanical weathering**.
- **Joints and Fractures**; these have the effect of increasing the surface area available to **chemical weathering**, allow water and air to penetrate the rock and provide lines of weakness for mechanical agents.
- **Climate**; certain processes are totally dependent on the existence of particular climatic conditions (e.g. atmospheric freeze-thaw cycles are required for frost shattering to operate, **chemical weathering** operates more efficiently in very warm climates).
- **Relief**; areas of high relief and steep slope which promote mass wasting such as landslides, slumping, soil creep and solifluction facilitate the continual exposure of "live" rock to **mechanical weathering**. However, in these areas, water runs off rapidly (especially if there is an absence of soil, peat or vegetation) and **chemical weathering** may therefore be limited. In areas of gentle relief, thick deposits of soil and other material are usually present, limiting **mechanical weathering** but holding water and promoting **chemical weathering**.

It can be said that the cycle of **erosion** is marked by a gradual change from dominantly mechanical to dominantly chemical (Small, 1970).

2.3.5 Transportation

Transportation is a series of processes which transfer material from its origin to locations away from its origin, typically to a point of lower altitude.

i) Transportation on slopes

- **Gravity-driven Mass Movements**

Mass movements on slopes can be classified into two major groups, "flows" and "slides", and describe the movement of material under the influence of gravity without the benefit of a contributing force such as flowing water, wind or ice. There is a continuum existing between a river where water dominates over debris and rockfalls where there is a dominance of debris and little water (Goudie, 1986). Because of this continuum, multiple mechanisms of mass movements may occur; classification, therefore, will be arbitrary. Figure 5 illustrates a triangular classification diagram based on mechanism and moisture content.

Flows can be subdivided into rapid and slow flows. Rapid flows (earth flows) occur when the soil becomes saturated and mobile. Masses of earth on hillslopes may slip suddenly, leaving a crescentic scar above and a bulging toe where they come to rest. In mountainous areas, where the soil is very saturated and has a high proportion of clays, a "mud-flow" may occur. This is sometimes associated with the transportation of large weathered blocks. Rapid flows can also occur on peat moors, these are often described as "bog-bursts".

Slow flows (creeps) can be defined as the slow and almost imperceptible movement of rock and soil particles downhill under the pull of gravity (Small, 1970). Anything which disturbs the soil particles (expansion and contraction, freezing and thawing, growth of needle ice, burrowing of worms, animal passage, ploughing) will cause some downwards displacement. The angle of slope (driving soil creep in the long term), vegetation cover, soil type and the amount of organic matter wet soils contain all play an important role in determining the rate of soil creep (Evans, Pers. comm., 1997).

The most dramatic mass movements of the sliding type are landslides and rock avalanches. These are limited to very steep slopes where very rapid sliding of accumulated rock debris over a discrete surface or plane can occur. The accumulated material usually forms talus cones at the foot of the slide, with the largest fragments, due to their higher transport velocity, being at the front of the cone. Where slopes are vertical (cliffs), free-fall of material can be achieved. Fragments of rock, loosened by **weathering**, heavy rain or snow will fall directly to the base of the slope. As a result, the underlying rock is constantly exposed to **mechanical weathering**. Associated with this is "toppling", where blocks of rock move forwards about some pivotal point.

Another form of slide is the rotational slip, which involves a degree of flowage. These occur where an accumulation of weathered material exceeds the resistance of the deposit to shearing (this resistance can be reduced by saturation of the deposit by water). The upper part of the deposit then slides down a curvilinear shear plane with the result that the displaced mass is tilted back and the toe actually rises up. This method of transport not only affects weathered material, but also solid rock

- **Water Driven Mass Movements**

The presence of water in slope materials is an important factor in their stability or instability as it results in extra forces in the soil. If the soil is unsaturated then a suction force is exerted which draws together soil grains more closely (capillary tension). If the soil pores are totally filled with water (saturated), the water will exert a pressure which tends to push the grains apart. Where high pore water pressures are reached, slope material may become unstable. This can be caused by heavy rainfall, the sudden melting of snow, the blocking of drainage systems, seepage of irrigation water or slope saturation caused by the impounding of a reservoir behind a dam (Goudie, 1986).

An important process is **runoff** (surface wash). This is the downslope transport of regolith (soil and broken rock) across the ground surface through the action of water. There are two distinct processes; raindrop impact (Figure 6), and the flow of water across a slope (surface or sheet flow).

Where there is limited vegetation cover, poorly structured soils and/or high energy storms, **runoff** will have the greatest effect, effectively transporting away material downslope.

The action of water is only really effective after sustained or heavy precipitation (or after snowmelt). Any excess of rainfall after the soil has become saturated will cause puddles to form in small depressions. If rainfall continues, these will overflow to give rise to a mobile layer of water which will begin to flow downslope as sheet-wash (Figure 7 & 13). If the layer of water is shallow and the ground smooth, the flow may be laminar in nature but, if it is deeper and the ground rough, then turbulent flow will ensue. This creates eddies and has a greater capability for transporting fine particles (sheet **erosion**).

Surface irregularities may cause a concentration of the water into rills, which subdivide and rejoin in an **anastomosing** pattern. Downslope, as the volume of water (and its erosive power) increases, the **rills** may develop into gullies and, in extreme cases, ravines. Some upland rill development is of extreme importance, a major element in landform development (e.g the Howgill Fells, N. England).

The extent of any rills, gullies or ravines which may occur depends on a number of factors: the intensity of the rainfall, the steepness of the slope (**runoff** is generally greater on steep slopes as the increased velocity reduces the time available for loss due to percolation), the permeability and **porosity** of the soil or rock, and the nature of the vegetation (grass reduces rainsplash **erosion**, impedes surface flow and aids **infiltration** via root passages) (Small, 1970). A greater surface area of vegetation may increase the interception of rainfall and delay or even inhibit surface **runoff** (refer to Section 2.5 of this report).

ii) Transportation in rivers

The different methods of transportation employed in **fluvial** systems include:

- **Traction**

This process involves the rolling and bumping of particles (**bedload**) along the **channel** bed. When discharge and velocity of flow increase, the capability of a stream to transport a larger size of **bedload** also increases. The critical velocity which has to be exceeded to mover larger rocks can sometimes only be achieved by very high magnitude floods. However, even **bedload** that may have remained in-situ for hundreds or thousands of years can be re-mobilised again when a powerful enough flood occurs.

- **Saltation**

Saltation is the "jumping" of relatively small grains along a stream bed. Any particle presents some degree of obstruction to the flow of water. As it does so, hydraulic pressure will build up behind it until it reaches a point beyond which the particle will be rolled (traction) or even thrust up into the body of moving water. However, unless the velocity of water is above that required to maintain the transport of the particle in suspension (settling velocity), gravity will cause the particle to return to the bed at which point hydraulic pressure will once again build up and the process will be repeated.

- **Suspension**

The vast majority of fine material is carried as a suspended **load** by the river. The maintenance of these particles in suspension is dependant upon the turbulence of a river and also on the velocity of flow, which must be above the relevant settling velocity of the particles.

- **Solution**

Where **chemical weathering** is very active (due to climate and/or lithology) dissolved rock is transported to rivers via overland or subterranean flow pathways. In these areas the transportational **load** is in **solution** and there may be little traction, **saltation** or suspension of particles.

The total **load** of a stream or river will vary, both through time and spatially, depending on the energy available. As a result there are potential stream **load**s which can only be moved when discharge and velocity conditions allow them to be.

The ability of a river to undertake geomorphological work is dependant on the energetics of the system. Rivers and streams possess kinetic and potential energy, with the amount of energy being governed by a number of factors:

- Gravitational attraction: anything which increases this force will promote greater stream energy. An increased volume of water (e.g. a stream in spate) will be subject to a greater gravitational pull than a small volume of water and will therefore have more energy and a greater ability to erode and transport.

- The height of a stream above the base level of **erosion** (a theoretical limit below which rivers cannot erode their beds, i.e. sea level) governs the amount of potential energy possessed by the stream. The higher above the base level of **erosion**, the greater the amount of potential energy a stream has.

- **Channel** gradient is a major control over water velocity. The greater the velocity, the greater the amount of kinetic energy (energy being used up by water and its **load**).

Potential and kinetic energy possessed by streams are dissipated (converted into heat and sound) by the frictional retardation of the water as it comes into contact with the **channel** bed, margins and other obstacles. The process of **corrasion** may also reduce the level of energy in a stream.

Factors affecting frictional loss of energy include:

- **Bedload size**; large particles moving over rock cause greater heat energy loss than water alone moving over rocks.

- **Channel morphology**; the efficiency of a stream can be defined as its hydraulic radius which is determined by the ratio between the cross-sectional area of the **channel** and the length of its wetted perimeter. The greater the hydraulic radius, the more efficient the stream will be. The most efficient **channel** form is one which has a semi-circular cross-section; however, the occurrence of this type of **channel** is rare in natural systems.

- **Size of a Stream**; larger streams are more powerful agents of **erosion** and transportation due to their possession of both great total energy and a reduction in the impact of **channel** roughness. As discharge increases, so too does the wetted perimeter, but the hydraulic radius decreases. Thus, the effects of frictional losses are relatively reduced and the stream may appear to have a greater ability to transport material. However, the larger discharge is usually associated with large **bedloads** and as a result friction and **corrasion** will be enhanced.

It can be seen that many aspects of **fluvial** activity are inextricably linked and general assumptions are difficult to make.

The force required to entrain a given particle is called the critical tractive force and the velocity at which this force operates on a given slope is the **erosion** velocity. A greater tractive force is required to entrain larger grains. The competence of a stream defines the largest grains which it can move. The competent velocity of a stream (**erosion** velocity) is the lowest velocity at which grains of a given size will move. Lower velocities are required to move sand or gravel than silt (due to the inherent cohesive force of silt). The relationship between velocity and particle size is shown in Figure 8.

Erosion in rivers is largely achieved by the process of **corrosion**, **corrasion** and **cavitation** (Figure 9).

- **Corrosion**; this is the purely chemical **erosion** of rock surfaces by flowing water and is difficult to distinguish from **chemical weathering**. If the **bedload** or **channel** margins become subarielly exposed due to low flow conditions, then they may be subject to atmospheric **weathering**. The by-products of this will be removed by the stream at a higher discharge. **Corrosion** weakens the structure of rocks in the **bedload** or margins and thus assists other erosive processes (Small and Witherick, 1986).

- **Corrasion** is the mechanical wearing away of particles, generally by the direct impact or grinding action of other particles (Figure 10). The impact of debris in transport on rock surfaces or detached particles can lead to their fragmentation. This process is most effective if the stream **load** comprises hard, coarse and angular fragments.

  Abrasion, or the grinding action of particles on each other, is most effective when the impact of the particles on the bedrock is vigorous and the particles are coarse, hard and angular. The processes of **corrasion** are not just limited to flowing water. **Corrosion** can also be caused by falling or sliding rocks and by materials transported by wind, ice and breaking waves.

  One method of **corrasion** is the result of the sheer force of water on bedrock without tools, known as evorsion. The hydraulic action of water can remove loose material by the force of impact of water alone. This type of **erosion** often occurs in alluvial **channels** (Morisawa, 1968).

- **Cavitation**; this only occurs under very high water velocities. One of Bernoulli's theories states that total energy in a stream is constant and that a constriction in a river **channel** will cause an increase in stream velocity. This will, in effect, increase the kinetic energy level of the stream. As total energy must remain the same, the potential energy will therefore decrease. This is expressed as a reduction in pressure. If pressure falls to the vapour pressure of water, bubbles will form. When the **channel** widens and velocity decreases, the pressure will rise and the bubbles collapse. This will release shock waves which travel towards the **channel** margins and create stresses, causing rapid **erosion**. **Cavitation** is usually restricted to high velocity areas such as waterfalls (Figure 10), rapids and some artificial conduits. However, the action of boat propellers can also create **cavitation**.

All of these methods of **erosion** are assisted by vortex action which sucks and lifts loose particles upwards and downstream with the vortex current. Where separation of flow occurs (e.g. around boulders), a veering and overturning of water as spiral flow can also occur.

2.4 The Sensitivity of Landscapes to Erosion.

Anthropogenic activity interacts with physical, biological and chemical systems. What is problematic, and forms the focus of attention for this study, is when man's activities cause these systems to shift from their established quasi-equilibrium state and behave differently, often with dramatic consequences.

The actions of water, wind, temperature and glaciers which, under natural conditions, proceeded slowly and, from the point of view of a human generation, go unnoticed, have been significantly accelerated by man's activities with consequences that are in many cases highly unfavourable for human society. Through geological time, "historical **erosion**" played a significant role in the formation of the Earth's relief.

In our time this "historical **erosion**" can be thought of as "current **erosion**" which significantly re-works the surface of the planet. Natural rates of "current **erosion**" in some locations can be very high. For example, in New Zealand and other alpine regions, high precipitation, high relief, glaciers, earthquakes and easily weathered rock increase the rate of **erosion**. In extreme cases, for example in the New Zealand Alps, rates of natural **erosion** are $100m^3$/ha/yr which equates to a surface lowering of 10mm a year. This is much higher than most "accelerated" rates of **erosion** (Evans, Pers. comm. 1997). Such rates of natural **erosion** must be taken into consideration when assessing the overall impact of **erosion** in the uplands induced by anthropogenic activities.

This (current) **erosion** can be categorised in two ways: firstly, as "normal **erosion**" when the **erosion** processes take place slowly, preserving the balance in natural ecosystems, and secondly as "accelerated" or "abnormal" **erosion** when the balance in natural ecosystems is disturbed or destroyed. Accelerated **erosion** is the cause of dangerous dislocations and removals of soil and rock particles which cause much concern. Additionally, large scale morphological impacts occur on river systems, these include channel migrations and downcutting (e.g. on the River Bollin, Cheshire)

The sensitivity of the landscape to **erosion** can be thought of as depending on the level of the threshold at which **erosional** forces overcome the resistance of rock, soil and vegetation. Sensitivity is high when the thresholds that have to be crossed to trigger **erosion** are low so that **erosion** takes place frequently, although the impact of the event on the landscape is not great (e.g. intensive grazing). Where sensitivity to **erosion** is low, the landscape will suffer only when it is subject to a large stress, which occurs only rarely, but their impacts are great and the resultant scars on the landscape generally persist for a long period of time (e.g. an earthquake or volcanic eruption) (Evans, 1993).

The majority of thresholds that need to be overcome before **erosion** occurs change throughout time. For example, a change in vegetation cover as climate alters may make the landscape more or less susceptible to **erosion** (e.g a change from wildwood to: heather, grazed out heather, the onset of **erosion** to **upland sheet erosion**.). However, such "natural" changes in threshold levels usually occur at a much slower rate than those brought about by man's actions. If the impact of grazing animals were to be removed, then this trend could be reversed.

2.5 The Role of Vegetation

Vegetation can affect the balance between the **infiltration** of water into the soil and the overland **runoff** of water. Roots, decaying plant material and other biotic factors encouraged by the presence of vegetation can affect the physical properties of soil, typically by improving the structure of the soil and leading to improved absorption and **infiltration** of water.

Vegetation also has important insulating properties, protecting the underlying soil from the effects of the sun and the frost. In this manner, heather insulates moorland. When it is lost, several negative impacts may occur. In the summer, on exposed areas of peat, the action of the sun can result in the peat drying out, and shrinkage cracks may appear, allowing any rain falling to drain away rapidly and therefore, not re-wet the peat. The peat also becomes susceptible to desiccation and **erosion** by wind. In the winter, needle ice can grow under the peat surface and consequently lift it upwards, fragmenting it and exposing it to further **weathering** and **erosion**. Heather will hold and insulate snow, delaying its thaw and potentially reducing **runoff** rates. The soil surface remains unfrozen and more permeable.

Surface litter and dense foliage may be able to intercept water and detain it long enough to allow complete absorption into the soil. Surface litter and dense foliage is also likely to facilitate evapo-transpiration. Almost any kind of vegetation has the potential to impede the surface flow of water and therefore reduce its erosive efficiency. However, different types of vegetation vary in their efficiency. For example, Norton and Smith (1937) discovered that **runoff** from maize plots was on average 1.5 times greater than that from a ley (a field temporarily under grass), with the peak discharge being 2.5 times greater. However, vegetation can direct water into **channels** or retain it, allowing sizeable volumes to build up which, upon their release, may form **rills** or gullies.

Evans (1990) describes a slope in the Peak District where vegetation completely covered the soil in 1948. The area covered by vegetation decreased over time due to grazing pressures, leaving over 1.5 km^2 of bare soil in 1986, an increase of 42% since 1975. Evans calculated the rate of **erosion** from this area to be 17.5 m^3 per year, between 3.5-7.0 times faster than the highest mean rates of **erosion** recorded on arable land.

Another assessment of the **runoff** of water from vegetated land was undertaken in small dense plots of ponderosa pine in N. America (Anon, 1947) where all of the litter and surface detritus was removed but the humus and plants were left. This experiment showed that **runoff** doubled in the first 15 months following litter and detritus removal while **erosion** increased more than 72-fold. Watering experiments (Maran and Lhota, 1954) on plots with a range of soil types also showed that the amount and rate of **runoff** was always small from coarse-grained stony plots irrespective of slope, and that the amount and rate of **runoff** from pasture was several times greater than that of even the poorest of forest stands.

Delfs *et al.* (1958) conducted management experiments on catchments and measured **runoff** and **erosion** on bare ground and ground with forest cover on a gradient of about 40%. On the bare soil, the **runoff** was about 17 % of the rainfall and the **erosion** was 1500 g per m^2. Under the trees with different surface covers, the corresponding figures were: Humus, 4%, 50 g per m^2; *Aira/Vaccinium* cover, 0%, 0.2 g per m^2; Needle litter, 1%, 4 g per m^2.

Burger (1943) describes the mean solid matter transport of a forested area as being 85 m^3/km^2/annum, while from an area one third forest, two thirds pasture, the amount was 145 m^3/km^2/annum. Hoyt and Troxell (1934) note that during the first year after burning, the first rains washed ash and loose material into the streams, and 3 months after the fire, the entire stream bed was buried. Tallis (1985) notes that forest clearance would certainly lead to increased runoff rates.

A review by Musgrave (1954) summarises the role of vegetation. His work on sloping plots studied the effect on **erosion** of rainfall characteristics, vegetation type and crop rotation, slope, length of slope and soil type. His work showed that at least 75% of measured **erosion** occurred during summertime convectional rainstorms, which have a high level of raindrop impact energy. Where this rain fell on a closed vegetation canopy, protection could be complete. Forest and grass were recognised as the best protectors. The worst protection was given by intertilled row crops (e.g. maize, cotton, potatoes, and the fallowing of land). Smith and Crabbe (1952) found that **erosion** from mainly arable land was 500 to 1000 times greater than that from forest.

Newnham (1949) describes the New Zealand experience: "Very little research has so far been carried out on the effect of farming operations on **runoff**, soil loss......and soil **erosion** generally, but experience in this country agrees with that of other countries... the capacity of the soil to absorb and hold water is much greater under natural conditions than it is when farmed". Vorster (1949), when comparing cropped and bare areas of slope, concluded that on comparable plots, the slope had little effect on the volume of **runoff**, but **erosion** losses were greater on the steeper slopes. Undisturbed natural vegetation gave almost perfect protection; lightly utilised vegetation was nearly as good; perennial pasture gave good protection on both slopes and row crops gave no resistance to **runoff** and none to **erosion**.

In addition, vegetation acts as a good insulator protecting the soil from the effects of the sun, frost, wind and rain. The foliage will intercept rain, prolonging the time taken to reach the soil and therefore reducing the risk of the soil becoming saturated and runoff occurring. Bare soil also suffers from the impact of rain or hail detaching and transporting soil particles. Good root systems also improve the drainage of the soil, and surface litter and dense foliage increase the rate of evapotranspiration. Most kinds of vegetation have the capacity to impede the surface flow of water and therefore reduce its erosive efficiency.

For example, Evans (1990) describes a slope in the Peak District where, due to grazing pressure for more than 30 years, the vegetation cover diminished to leave a bare slope. The rate of erosion from this area was calculated to be 17.5 m^3 per year, between 3.5 and 7 times faster than the highest mean rates of erosion recorded on arable land. The rate of increase in the expanse of bare soil stopped when the number of sheep grazing the slope was reduced. Evans found this rate of erosion to be similar for other parts of the Peak District.

The vegetation alongside a river has the potential to reduce the impact of non-point source pollution such as agricultural **runoff** from a variety of sources (for example slurries from livestock or nitrates and phosphates from fertilisers). Mainstone *et al.*. (1994) provide a review of land management techniques for the prevention of diffuse pollution within controlled waters.

A well vegetated riparian buffer zone will act as a trap for alluvial sediments that may be washed from the adjacent fields. If crops are harvested at a time when storms are more frequent (e.g. the early autumn), then the large surface area of exposed soil becomes very susceptible to **erosion** and transportation. This fact is exacerbated by the use of land drains and ditches, both of which will convey excess water and sediment to the **channel** very efficiently, without allowing for sedimentation before the river is reached.

The evidence presented in this report by the literature may well indicate that ecological **overgrazing** will lead to a negative change in the vegetation structure and occurrence. Even in a mild form, it may result in the loss of the sward and exposure of bare earth. Other factors such as fire, atmospheric pollution and control of vegetation can have severe negative impacts upon the vegetation cover and, as a result, can have severe implications for **runoff** rates and flooding.

Vegetation, therefore, especially when allowed to develop into a complex community (herbs, shrubs, and trees) offers the best level of stability to a landscape. In addition to binding the soil and regolith, and reducing the effects of many forms of **weathering** and **erosion**, the foliage will intercept precipitation and, as a result, the downstream effects of storms may be reduced. Where vegetation is absent (deforestation, fire, **overgrazing**), **runoff** rates will increase (especially on steep slopes with impermeable soils or rock) and the impact on the receiving water course will potentially be more severe.

2.6 Agricultural Change in the Uplands

Modern UK farming is highly intensive in terms of capital, the high levels of mechanisation, the large inputs of energy required, and the levels of fertilisers and pesticides utilised and, this is reflected negatively by the relatively low labour force. This intensity of farming is a result of a long period of agricultural development (Briggs and Courtney, 1989). Earnle (1961), in his review of agrarian change in Britain, identifies the 18th or early 19th centuries as being the time of major agricultural revolution, whilst Kerridge (1967) thinks it to be earlier. The roots of modern farming can be traced back to at least the 16th century.

From Roman times, as the population grew, cultivated land expanded and encroached into woodlands and other "wild" areas of the countryside. However, there were "too few people to civilise the whole landscape" (Hoskins, 1976). In Medieval times in the North York Moors, sheep and other herbivores restricted natural regeneration of woodlands which were felled for construction and fuel (Rees, pers Comm., 1997). Non-uniform agricultural systems were in operation before 1500, open-field systems existing in some parts of the country and pastoralism being found elsewhere. In the uplands, the infield-outfield system dominated (Kerridge, 1967): the infield was the lower land, cropped every year and fertilised by animals, while the more distant outfields were left as grazing land. Systems of herding stock were also practised.

By 1600 there was an extension of the enclosure system. This wiped out the open fields and took into cultivation large areas of open heathland, forest and moors. In the uplands, the physical demarcation of boundaries was not always undertaken; much of the wall building we see today was undertaken after 1750.
With the advent of the 18th century a change in principles was beginning to occur, based on the application of scientific thought. Livestock and crop husbandry were being developed and applied, new crops were being introduced, the seasonal rotation of different crops or the alternation of crops and livestock was being practised, and the role of specific nutrients was realised.

The consequential emergence of modern farming was aided by three main developments:

- Mechanisation dramatically reduced the man-hours involved in farming, increased the effectiveness of ploughing, sped up harvesting and milking and, with the use of computers, has become partially automated.

- Plant and animal breeding can produce stock and strains which yield more produce, are more resistant to disease and environmental conditions, and which grow faster. The potential for high intensity turnover of livestock and produce can therefore be realised.

- The use of fertilisers and pesticides which has also had a marked positive impact on yield.

These developments have wide ranging implications for modern farming. Yields have soared whilst, at the same time, land availability has decreased (due to urban expansion). The number of people employed in the industry has also fallen and there has been a rationalisation of the size of farms, with small farms being amalgamated.

Agriculture today is highly intensive. It is also strongly linked to past activities; these have moulded not only farming principles and experience but also much of the environment in which modern agriculture take place (Briggs and Courtney, 1989). This situation makes it difficult to

isolate the effects that present day practices have on the environment and, in particular, makes it difficult to assess their impact on the rate of **erosion**.
The uplands of Britain have been the most difficult regions to cultivate; the majority of farming in these areas is concerned with the breeding and rearing of sheep and cattle. Over one third of the total land area of England and Wales is more than 250m above sea level. Temperatures are low (the effect of altitude reduces temperature; zero degrees at sea level is roughly -10 degrees Celsius at 1000m, without the added effect of windchill which is a reduction of 1 degree per mph of wind speed), the growing (and grazing) season is reduced, precipitation levels are high and, in many cases, the soils are thin and acid, and therefore hostile to vegetation.

The shorter, cooler summers occurring at altitude mean that grass growth begins later and end sooner than at lower altitudes so that the output of dry matter per acre is less than one third of lowland pastures. Sir George Stapleton in the 1930s estimated the average meat output of the average upland pastures as being up to 15 times less than lowland pastures.

Nevertheless, farmers have managed to convert rough grazing land and heather moorland into permanent grass and, in a few cases, even arable land. Between 1952 and 1972, some 250,000 acres of rough grazing were ploughed up and sown with improved grasses in Wales and in England about 370,000 acres have been reclaimed in the hills (Grigg, 1989).

The use of uplands in agriculture is not a new phenomenon, Until about 5000 BC the hills were covered with deciduous forest up to an altitude of 1700 ft, possibly to 2000 ft. This was cleared by Neolithic people in the period 3300-2500 BC and later in the Iron Age. There is evidence that in the Middle Ages, farms were established at altitudes not attained later (possibly due to climate change). Certainly, established upland farms were abandoned at later dates reflecting the difficulty of working there. The wool industry of the sixteenth century favoured attempts at recolonising the uplands but in most cases they were to be abandoned again, and permanent grass became neglected and rough pasture re-established itself. This trend was not reversed until the outbreak of the Second World War, where the uplands were once again cultivated (Grigg, 1989).

2.7 A Brief Review of Agricultural Policies Which May Direct Upland Farming

The problems associated with farming in the hills have been recognised for a long time and in the 1930s farmers began to benefit from the introduction of subsidies. In 1937 the use of lime was subsidised and in 1940 a subsidy was given on every hill ewe; this was extended in 1943 to each hill cow. After the end of World War Two, the 1946 Hill Farming Act added improvement grants to the headage payments. Guaranteed prices were established because of the act and in 1967 the range of financial aids for improvements was extended (Grigg, 1989).

In 1975 the EEC introduced a policy of subsidies for Less Favoured Areas (in the UK this is considered to be the hill regions). This facilitated the continuation of these payments as Hill Livestock Compensatory Allowance (HLCA), and realistically the value of the subsidies to hill farmers became greater than in the past. In 1980, the EEC began to support sheep prices directly, the introduction of guide-line prices for sheep meat encouraging hill farmers to fatten their lambs for sale (Land Use Policy, 1986).

There are two major types of farming in upland England and Wales. Sheep farms are found in the higher and more remote hills which utilise grass (mainly rough grazing) and heather as the main feed source. In some areas beef cattle are kept, but the main livestock is overwhelmingly sheep (see Table 1). The sale of lambs and ewes provide most of the farmers income, the sale of wool is a small component of the total.

	Mostly Sheep		Sheep and Cattle		Both Types	
	million acres	%	million acres	%	million acres	%
Rough Grazing	1.01	75.9	1.28	45.2	2.30	55.2
Grass	0.30	22.6	1.31	46.3	1.60	38.4
Tillage	0.02	1.5	0.24	8.5	0.27	6.4
Total	1.33	100.0	2.83	100.0	4.17	100.0

Table 1. Land use in the hills and uplands by type of farming in England and Wales (after Eadie, 1984).

The upland slope cattle and sheep farms are the second type of farm; these are typically located between the arable farms of the lowlands and the hill sheep farms. The environment here is more favourable than on the higher slopes, with a greater area of improved grass and cropland, and as a consequence, beef cows are kept as well as sheep.

Hill farming plays an important role in the agricultural economy as it provides sheep and cattle for fattening in the lowlands for meat. If the animals bred in the uplands were displaced to the lowlands, other enterprises would have to be moved elsewhere. However, the upland enterprises require a large subsidy, which has increased considerably with time. In the 1950s 3% of British government expenditure on agriculture went to the uplands; by 1981-2 it was 10%. In the 1970s this source of money provided upland farms with 74% of their net income (Grigg, 1989). However, guaranteed prices do not make the net income great; at times many farmers have an income lower than a farm-worker (Hall, 1966).

Since the UK has entered the European Community, the Common Agricultural Policy (CAP) has had a major influence on farm support schemes. This European Community (EC) policy provides the framework for agricultural policy in all Member States and is a very powerful economic instrument. Its primary objective was to "promote technical progress and make more effective use of natural resources" and it aimed to "ensure the standard of living of rural communities and availability of food supplies to the EC". It did not make reference to the environment or protection of natural resources (RCEP, 1996), although the HLCA does.

The main mechanisms used to achieve this objective were the setting of guaranteed prices for the major commodities and the paying of export refunds to compensate traders for selling Community produce at lower world prices. A result of this system was the encouragement of surplus production. In addition, the import levies imposed protected producers from having to compete with lower cost products from elsewhere.

Direct subsidies account for over 50% of UK farm incomes. Where farms are located in Less Favoured Areas (LFAs), farmers are even more dependant on subsidies. In 1994, Scottish farms located in these areas were supported by subsidies which accounted for 87% of their farm incomes (RCEP, 1996).

According to Farmers Weekly (1996), more than 60% of ewes and nearly 70% of beef cows are found in LFAs (the uplands) which account for more than half of the UK's agricultural land. In 1992, reforms were made to the CAP, which cut support prices for major commodities and reduced access to intervention in the livestock sector (GATT rules). Arable area payments and increased livestock premiums were introduced to help farmers adjust. In addition, obligatory set asides were introduced in the arable sector along with the extension of livestock quotas, to reduce excess production.

These reforms focused far more upon the environment than the original CAP. All Member States were obliged to introduce environmentally sensitive farming. There are voluntary schemes running in England, Wales, Scotland and Northern Ireland, which are detailed below:

- Environmentally Sensitive Areas (ESAs).

Farmers within the designated areas are eligible and those entering into a ten year management agreement (MAFF, WOAD, SOAEFD or DANI) receive an annual payment for land put into the scheme. Grassland is not allowed to be converted into arable land and there are restrictions on the use of fertilisers and chemicals. Features such as walls, barns, ditches etc. must be maintained. If a land-use practise is deemed to have greater environmental benefits, it will receive a larger payment. (RCEP, 1996).

- Nitrate Sensitive Areas (NSAs).

If the application of fertilisers and manure is restricted on land overlying drinking water aquifers, autumn cover crops are sown and restrictions are placed on the ploughing of grassland. Farmers in these areas will receive annual payments. This only occurs in England.

- Nitrate Vulnerable Zones (NVZs)

If an area is designated as an NVZ, financial support may be available to waste management schemes. Nutrient application rates may be regulated, but stock numbers are unlikely to be limited as a result

- Countryside Stewardship.

This is a tiered scheme which gives an annual payment to farmers and landowners who adhere to ten year management schemes which promote conservation of specific landscapes and improve public enjoyment. This only occurs in England (MAFF).

- Tir Cymen.

This is limited to three locations in Wales and farmers who enter into a ten-year agreement of whole farm management plans receive payments for maintaining and enhancing areas of conservation and landscape value.

- Moorland Scheme.

This offers an incentive to farmers in defined areas outside ESAs. The aim is to encourage restoration and conservation of heather and other shrubby moorland by reducing grazing pressures. Payments are made for each ewe removed (MAFF). There has been poor uptake of this scheme (Drewett, Pers. comm. 1997)

- Habitat Schemes.

This encourages farmers to create, protect or enhance wildlife habitats by managing land in an appropriate fashion. Habitat types differ in each country of the UK (English Nature, National Park Authorities).

- Countryside Access Scheme.

This is restricted to guaranteed set-aside land, which is suitable for new or increased public access.

The headage payments for sheep, dairy cows and beef cattle appear to encourage maximisation of stock numbers, although this is usually within the limits of practical **carrying capacity** and quota restrictions (focusing on the welfare of livestock rather than the ecological **carrying capacity**). In LFAs, stock are eligible for Hill Livestock Compensatory Allowance (HLCA), which is payable on top of the standard headage payments.

It may be true to say that, without public subsidy, hill farming in its current form would not be viable. In 1995, British Farmers received £655 million in special allowances (Wildlife Trusts, 1996). These were composed of the Sheep Annual Premium Scheme (SAPS) and the HLCA. Farmers wishing to claim under the SAPS must own or lease an appropriate number of stock which is subject to the quota. The stock can be bought on a permanent basis or leased on an annual basis. Quotas are not tied to the land and may be transferred within an LFA. This trade in quotas has had the result of concentrating sheep stock, which has led to **overgrazing** in some areas (Wildlife Trusts, 1996).

In 1993, Member States acquired new optional powers to impose environmental conditions upon farmers receiving headage payments to reflect the specific situation of the land. The UK government has reserved the right to make compliance with some or all elements of the non-mandatory "Code of Good Upland Management" a condition for the payment of HLCAs. This approach has been adopted for other livestock payments and is being implemented (RCEP, 1996).

Currently options for CAP reform are under discussion following the recent publication of the European Commission's AGENDA 2000 proposals.

In addition to the agri-environment schemes, other incentives to improve the environmental aspects of farming are available. These include the Woodland Grant Scheme, the Farm Woodland Premium Scheme, small grants from local authorities and conservation agencies for projects such as hedgerow planting and restoration, and management agreements on SSSIs (English Nature's WES Scheme). These can all help to reduce the risk of **erosion**, soil **runoff** and leaching. The Forestry Commission has released guidelines which include methods for the reduction of silt mobilisation.

The multitude of existing grants and schemes is confusing. Some appear to be in direct competition with each other for adoption by land owners and, in some cases, schemes are in direct conflict with each other (Wildlife Trusts, 1996). For example, the Moorland Scheme pays farmers £30 a head to remove stock from hilltops whilst subsidies such as Hill Livestock Compensatory Allowance (HLCA) and the Sheep Annual Premium Scheme (SAPS) actively encourage farmers to stock more animals. The most financially rewarding package will obviously appear to be more attractive to those involved in upland agriculture. According to the Wildlife Trusts (1996), since its introduction in 1994, the Moorland Scheme has only had a response from 15 English and 5 Welsh Farmers, with the removal of only 6000 ewes. The incentives to de-stock land do not appear to be competitive with livestock subsidies and, as a result, farmers are not encouraged to join the scheme.

2.8 Trends in Upland Farming Practice

In his review of UK agriculture, Grigg (1989) details livestock numbers in England and Wales from 1700 to 1985 (Table 2).

Date	Cattle	Sheep	Pigs	Poultry
1700	4.5	12.0	2.0	-
1800	3.4	26.7	-	-
1875	4.8	22.0	2.1	10.8
1895	5.1	18.6	2.7	28.8
1913	5.7	17.1	2.1	29.7
1919	6.2	15.1	1.8	25.3
1938	6.7	17.9	3.6	53.3
1949	7.7	11.7	2.1	57.8
1961	8.8	19.1	4.6	93.2
1973	10.3	19.4	7.3	116.7
1985	9.1	25.6	6.8	96.2

Table 2 Livestock numbers (millions) in England and Wales 1700-1985. (From Grigg, 1989).

The report "Agriculture in the United Kingdom: 1993" details how the sheep population of England and Wales in 1993 had increased to 43 million animals, Egdell *et al.* describe this as a 40% rise in England, 29% in Scotland and 23% in Ireland in the last 20 years. In Wales there has been a trebling of sheep numbers in the last 50 years from 3-4 million in 1940 to about 11 million today (Wildlife Trusts, 1996). In Ireland, the National Sheep Association (1995) describe an increase in sheep numbers of 150% from 1980 to 1993 compared to a rise of 40% in England and Wales and 24% in Scotland.

The National Sheep Association (NSA) in a recent communication (Milton, Pers. comm. 1997) document a reduction in sheep numbers from 1993 (Table 3).

Date	Sheep (millions)
1993	43.9
1994	43.3
1995	42.8
1996	41.5 (provisional)

Table 3. Sheep numbers from 1993.

The Wildlife and Countryside Link (WCL) in their 1997 report "Farming the Uplands in the Next Millenium" (written on behalf of members including the Council for National Parks, National Trust, The Wildlife Trusts, Wildfowl and Wetlands Trust, WWF-UK, RSPB, and CPRE) clearly state that recent agricultural changes (e.g elevated grazing pressures) have affected the natural environment in numerous ways including the loss of habitats such as heather moorlands, associated flora and fauna, the creation of bare soil and its subsequent erosion.

2.9 The Intensive Grazing/Overgrazing Issue

Definitions of the term grazing pressure/ **overgrazing** do vary, depending on the background and context in which it is used. An information sheet produced on behalf of the Peak District Moorland Management Project (including representatives from: Country Landowners Association, Countyside Committee, English Nature, National Farmers Union, National Trust, Yorkshire Water) asks simple questions which direct the reader to address the issue of the impacts of grazing pressure.

The definitions it describes are tailored to suit the aims of different people.

Is my Land Overgrazed?

The answer to this depends on who is asking the question:

a) If you are an ecologist, the answer is possibly yes. All of the hill slopes in the Peak District should be covered in open woodland of birch, rowan, hazel and oak, with glades filled with bilberry and heather between the trees. Our ancestors cleared the trees, using fire and grazing animals to help them, and the continued absence of trees on the hill slopes is certainly due to grazing pressure. **On this view, the lower moors are certainly overgrazed.**

b) If you are a grouse-moor owner, tenant or manager, you will be quite happy with the lack of trees, and will regard invading birch saplings as weeds to be eradicated. **If however, the heather is retreating around its edges, or recently burned patches are coming back as grass rather than heather, you will regard your moor as overgrazed.**

c) If you are a sheep farmer, you may be quite happy to see heather being replaced by grasses (so long as it is sweet grasses such as fescues and bents, not mat grass or purple moor grass). **If however, the sward is broken up with bare patches of peat or soil, if the grasses never flower, or if they do the seedlings are pulled up so they cannot survive, then yes, even from your viewpoint the land is overgrazed.**

Definitions of overgrazing taken from Information Sheet no. 2. Peak District Moorland Management Project.

The National Sheep Association (NSA) believes that there is a proper stocking rate which will allow farms to be farmed to optimum levels and provide environmental returns. Stocking rates of each farm have been set as a matter of sheep breed and history. In other words, most of the hill and upland farms will have carried the same numbers of the same breed for many generations. The NSA also feel that each farm has a proper stocking density which is correct for that farm. This depends on the lie of the land (whether it faces the sun or is in the shade,) its altitude, latitude, soil type, fertility level and the type of herbage it sustains (Milton, Pers. comm. 1997).

Thompson and Kirby (1990) define upland **overgrazing** as a situation which occurs when "too many sheep or other livestock are permitted to graze heather moorland vegetation for too long a period in the year" with a resultant alteration to the vegetation structure. Armstrong (1988) has used a computer-based model to calculate the number of sheep a hill farm can support without incurring a decline in the heather cover. This work has resulted in examples of how the age structure of the heather, quality of adjoining grassland and offtake by sheep all influence the number of sheep that can be sustained.

Indeed there is a level of livestock which can be sustainable upon land, with minimal if not beneficial effects upon the vegetation (undergrazing can itself be a problem, both agriculturally and ecologically). The **carrying capacity** of a sward is often imprecisely defined and the limiting stocking densities are rarely quoted. Evans (1977) describes how the **carrying capacity** of the land can be considered in terms of a) productivity and b) potential to initiate **erosion**. The **carrying capacity** of a sward with regard to productivity can be estimated if the herbage yield of a sward is known, and the number of stock can be related to this. The **erosion** potential is the number of stock per unit area which causes a breakdown of the turf and leads to accelerated **erosion**. However, estimating such sustainable stocking densities is complicated due to locally high densities of grazing animals skewing such values. This is directly related to the concept of the geomorphological thresholds which have to be crossed before **erosion** can take place (introduced in Part One of this report).

2.10 Conclusions

- **Erosion** is a process which has been occurring throughout geological time, long before the presence of man.

- There are complicated interactions between physical, chemical and biological systems which operate in drainage basins.

- Water, wind, ice and rocks can all cause **erosion** to occur. The same can be said for animals, humans and machines.

- **Erosion** rates are very varied across the surface of the Earth and it is very hard to ascribe accelerated rates of **erosion** to anthropogenic causes. Background rates of **erosion** in some situations, exceed those caused by anthropogenic activity. Therefore, there is a level of subjectivity about defining rates of **erosion** which can be described as being accelerated.

- The designation of areas of active **erosion** as unnatural or natural may well depend on whether the **erosion** is having a deleterious effect upon a large number of people. If enough people recognize this to be the case, then it the **erosion** will be recognized as being unnatural. Therefore, the cause for concern about **erosion** rates could be seen to hinge on politics as well as scientific theory. This is the case for accelerated soil **erosion** in the UK lowlands, where much governmental concern has been expressed. However, this is not true for the UK uplands.

- **Erosion** and **runoff** rates are lower where dense robust vegetation is found, compared to areas with little or no vegetation. Therefore vegetation has a role stabilizing landscapes.

- There has been a change in farming in the UK uplands, with a shift from cattle and sheep to sheep dominated farming and an increase in stocking rates. This is largely due to subsidies on sheep introduced when the UK joined the European Community and signed to the Common Agricultural Policy (CAP). Agri-environmental schemes are operational but appear to be undersubscribed.

- Many organizations and individuals have raised concern over the impact of grazing pressure on vegetation and soil in the uplands.

- The level of stocking which causes concern for individuals, is different for maintaining sward productivity, ecological diversity and sustainability, and preventing soil exposure and **erosion**.

PART TWO

3. A REVIEW OF RELEVANT RESEARCH AND INFORMATION

3.1 Introduction

The information used to form the basis of this Section of the report has been collated from a wide variety of sources. These include;

- Published literature searches.
- Grey literature searches accessed via questionnaires, telephone surveys, meetings and the Internet.
- A workshop on upland **erosion** attended by key persons from a variety of organisations.

The synthesis of this information will provide a means of assessing whether there is evidence that the impact of grazing animals is contributing significantly to the degradation of the uplands (**erosion**) and an increase in **runoff** rates. Other impacts upon the uplands which may contribute to accelerated **erosion** will also be considered to give a holistic appraisal of the problem.

3.2 The Impact of Livestock on Upland Erosion and Runoff Rates

3.2.1 Introduction

Many authors have described potential links between intensive grazing by sheep and **erosion** (Evans, 1977, 1996, 1997a; Sansom, 1996; McVean and Lockie, 1969; Birnie and Hulme, 1990; Tivy, 1957; Thomas, 1965; Baker *et al.*, 1979) in locations ranging from the highlands and islands of Scotland, to the Southern Uplands, Central and North Wales, the Peak District and the Lake District.

The RCEP (1996) lists a figure of 35% of soil degradation due to overgrazing throughout the world and 23% in Europe. More than half the world's pasture land is affected by overgrazing; it is more common than is generally recognised.

Examples of overgrazing and soil degradation through this last century have been identified. Over 100 people were forced to leave the Monach Islands in the Outer Hebrides in the early 1800s after overgrazing weakened the grassland and a storm blew the topsoil away. In the nineteenth century in the Tatra National Park in Poland, changes in management and numbers of stock severely damaged alpine meadows and the wildlife and game associated with them. In 1960 the land became national property and the majority of the sheep and other livestock were removed to allow nature to restore the land (Zbiorowa 1962).

In America in 1934 the Taylor Grazing Act became law to prevent the "free and unrestricted grazing of livestock on public lands". This Act aims to protect 80 million acres of public land. Today the Taylor Act remains one of the primary authorities used by the Bureau of Land Management to improve and maintain the health of public rangelands (United States Department of Agriculture). A recent survey of Iceland has shown that desertification or severe or catastrophic soil erosion is affecting some 40% of the total area of Iceland (Soil Conservation Service of Iceland).

The Wildlife Trusts have produced a report entitled "Crisis in the Hills" which focused upon issues associated with high grazing pressures. In 1996, The Friends of the Earth released a report which assessed "Soil **Erosion** and its Impacts in England and Wales" (Evans, 1996). This report discussed the impacts of grazing animals as well as a wide range of other issues. Evans (1997a) focused specifically on "Soil **Erosion** in the UK Initiated by Grazing Animals" and highlighted the need for a national survey.

Much recent attention has therefore been given recently to the impact of grazing animals in the uplands. This chapter will review this information and assess whether, there is evidence of grazing animals (in particular sheep) causing large scale degradation in the uplands and increasing **runoff** rates.

3.2.2 The effects of grazing animals upon vegetation, soil and rocks

As discussed in Section 3.2 of this report, the negative impacts of grazing pressure (**overgrazing**) have different implications for different people. The number of animals which can graze on a unit area of land before a specific negative effect occurs can be termed the **carrying capacity**. Cowlishaw (1969) gives a definition of this (mainly applicable to graziers); "The **carrying capacity** of a pasture or range is the number of animals of a specified type that can subsist on a unit area and produce at a required rate over a specified period". This is an area where research effort has been focused in the past (e.g. Rawes and Welch, 1966).

However, the **carrying capacity** which is desired by ecologists and soil conservationists is different to that required by farmers. Evans (1997) describes how "**overgrazing**" can lead to the loss of preferred vegetation cover resulting in the exposure of bare soil and consequent **erosion**.

A widely used definition of **overgrazing** is a level of grazing which exceeds the ecological **carrying capacity** of the land. This is different to **overgrazing** levels which are described as exceeding the livestock **carrying capacity** of land. If the latter is used to recommend stocking densities then assessments will always favour more grazing animals on the land than the natural vegetation can sustain. Evans (Pers. comm. 1997) points out that too many animals can also cause **erosion**, and this may well occur at a different stocking level to that which will sustain the ecology of the land or that which will sustain livestock. Indeed it may be a lower stocking rate than either the ecological or economic **carrying capacity** (refer to Section 3.2.3 of this report and Evans, 1997a).

The livestock **carrying capacity** of the land can be increased by the use of artificial feeders, whereby a farmer can nourish his livestock by taking food supplements directly to the hills lopes or moortops. Hudson (1984) describes the supplementary winter feeding of sheep using feed blocks and provision of hay. The use of supplementary feeding stations can cause localised damage from **poaching** and **overgrazing** (Shaw *et al.*, 1996). This can be avoided by placing hay away from the moorland, using feed blocks on many dispersed sites, avoiding placing the feed blocks on newly burned or aged heather (Armstrong, 1988) or by overwintering stock elsewhere (Figure 11).

Walker and Elias (1993) describe how the introduction of winter feeding on Mt. Berwyn has increased the amount of time sheep can stay on the mountain and how this has directly led to localised **overgrazing** of heather. Anderson (in Bunce, 1989) describes how an 800 ha estate in County Durham lost 500 ha of heather in 20 years as a result of winter feeding..

Food supplements can therefore create an artificial **carrying capacity** for the land which can sustain livestock productivity irrespective of the extent of any deterioration of the natural food source (the sward).

During periods of lambing, localised concentrations of sheep are found on the lower slopes of the hills as the ewes are brought into more clement conditions. Where the grass crop is not sufficient to support this swollen population, supplementary feeding is often
required. In these situations, it is not uncommon to find much tramping of the sward and as a consequence, exposure of the soil, due to the passage of high numbers of livestock.
An alternative to supplementary feeding is the housing of sheep during the winter months, and especially during lambing time. Although grazing pressure is therefore reduced whilst the stock are inside, and the sward has an opportunity to increase in density and quality in early spring, there is a tendency for the stock to graze this sward more intensively during the periods they are outside because there is no longer a need to send any stock further afield to graze as the food resource is locally at hand (Spensley, Pers. comm. 1997).

The species and breed of the grazing animal do have a control over the specific effect of animals in grassland systems. For example: sheep are essentially grazing, not browsing animals (Yalden, 1981). They pull their food but, unlike cattle, due to their narrow muzzles they are more selective in their choice of food (e.g. a preference for the more nutritious stem-bases of grasses). Sheep also prefer grazing short vegetation. In heather they have been observed to concentrate on patches of short grass within heather stands and "nibble" at the heather margins (Grant *et al.*, 1978).

When heavy grazing of preferred grasses (e.g. *Festuca rubra*, *Poa* and *Agrostis*) occurs (Milner and Gwynne, 1974) and the stocks of these become depleted, sheep become forced to graze other vegetation. In particular, heather (*Calluna vulgaris*) is very important as it is evergreen when other grasses are dead and can protrude at times through snow cover. Other foods of note include bilberry (*Vaccinium myrtillus*) and cotton-grasses (especially *Eriophorum vaginatum*).

Jones (1967) remarks that daily grazing of sheep tends to begin and end on both rich and poor swards while, during the middle of the day, grazing activity tends to concentrate on the better swards. Jones (1967) and Grubb and Jewell (1974) detail how grazing tends to occur during the day, with an upslope retirement of sheep occurring at night. This can also be seen in eroded areas. In addition, bare patches in eroded areas make access to the edge of vegetation easier, potentially exacerbating the effects of **overgrazing**. This principle also applies to areas which have suffered from a recent fire.

The effect of grazing animals can be summarised as:

- Harvesting the growing sward.
- Returning plant residues to the soil.
- Altering the soil environment by trampling.

It is the impact of intensive removal of vegetation and the effect of trampling which is of concern.

One of the most fundamental and important problems of most grazing systems is that the productivity of the sward may not match the animals food requirements, as there is too much forage in the summer (in some cases) and not enough in the winter, especially if the vegetation is stressed (e.g. due to a paucity of rainfall). This is the reason that grass has to be conserved (or other forms of forage have to be used) to supplement the diet of livestock during certain periods of the year. A mature cow consumes approximately 10-30 kg of dry matter per day; a mature sheep requires around 1-2 kg dry matter per day. Evans states that in a natural system where animals can graze freely, this mismatch is less of a problem. It is when humankind starts interfering with the system and encouraging an increase in the animal population that problems can arise (Evans, Pers. comm., 1997).

However, other factors such as the nutritional quality of the herbage and the age of the animal also influence the amounts eaten. The effort required to obtain food also has a major impact upon the amounts required; the harsh environmental conditions encountered in upland grazing require the most effort of all, and consequently a greater amount of food is needed (Briggs and Courtney, 1989; Rawes and Welch, 1969).

The intensity and extent of damage as a result of grazing does vary according to a number of factors. These include: stocking rates, wetness and conditions (altitude and aspect) of the site, species of grazing animal, time of year and length of time the grazing animals are on site (RSPB, 1995). Further reviews of this can be found (e.g. Grant *et al.*, 1978, 1982; Grant and Maxwell, 1988; MacDonald, 1990; Mowforth and Sydes, 1989; Welch, 1984). There is also a difference in resistance to trampling between improved and reseeded pastures and upland open grazings, with improved grasses being much more resistant.

The assessment of the impact of herbivores needs to take into account seasonal diet, distribution through the habitat, type of grazing species, the interactions between them, and availability of alternative food sources. Lance (1983) describes how the period of grazing strongly influences the effects of grazing; land may be understocked in the summer and overstocked in the winter, while in many situations there is a fixed, year-round stocking density. Evans (1997b) deals with the seasonal aspects and the selectivity of vegetation by sheep. He also notes that bare soil is disturbed more in summer when lambs are more "frisky" than in winter.

Evans (1977) identifies critical times for intensive grazing. These are; the spring, where the growing season is beginning and grazing reduces leaf area with a corresponding reduction in photosynthesis; at seeding, when grazing inhibits seed production and plant production; and at the end of the growing season when the plant should be storing reserves of food for winter. The grazing of animals on fragile or stressed vegetation should be avoided, especially at these times of the year.

Brown (1954) describes how intensive grazing also weakens the root systems of plants and thus reduces growth. Sansom (1996) discusses the impacts of heavy grazing on the grass community and describes how the root and shoot lengths of grass have been reduced to a combined length of 3-4 cm in many areas. This obviously has implications for the effectiveness of the sward in intercepting water. In addition, it reduces a plant's resistance to uprooting (from **poaching**, grazing, frost-heave or river floods).

In drought conditions, a "tight" (short, cropped) sward will react more adversely than a long, less grazed sward as it affords little insulation to the sun. The constant grazing and trampling pressure can stress the plants as they lose water through cut and crushed leaves whilst they attempt to reduce this loss via stomata. Sansom (1997) also identifies possible links between the reduction in surface vegetation biomass and a corresponding reduction in evapotranspiration during the summer which may have a knock-on effect to the local climate.

Otterman (1974) links the exposure of high **albedo** soils, denuded by intensive grazing, to regional climatic desertification. Measurements and models appear to show that denuded surfaces are cooler when compared under sunlit conditions to surfaces covered by lower **albedo** natural vegetation. This observed "thermal depression" effect should, theoretically, result in a decreased lifting of air necessary for cloud formation and precipitation, and therefore could lead to regional climatic desertification.

Otterman's work focuses upon the Sinai-Negev deserts but parallels may be drawn to the UK where, due to grazing pressures, vegetation which has a low **albedo** (such as heather) has been replaced by species having a higher **albedo** (e.g. cotton grass and a tightly cropped sward) or areas of bare ground which have a high **albedo** soil.

If there is a link between vegetation loss or change and reduced rainfall, then the grazing pressures exerted could be directly linked to additional climatic stresses experienced by much of the UK under the recent "drought" conditions.

Evans (1977) states that "once colonisation becomes dominant over **erosional** processes, changes in climate at the soil surface will further encourage colonisation. Moisture will not be evaporated from the surface as quickly and there will be less disturbance of the surface by the wind and rainfall. Germination of seeds and growth of stolons into bare soil will be favoured". He continues, "the increasing numbers of sheep (in Hey Clough, Peak District, UK) from 1944-1968 and the shortening of the growing season increased the pressure on the better pastures, leading to a breakdown of the turf mat and soil **erosion**.

The reduction in the numbers of sheep in 1969 initiated recolonisation of the surface by vegetation and a fall in the rate of **erosion**". Indeed, this appears to be the case in many situations once the grazing pressure is reduced or halted, landscapes begin to recover. Today there are less sheep grazing the east side of the Derwent Valley and the west side of Kinder Scout. This has allowed vegetation to recolonised the bare soil even at higher altitudes (Evans 1997a).

Sheep are social animals, but do retain an individual "home-range". This is shared by other sheep and so, together, they form a social group. Grubb (1974) describes a typical group consisting of about 20 ewes. Several authors (Hunter and Milner, 1963; Jones, 1967) describe the "attachment" of sheep to specific regions of hillside. This phenomenon is often referred to as "hefting". Under light shepherding, the increase or decrease of sheep numbers in specific areas may not affect the grazing pressure as the defence of a home range could cause some sheep to graze elsewhere. In addition, the removal of sheep from one home range could leave another untouched (Yalden 1981).

In many upland locations today, active shepherding of flocks of sheep is lacking. Traditionally, shepherding has two main functions; to "heft" a particular flock of sheep to a given area and to move the sheep around to ensure more even use of the available land, including the Less Favoured Areas (hill regions) (Shaw *et al.*, 1996; Coulson *et al.*, 1992). However, the numbers of staff working many farms has declined severely, making regular shepherding almost impossible. This promotes the concentration of groups of sheep on discrete areas (hotspots of grazing pressure), where the grazing pressure is typically above the **carrying capacity** of the vegetation.

Sheep and cattle should be herded to promote the grazing of a wider area of hill and moorland, avoiding a concentration of grazing effort. However, the continual movement of livestock could cause **erosion** due to trampling damage, especially where routes are confined by steep slopes or woods (Evans, 1996). This phenomenon can be seen to occur as a result of walkers disturbing sheep.

A study conducted by Anderson and Radford (1994) on the impacts of shepherding on the Kinder Scout area in the Peak District showed that active shepherding (between 6 and 22 gathers per year) had the effect of reducing grazing intensities from 2.5 ewes ha^{-1} to 0.18-0.43 ewes ha^{-1}. This encouraged the revegetation of previously bare and eroding ground, illustrating the benefits of shepherding.

In their review of "The Historical Effects of Burning and Grazing of Blanket Bog and Upland Wet Heath" Shaw *et al.*, (1996) refer to an information sheet supplied by the Peak District National Park Authority (PDNPA) which advises landowners that the problems of **overgrazing** may be alleviated by active shepherding, as it increases the use of better vegetated areas and reduces the use of overgrazed areas. Evans (1996) concurs with this.

As a grazing animal moves around, it exerts a large amount of pressure on the land surface. This modifies both the sward and the soil. A force of up to 1600 g cm^2 can be exerted by a single mature animal (depending on its weight). As a sheep or cow moves about, the weight is concentrated upon two hooves at a time, and the pressure will increase. The forces exerted comprise a vertical (normal) component and a horizontal (shear) component, also increasing the impact on the soil and sward (Briggs and Courtney, 1985). Figure 12 illustrates some of the interrelationships involving trampling.

Some trampling may actually encourage growth by stimulating the development of basal tillers. However, as trampling pressure increases, the tearing and bruising of plants begins to occur. Briggs and Courtney (1985) surveyed seventeen sites on uniform clay soils in South Yorkshire and showed an almost linear decrease in the sward cover as stocking rates increased. Campbell (1966) found a 15% reduction in the growth of grass after a single day of grazing by cattle at 150-300 animals per hectare.

Edmond (1963) also demonstrated the importance of soil conditions in this context: the trampling of a wet soil by 45 sheep per hectare reduced herbage yields by 90%; on a dry soil the same stocking density gave a reduction of 53%.

The ability of the soil to withstand the pressure of an animal is dependant upon its shear strength. If the pressure exceeds the shear strength of the soil, then failure occurs and the hoof penetrates the soil. Liddle (1975) identified the general ecological principal that "the effect of the degree of impact from feet, hooves or tyres is inversely related to the potential productivity of the sward".

The effects of trampling and deformation of the soil by livestock are wide ranging (refer to Figure 13) and include closure of pore spaces, an increase in moisture retention, a reduction in **infiltration capacity**, destruction of soil organisms, and interference with the breakdown of organic matter. Ultimately, changes in sward composition and soil **erosion** may occur. Gradwell (1968) found that damage caused during winter grazing failed to be repaired during the summer rest period, a condition that was also noticed by Briggs (1978). Compaction of soil as a result of trampling will result in it becoming more impermeable. Rain falling on such surfaces will collect in depressions created by hooves and "puddle". If rainfall continues, surface **runoff** will ensue, especially on slopes. This will actively transport away soil particles and any other loose material.

The land can be thought to have a **carrying capacity** (typically based upon stocking densities) beyond which **poaching** is likely to be severe and, due to positive feedback loops, self reinforcing (Briggs and Courtney, 1985). As the characteristic behaviour of animals results in an irregularity of trampling and grazing pressure, the concept of a **carrying capacity** is difficult to define. The irregularity of trampling pressure that arises from this behaviour can be the cause of serious **poaching** problems. As a direct result of this, even where the stocking density for a field may be low, around focal points (e.g. around feed troughs, water troughs, gateways and shelters) it will be higher. Here, where trampling pressures are greater, **poaching** will occur (see Figure 13 and 54).

As described in Section 2.3.5 of this report, under the influence of gravity, mass movements of materials occur on slopes. The lowest magnitude of movement, soil creep, often results in the formation of small terracettes. Typically, these are up to 30 cm in width and are often unvegetated, occurring on grassy slopes which have an angle of 30° or more. They often occur in parallel series, running approximately along the contours of the hill slope, with a spacing of about a metre (Small and Witherick, 1986). It is arguable, however, that these features could be formed by the passage of animals.

Terracettes are undoubtedly exaggerated by the passage of animals, especially livestock such as cattle and sheep. Loxham (1997), describes how sheep accentuate terracettes, and how, once the mineral soil is exposed, they can provide a nick-point for the start of **upland sheet erosion** ("where bare soil has been exposed and maintained by the combined impact of animals, rain, wind and frost on the landscape" Evans, Pers. comm. 1997).

Loxham has also found similarities between recognising the warning signs of linear **erosion** normally associated with recreational pressure and the "symptoms of grazing induced **erosion**" (Davies and Loxham, 1996). He describes specific symptoms of grazing induced **erosion** which, over time, can progress to a total loss of vegetative cover and full blown **upland sheet erosion** (see Figure 33).

- **Sheep Scrapes (Scars) and Pigeon Holes.**

"Pigeon holes" are often found on grass surface paths where the passage of walkers over time results in the development of lenticular patches (about 0.3m x 0.3m in size) of eroded ground that can appear like steps ascending a slope. They indicate the breakdown of the vegetation layer and expose the soil to **erosion**.

At a larger scale, lenticular "sheep scrapes" develop where the sheep scrape themselves onto vegetation, typically on a break in slope, and rub a semicircular hollow (these can become extended into larger features when eroded, as mobilised soil and scree move downslope and form an apron). Evans, 1977 describes these as "sheep scars" while Thomas (1965) refers to them as "sheep burrows". Their formation causes compaction and exposes the underlying soil and root systems. It is only a short progression from sheep creeps to local **upland sheet erosion** which can then link to other sheet scrapes to initiate full blown **upland sheet erosion**.

- **Sheep Tracks (Trampling)**

Loxham (1997) sees trampling as one of the causes of large scale **upland sheet erosion** on intensively grazed vegetation. He describes how the passage of sheep across hill sides causes a loss of vegetation and the exposure of fresh soils. The contouring tracks (trods) can be easily differentiated from linear footpath **erosion** (they are defined by their narrowness, less than 0.5m, and the rough terrain they traverse). If these coincide with heather communities, they can be easily identified, especially from a distance, particularly from aerial photographs.

On steep slopes (above 15 degrees), trampling can cause gullying and result in a downslope transport of material. This debris can smother vegetation, killing it and expanding the areas of bare ground. Where damage from trampling and sheep creeps are found together, greater slope instability is often created. Loxham (pers Comm. 1997) feels that grazing and trampling pressure are probably the primary causes of large scale **upland sheet erosion** in those areas not normally subject to recreational pressure.

- **Colouring of Scree.**

Undisturbed scree beds are characterised by their uniform grey appearance. If the material is disturbed (for example by scree-running or the continual tracking of animals) it will present an obvious contrast to the undisturbed material as it will be marked by colours that are dependent on the rock type and stage of **weathering** (typically ranging from white to red).

Loxham (1997) describes scree beds and boulder fields as being good examples of physical structures which are in equilibrium with their surrounding environment. They have a natural angle of repose of 30-40° and remain *in situ* (the effect of gravitational attraction being balanced by frictional retardation between the scree boulders and the underlying bedrock). When this balance is disturbed (by the passage of humans, animals or rockfalls from above) then the material will move downslope. If the material is lubricated by water, then the effect can be greater (refer to Section 2.3.5 of this report).

The colonisation of stable scree fields by vegetation (e.g. ferns, mosses and lichens) is a slow but continuous process. Such vegetation is indicative of stability. At lower altitudes, if grazing is excluded, dwarf shrubs and trees may become established, adding to the stability of the slope (this can eventually evolve to woodland). However, if these areas are disturbed (by human recreational activity and livestock), they rapidly devolve into mobile slopes; rock material can move downslope under the slightest pressure, smothering areas of vegetation and prohibiting recolonisation of the scree. This is apparent in many parts of the Lake District, where "steep alternating tongues of vegetation, both of heather and grass, are interspersed by scree beds, some of which are stable (uniform grey) and others which are actively eroding and growing in size (see Figures 27 and 30).

As a result of disturbance of the scree by animals, other **erosion** processes (**weathering, attrition** etc.) are encouraged and the expansion of the eroding area is soon witnessed with a raised potential of increased **runoff** rate and transport of material into receiving water courses (see Figure 31).

3.2.3 Evidence for a reduction in upland stability due to ecological change

After the historical clearance of trees and shrubs in the uplands during the last 5000 years, the use of the land for grazing by sheep, cattle and deer has produced what could be described as "a uniquely open and predominantly anthropogenic landscape" (Ratcliffe and Thompson, 1988). Thompson and Horsfield (1988) describe an absence in Britain of the natural altitudinal zonation of vegetation. This would have been an upland sequence of woodland, sub-alpine woodland, scrub and medium shrubs, low alpine dwarf shrubs and middle alpine grasslands. Instead, the uplands in many areas of Britain are characterised by short vegetation, with little rooting depth and foliage cover.

Sansom (1996) describes vegetation which dominated Britain during the "Wildwood" era (7000-8000 years ago) as being highly resistant to **erosion** and states that it would have intercepted up to 30% of rainfall. In contrast, only 10% of Britain is currently covered with trees. Evans (1993,

1996) ranks sensitive landscapes from "wildwood" (least sensitive) to arable (most sensitive) and states that more of Britain is presently more sensitive to **erosion** than it has been at any time since woodland clearance began.

Many authors have suggested that more intensive grazing regimes have resulted in a decline in biodiversity and a change in or loss of vegetation. A report by Anderson and Yalden (1981) describes how sheep numbers in the hill parishes of the Northern Peak District trebled between 1936 and 1976. Turn of the century maps of vegetation (described in Moss, 1913) suggest that there was 154 km^2 of moorland in the Northern Peak District dominated by heather (*Callunis vulgaris*) and bilberry (*Vaccinium myrtillus*). In 1981, this area had been reduced to 99 km^2, a loss of 36% of heather and bilberry coverage. These reductions in specific types of vegetation are consistent with those produced elsewhere experimentally by sheep grazing studies.

According to a report produced in 1996 for the Council for the Protection of Rural England (CPRE) and the World Wildlife Fund (WWF-UK), 71 % of ericaceous moorland in England could be subject to the impact of **intensive grazing pressure**. It describes an increase of 34 % in the number of sheep in the severely disadvantaged LFAs (exposed hills and moortops) between 1976-1992 and a 79% increase in the disadvantaged areas (hill slopes).

Hester (1996) describes how livestock subsidy has resulted in large-scale **overgrazing** in the uplands, which has in turn led to a massive decline in biodiversity. Habitats and species which are listed as threatened by **intensive grazing pressure** in the UK Biodiversity Action Plan are Upland Oakwood, Purple Moor Grass and Rush Pastures, Native Pinewoods, Yellow Marsh Saxifrage, Capercailie and Wild Catoneaster.

Harnden (Daily Telegraph, May 6, 1997) describes how on Clare Island (Ireland), the once flourishing grouse population has now all but disappeared. Botanists from the Royal Irish Academy have found that 41 plant species, including rare alpines and heather, have now all but gone. Chris O'Grady, former chairman of the Irish Island Federation, is quoted to have said that the effect of intensive grazing on the island is not the fault of the sheep farmers but is due to those who set up the subsidy structure "without thinking of the devastating effects".

MAFF (1996) describe changes in vegetation and **erosion** arising from the impacts of livestock in their leaflet "Your Livestock and Your Landscape".

The Moorland **Erosion** Project (Phillips *et al.*, 1981) identified some of the major ecological impacts of grazing. Using grazing exclosures (an example of which is shown in Figure 14) it showed that summer-only grazing pressures of 0.25 sheep/hectare (1 sheep/4 hectares) are sufficient to reduce flowering densities and effectively prevent fruiting. This could have serious implications for the reseeding of vegetation. Anderson and Radford (1994) discuss similar issues.

In addition, the Game Conservancy Council in their 1995 Review describe that research undertaken for 5 years has shown that **overgrazing** by sheep has caused a major decline in the black grouse population by reducing the abundance of favoured food plants, nesting cover and brood rearing areas (although black and red grouse have different requirements). Where sheep are grazing throughout the year at a density of 1 ewe per hectare, there are 40 % fewer grouse compared to areas where grazing occurs at 1 ewe per hectare in spring and summer only. The brood rearing success of the grouse is also reduced.

Sydes (1988), using information from the National Countryside Monitoring Scheme calculated losses of 10-20% of heather moorland since the 1940s, a third of which he believes are attributable to intensive grazing.

As a result of such work, much attention has been given to understanding the relationships between grazing and plant productivity. Consequently, stocking densities have been identified and suggested. These will be geared towards specific targets, such as the prevention of ecological degradation or denudation, or sustaining the livestock productivity of pasture.

In their report "Crisis in the Hills" the Wildlife Trusts (1996) describe appropriate grazing levels as being 0.5 ewes per hectare for blanket bog (if it has not been burnt) and, 1.6 ewes per hectare for young heather (Andrews and Rebane, 1994). They found current stocking densities on some upland farms as being greater than 7 ewes per hectare. Statistics from MAFF (1996) describe stocking densities of sheep in the Swale, Ure and Ouse catchments (Yorkshire) as exceeding 10 to 13 sheep per hectare of grazing. With regard to **erosion**, these stocking densities are high (Evans, 1997a), especially when the total number of animals may well have to be doubled to take into account the number of lambs (which are not considered to be a grazing unit until 16 weeks of age; Spensley, Pers. comm., 1997). As hooves are a destructive tool acting on both vegetation and soil, it is the total number of animals which is important (Evans, Pers. comm., 1997).

Work conducted by Jones (1967) highlighted two important points:

1) A twelve year period of protection from grazing may not allow heather moorland to re-establish after heavy grazing has removed it (in other words, the land may take much longer to recover).

2) Grazing pressures of less than 0.6 sheep per ha are compatible with the survival of heather and bilberry in substantial quantities in all-year grazing regimes. Above this level, these plants are completely suppressed.

Hewson (1977) made similar observations on the loss of heather from moorland, as did Brack (1978). On blanket bog, heather can be suppressed by much lighter grazing pressures; on burnt blanket bog, summer-only grazing pressures of 0.5 sheep per hectare can prevent the recovery of heather due to the concentration of sheep on burns. Woodland can eventually be suppressed in the same manner, as prolonged sheep grazing can remove new seedlings and, with time, old trees will die (Yalden *et al.*, 1981).

Newson and Bathurst (undated) describe a stocking density recommended by Miller, Miles and Heal (1984) for Exmoor as being 2.2 - 2.5 sheep per hectare. This is higher than that recommended by Phillips *et al.* (1981). Apparently, this is reasonable as it is difficult to recommend an optimum sheep stocking rate for heather moorland because of the importance of the proportion of grassland to heather on the moor, the distribution of sheep and the productivity of heather, climatic variability, breed of sheep etc.

Carr and Evans (unpublished) suggest that grazing densities year round of about 0.5 ha per sheep (2 sheep per hectare) were sufficient to initially cause a decline of heather moorland, and then to initiate **erosion** in the form of sheep scars within the better quality acid-grasslands, which often had wavy hair grass as the dominant species (Evans, 1993).

In the Phase 2 Report of the Moorland Restoration Project (Tallis and Yalden, 1983), regular field observations clearly showed that fenced areas of bare ground re-vegetated far better than unfenced, grazed areas. Tallis and Yalden describe that established vegetation is reasonably resilient but eroding ground, however formed, is very fragile, and even light grazing inhibits re-vegetation. The conclusion from their experiments is that exclusion of grazing animals for a period of time is essential in order to achieve re-vegetation of bare peat.

MAFF (1993) state in their Code of Good Agricultural Practice for the Protection of Soil that "when the plant cover is broken (by livestock, unsealed tracks, drainage ditches or recreational activities) soils are particularly prone to water **erosion**". They continue "when **overgrazing** has, or is likely to, cause a problem stocking rates should be reduced." MAFF encourage the regeneration of plants as a method for protecting vulnerable areas against **erosion**.

3.2.4 Evidence for upland erosion by grazing animals

There are a limited number of studies into the direct effects of grazing animals on **erosion** in British uplands (e.g. Evans, 1977; Birnie and Hulme, 1990, Tivy, 1957; Thomas, 1965) and, although much work has been undertaken in America on the impact of grazing on forests (e.g. Allen and Bartolome, 1990; Blackburn, 1984) and riverbank stability (e.g. Marlow *et al.*, 1987; Renard, 1988) there is a paucity of research into the effects of grazing animals on soil **erosion** and loss (e.g. Owens, Edwards & Van Keuren, 1997).

Evans (1992b) identifies that **erosion** initiated and maintained by animals grazing upland grassy swards occurs in soil associations covering 2.7 % of England and Wales and 16.4 % of Scotland. Even in 1965, Thomas surveyed the slopes of Plynlimon (Wales) and found that 5% were affected by "**upland sheet erosion**" induced by sheep.

Scottish Natural Heritage (SNH) has undertaken a survey to quantify the extent and spatial distribution of soil **erosion** in the Scottish Uplands. This was originally accomplished by the interpretation of aerial photographs (Grieve *et al.*, 1994) and was extended by the use of questionnaires sent to professionals who had detailed local knowledge. A range of **erosional** processes were studied including gullying, slope failure, minor land slips, scree activity and debris flow. SNH concluded from this survey that a widespread and obvious **erosion** of mineral soil is occurring in the Scottish Uplands.

The questionnaires indicated "that 40% of reported instances of gullying were associated with land management, mainly heavy grazing by sheep and deer, or drainage work". SNH also concluded that a major factor which is contributing to an increase in soil erodibility is the loss of protective vegetation cover on slopes.

Loxham (1997) feels that the problems of upland **erosion** found in Scotland "is a situation mirrored in the Lake District and in other upland areas to a greater or lesser degree, where sheep rearing is the main agricultural enterprise".

Loxham (1997) also describes some of the particular aspects of upland farming which promote sheep originated **erosion**. These include the "changing husbandry, shepherding, supplementary feeding, year round grazing, ratios of cattle to sheep, an increase in the density of grazing animals beyond the **carrying capacity** of the farm unit, over wintering in woodland and on the fell, and off wintering of first year lambs to lowland farms". Tallis (1985) relates the current **erosion** (initiated 200-300 years ago) of southern pennine moorlands to intensified grazing and trampling on the moorlands, compared to past **erosion** events which predate major forest clearance (1000-1200 years ago) which may have been generated by naturally occurring mass movements.

Evans (1990) describes an increase in area of bare soil on an exposed slope in the Peak District (Derwent Edge). This was about 4% per year between 1975 and 1986. The slope was covered in vegetation in 1948 but, by 1986 there was about 1670m^2 of bare soil, the vegetation having been lost as a result of grazing. He describes this area as having a rate of **erosion** (about 17.5 m^3 a year) which is 3.5-7.0 times faster than the highest mean rates of **erosion** recorded on arable land. The rate of increase in the expanse of bare soil halted when the number of sheep grazing the slope was reduced. Evans found this rate of **erosion** to be similar for other parts of the Peak District (e.g. Kinder Scout).

Bare peat soils are highly vulnerable to disturbance by the hooves of sheep, and lambs disproportionately disturb the soil surface and stop colonisation of the scar by vegetation in the summer (Evans, 1996). Wilson (1993) describes how the bare soil at Kinder Scout has become revegetated once the sheep were removed from the area.

A survey of **erosion** features in Scotland (Grieve *et al.* 1995) describes how as much as 6% of upland areas are covered by eroding peat, a sizeable area of land in which **erosion** was either initiated by or has been maintained by grazing animals. Tallis and Yalden (1983) concur with this view, stating that active **erosion** at peat margins is clearly accentuated, if not caused, by intensive sheep grazing.

Evans (1997a) gives a full account of the formation of sheep scars and the effect of their formation. He describes how sheep most commonly form crescent-shaped scars at breaks in slope where they rub against vegetation. "The scars are not only used as scratching posts but also for shelter. The scars can be small (having a height to width ratio of less than 1:5) or large. The larger scars have an 'apron' of bare soil below the backwall of the scar and can be complex in shape when they coalesce with adjacent scars." Evans continues by saying how the 'apron' cannot become re-vegetated because the surface is constantly disturbed by the hooves of sheep, the impact of frost and other natural agents of **erosion** (see Section 2.3 of this report).

In the 1980s Carr (1990) assessed the summer stocking densities of sheep in Coledale (the Lake District) where sheep scars were extensive. Stocking densities were 0.2 - 0.4 ha per sheep. Evans (1977) found that bare soil was created in Hey Clough (Peak District) during the 1960s with year round stocking densities as low as 0.5-0.6 ha per sheep. On the Armbroth Fells (Lake District) scar initiation probably took place at summer grazing densities of 2.0 ha per sheep. The occurrence of such scars is widespread throughout upland Britain. Loxham (1997) says "sheep have always created these scrapings to protect themselves, (the problem is) there are just so many more of them today. The incidence and evidence of these scrapings are available in every major valley throughout the region" (The Lake District).

Greene *et al* (1998) investigated the effects of high and low grazing regiemes on the surface soil properties of a dunefield land system in E. Australia. They concluded that at low sheep grazing densities (0.2-0.3 animals per hectare) the soil remained in excellent condition. However, at high intensity grazing (4 animals per hectare) there was a rapid depletion of perennial grasses, removal of most of the shrubs and a conversion of the soil structure to one that was either easily erodable or, formed a strong, physical crust. They conclude that this crust may cause a change in the hydrology of the land system and limit recovery of palatable sward, thereby propagating grazing pressure elsewhere.

The formation of gullies has been attributed to the damage of blanket bog vegetation by sheep. If the gullies retreat and drain pool and hollow complexes on peat interfluves, then wind, frost and sheep can all play potent parts in further eroding peat into hags (Shimwell, 1974). Innes (1983) dated debris-flows in the Scottish Highlands by lichenometry and considers sheep grazing to have played a major role in creating instability of slopes and the occurrence of screes. This opinion is also echoed by Evans (1990) and Loxham (1997).

In addition to forming scars, sheep accentuate them. Evans (1990) describes how scar margins are broken down more quickly by sheep than by the natural agents of **erosion** alone. In this situation, it is normal for **weathering** of the backwall of the scar to undercut a turf mat which will consequently slump down and afford some measure of protection to the exposed soil. However, sheep rubbing or treading these turf mats prevent this situation being achieved. Therefore sheep scars can rapidly expand, joining up with others to create expansive areas of bare soil, especially at high altitudes and steep slopes where the natural retreat of the backscar is more rapid.

It is not just the impact of sheep which contributes towards the accelerated **erosion** of the uplands. Other animals do play a major role (though it is likely that the impact from intensive sheep grazing has helped to create an ideal habitat for rabbits). Rabbit populations have increased in many locations; survival rates have increased due to recent mild winters (Long, 1990). Short, closely grazed turf, especially when it is found in conjunction with dry sandy soils, is highly favoured by rabbits. Evans (1997a) describes how rabbits favour short grass for grazing. Where rabbits and sheep are coincidental on the same slope, the sheep can create scars and the rabbits can burrow into the weakened turf as well as the scars. Soil spread around burrow entrances then kills underlying vegetation (in the same manner that remobilised scree will). Deer can also create damage, as highlighted by Evans (1997b). In Scotland this is a serious problem, where red deer numbers have been encouraged to promote shooting incomes.

Bare soil is also commonly exposed along tracks which are used by livestock. Evans (1997a) describes bare soil initiated by trampling along fence lines, around gateways and farm buildings, anywhere where livestock can congregate. Evans (undated) describes sub-parallel paths which can be seen on most Lake District fells. These are unlikely to be created by walkers as the majority use paths which run directly to the point of destination. Loxham (1997) feels that it is not a question of "sheep grazing habits having changed (although sheep numbers in some places are leading to a breakdown of natural herding instincts). It is more a case of sheep doing what they normally do, but doing much more of it i.e. foraging, tracking back and forth, trampling damage." This is as a result of greater competition for food (as there are more sheep than in the past) and of there being less food available (having been grazed out, removed by accidental or deliberate fires, or smothered by bracken or old heather stands).

Once bare ground has been established it is very difficult for the vegetation to recover, especially if environmental conditions are difficult (Evans 1990b) and grazing animals are present. Grant *et al.* (1978) recorded the tendency for sheep to graze near bare areas and, in doing so, enlarge them. Some soils and subsoils are extremely unstable (e.g. shale, scree and loose sand) and vegetation cannot easily take hold. This is exacerbated at high altitudes and, in some circumstances, once bare soil has been created, **erosion** will continue until a surface more suited to colonisation or one that is more resistant to **erosion** (e.g. hard rock) is exposed.

Drought over the past few years has also contributed to a reduction in the amount of vegetation available to grazing animals over the summer months as the vegetation, stressed by drought, stops growing. The pressure on vegetation is increased substantially over the winter months for the same reason. In both situations, the pressure from sheep is critical, resulting in the vegetation still being eaten and trampled, while not growing.

In 1937, Fenton noted that it took longer for bare soil to be recolonised by vegetation if sheep were present than if they were excluded. Evans (1990) relates different situations where this has been found to be true. Rawes (1983) found that within exclosures of blanket bog over 15 years, bare peat began to diminish in area as it was fragmented by colonising plants while Lance (1983) observed that burned and grazed heather in western Ireland was slower to increase in standing crop and ground coverage than burned but ungrazed heather.

In the Lammermuirs, south-east of Edinburgh, a fence separating ungrazed water- gathering grounds for Whiteadder Reservoir from adjacent grazed slopes separates an eroding grassy slope on the grazed side from a non-eroding grassy slope (Evans, unpublished). In the Cardingmill valley of the Long Mynd (Shropshire), steep grassy slopes outside an exclosure are eroding and appear exceedingly vulnerable, whereas within the exclosure there is little bare soil, and grasses come into flower and set seed (Evans unpublished). Similar patterns have been observed in exclosures in the Peak District (Tallis and Yalden, 1983). In the Peak District attempts to colonise bare soil with vegetation proved difficult, especially on peat and if sheep were not excluded (Tallis and Yalden, 1983).

In 1981, the Peak District Moorland **Erosion** Study, Phase 1 Report (Phillips *et al*, 1981) was published. It explored the nature and extent of the **erosion** problem in the Peak District. The report covered a wide range of topics and identified a range of factors (such as grazing animals) as being responsible for the degradation of 33 km^2 of upland. The report also reviewed the range of options available for attempting to restore eroded areas and put forward suggestions for a number of field trials.

Consequently, Phase 2 of this project was undertaken and the report was released in 1983, under the revised title of Peak District Moorland Restoration Project, Phase 2 Report: "Re-vegetation Trials". This report contains the results from a number of different experimental plots, some of which were fenced to exclude sheep and people, while some were seeded with heather and located on both peat and mineral soils. Where the plots were located on mineral soils which were protected from sheep, some success had been attained. However, where revegetation was attempted on bare peat, the trials failed completely.

The Phase 3 Report, "Restoring Moorland", Peak District Moorland Management Project (Anderson, Tallis and Yalden, 1997) relates the progress which has been made and describes attempts to restore heather cover to eroded or degraded moorlands. This report concludes that "not all damaged moorland can or should be restored. Restoration is appropriate for recently fire damaged sites, overgrazed vegetation and trampled or mechanically disturbed sites".

Macay and Tallis (1996) investigated the incidence of summit type mire erosion in the Forest of Bowland, Lancashire. They identified a wide range of causative agents (including climate, decline in upland management, and catastrophic fires). However, they believe that it is the current high sheep stocking levels that may prevent recolonisation of bare peat surfaces, thereby allowing peat erosion to continue.

Van der Post *et al* (1997) constructed a record of accelerated erosion in the recent sediments of Blelham tarn in the English Lake District. Two frozen cores from the tarn were subsampled and measured. A detailed chronology was established using sedimentological data, radionucleides and algae. This has resulted in an accurately dated reconstruction of sedimentation evidence over the past 40 years. Despite a large increase in lake productivity, the evidence Van der Post *et al* collected suggests that the increase in sedimentation rates can be attributed to erosion within the catchment (largely eroded soil). Citing from Van der Post *et al* (1997), "a comparison between the trend of accelerated sedimentation and the record of increased sheep stocking density for the area...as well as observations of contemporary surface processes within the catchment, both suggest that much of the recent erosion is a direct response to increased pressure from sheep grazing".

O'Sullivan (1994) undertook assessment of sediment cores taken from Slapton Ley National Nature Reserve. He identified that an increase in sedimentation of the Ley since 1950 is associated with the post-war intensification of agriculture and the resultant loss of top-soil.

3.2.5 Evidence for increased rates of runoff from areas grazed by livestock in upland areas.

There is a lack of information about the direct impact of grazing animals upon **runoff** rates.

Surface **runoff** occurs when rainfall is unable (for a variety of reasons) to percolate into the soil and therefore puddles on the surface or, if on a slope, runs downs it. An increase in surface **runoff** has many implications. It can cause soil **erosion**, as the moving sheet of water has a capacity to efficiently transport significant amounts of loose material downslope and, if threads of water join, the vertical incision of soil can occur as **rills** or even gullies. The increased amount of water moving overland enters receiving watercourses at a far greater rate than if it were to be intercepted by foliage or percolated into the soil, recharging groundwater systems as it did so.

Runoff is strongly dependant on the amount and intensity of rainfall. Changes in the physical makeup of soils and the land cover (e.g. the predominant upland vegetation) will also influence the amount of **runoff** because the rate at which soils can absorb water is controlled by soil structure, the slope of the land, vegetation cover and/or soil surface roughness, the soil **infiltration** rate and land management practises. The soil water content also controls the **infiltration** rate: saturated soils are unable to absorb more water (promoting **runoff**) and very dry soils can be difficult to re-wet. Compacted soils (from trampling) are more impermeable and rain falling on these soils will therefore be more likely to remain on the surface.

The loss of larger-leaved vegetation from the uplands due to a variety of land management practices (including grazing) must have some effect on the rate of **runoff**. Tallis (1995) notes that forest clearance would certainly lead to more **runoff**. Sansom (1996) describes how the uplands and valleys of the Yorkshire Dales have been "reduced to large areas of permanent pasture, grazed to within an inch or two of ground level". She suggests that **runoff** from these catchments must be greater in winter months than it would be if the same area had taller vegetation, of four to six inches in height, which would have a correspondingly larger surface area to intercept rain and slow down any **runoff** from heavy rain and snow. In addition, such vegetation would promote better soil structure, improve percolation of water into the soil and therefore, reduce the risk of **runoff**.

Langlands and Bennet (1973) concur with this theory and suggest that "greater grazing pressure may lead to lower rates of **infiltration** into the soil and consequently more **runoff** into streams. This in turn may lead to **erosion** of stream banks and headward retreat of gullies into peat". It has been shown in the previous section that the activities of grazing animals can result in areas of bare soil being established, exacerbated and, in many cases, maintained. An increase in such areas of bare soil will lead to more rapid **runoff** according to Branson and Owen (1970), with consequent flooding and river bank **erosion**.

As soil is removed, **erosion** and **runoff** may well increase further, as some of the lower soil horizons can be less resistant to water **erosion** and rain may infiltrate into them at a lower rate (e.g. iron pans) (Evans, Pers. comm., 1997). Langlands and Bennett (1973) identify that the reason for low rates of **infiltration** of water is due to compaction of the soil surface by grazing.

Evans (1977) identifies that where soil surfaces have a low **infiltration** rate due to vegetation, a rapid rise of stream flow at low rainfall intensities due to surface **runoff** is an important component of the flood hydrograph. This implies that the effect of **runoff** originating from unvegetated ground would be even greater.

Butcher *et al.* (1989) note that rainfall runs off bare peat much more quickly than off peat covered by dense cotton grass and Burt and Gardiner (1984) identify that peak discharges, **runoff** volumes and sediment **loads** are all higher from a small eroded peat catchment than an uneroded one. Evans (1990) noticed that the increased stocking of the moors fringing the Derwent Valley in the Peak District led to higher stream flows (see Figure 16). Evans also found that in Hey Clough (Peak District), rates of **infiltration** of rainfall into saturated bare soil are very low compared to adjacent grassed surfaces (1987).

Evans examined the effect of a rise in sheep numbers in the Peak District (1990) and found that the resultant **intensive grazing pressure** led to the exposure of bare soil and a compaction of the soil surface. Both of these features may increase the proportion of rainfall which runs off rapidly over the land surface. He examined streamflow data for the upper north Derwent catchment and describes a "plausible scenario". He describes low **infiltration** rates in the catchment in the 1930s when an extra 1250 sheep were stocked. In the 1940s and 1950s a series of dry years were recorded and severe winters reduced sheep numbers. This correlates with a reduction in **runoff** as a proportion of rainfall and in the 1960s and 1970s the data shows there is a marked relationship between increasing numbers of sheep and increasing levels of **runoff**.

Artificial drainage of the uplands will contribute to the increase in **runoff** rates. However, rivers still respond quickly to rainfall events even in areas where drainage (moorgripping) is not particularly common (refer to Section 3.8 of this report).

Evans (1990) identifies another land use change in the north Peak District which may explain an increase in **runoff**. This is the decline of heather and bilberry moors and their replacement with grassland (a phenomena widespread throughout British Uplands), in particular wavy hair-grass and mat-grass. These changes are attributed to **overgrazing** by sheep and reduced levels of moor management. It is the wavy hair-grass covered slopes that Evans (1990) states are especially vulnerable to **overgrazing** and **erosion**.

Where a high biomass of vegetation is lost, and replaced by short grasses or bare earth, the freezing of the soil may be exacerbated (as the insulating properties of thick vegetation are lost). The frozen soil will be impermeable to snowmelt or rainfall and thus the amount of water running off the land surface may be increased.

Owens, Edwards and Van Keuren (1997) have studied the **runoff** and sediment losses from a small pastured catchment in eastern Ohio (US). For one period (13 years) a beef cow herd grazed the water-shed rotationally during the growing season, but were fed hay during the dormant season. For the second period (3 years) there was summer rotational grazing only. For the final period (5 years) there was no animal occupancy. The annual **runoff** was more than 10% of precipitation during the first period and less than 2% in the following periods. The decrease in annual sediment loss was even more pronounced, each period yielding 2259 kg/ha, 146 kg/ha and 9 kg/ha respectively. Low amounts of grazing on adjacent summer-only grazed catchments supported the conclusion that the increased **runoff** and **erosion** in the initial 12 year period resulted from the non-rotational winter feeding on the pastures.

However, they state that the impacts of the grazing do not last long and that soon after the management regime was changed, **runoff** and sediment loss decreased markedly. It is suggested that if winter feeding must occur, it should be undertaken on areas with less severe slopes (i.e. off the moortops and slopes) and rotational grazing should be employed to prevent one area being subjected to an entire dormant season of intensive grazing.

Braunack and Walker (1985) considered that the natural recovery of soil physical properties after permanent pasture would depend on soil type, the severity of the grazing impact and the climate and biological agents acting afterwards. They found that after 16 years without grazing, the surface soil properties of a semi-arid woodland showed evidence of prior damage by grazing sheep. Gifford and Hawkins (1978) reported that infiltration rates may still have been increasing 13 years after grazing ceased. In some studies they reviewed, infiltration rates were actually lower for the first 8 years after protection from grazing.

Mwendera and Saleem (1997) assessed the hydrological response to cattle grazing in the Ethiopian Highland using study plots and multiple grazing regiemes. They determined that heavy to very heavy grazing pressure (3.0 animal unit months (AUM) ha^{-1} and 4.2 AUM ha^{-1} accordingly) significantly increased surface runoff and soil loss, as well as reducing the infiltrability of the soil.

Orr (1997) has looked at rainfall, discharge and land use in the River Lune catchment in Lancashire. Since 1900 the total annual rainfall for the catchment has shown either a static trend or a slightly downwards trend. However, when seasonal rainfall is examined there is a clear upwards trend in total winter rainfall, and a downwards trend in total summer rainfall. These trends are reflected regionally and there is evidence to suggest that there is even greater variability over the last twenty years. Discharge records for the catchment began in 1976 and while the mean daily flow in the lower and middle part of the catchment has been decreasing over the last 20 years, the trend in the higher parts of the catchment is upwards.

In the upper catchment the discharge is increasing at a higher rate than the rainfall so that if discharge is subtracted from the rainfall (which removes the need to separate seasonal evapo-transpiration and ground water storage fluctuations) groundwater recharge shows a strong downwards trend. Information researched on local land use shows that since 1860 when records began, sheep numbers in the Lune catchment have risen from about 7,000 to 50,000. Literature suggests that grazing densities greater than 1.5 sheep per hectare are liable to cause erosion in sensitive upland areas (eg the Lake District). Grazing densities in the Lune catchment are generally greater than 4 sheep per hectare and in some parishes more than 7 sheep per hectare (1988 figures) have been recorded. Orr surmises that the increased grazing densities may account for the increased runoff observed in the upper catchment due to compaction and reduced vegetation cover.

Greenwood *et al* (1998) examined the potential for the degraded physical properties of soil to regenerate naturally after exclusion of grazing animals at a long-term stocking rate trial in Australia. The unsaturated hydraulic conductivity (a property of both the porous soil and of the water flowing through it) was measured before grazing was excluded, and after 7 months and 2.5 years' grazing exclusion. These data were then compared with controls at 10, 15 and 25 sheep/ha. After 2.5 years, there were significant increases in unsaturated hydraulic conductivity at 5 and 15 mm tensions (similar to the depth of water in the soil horizon) in the ungrazed plots compared to the grazed plots. In addition, the hydraulic conductivities and bulk densities of the surface soils under the pasture which had been ungrazed for 2.5 years were comparable to those where the pasture had been ungrazed for 27 years. Therefore, it is suggested that the exclusion of grazing animals has a significantly beneficial impact on soil structure and drainage even over a relatively short period of time and *vice versa*.

Haygarth and Jarvis (1997) determined that runoff from grassland soils are a significant source of diffuse phosphorous to surface and estuarine waters and may cause eutrophication. Both the runoff rate and levels of phosphorous are elevated in the presence of cattle (or sheep) due to grazing pressure, excretal returns and poaching.

3.2.6 Impacts of grazing on river banks

Even to the casual observer the environmental impacts of grazing described above, the qualitative and quantitative changes in the plant community, and physical alteration to substrate (e.g. soil compaction by trampling, formation of unvegetated hollows and scrapes), are apparent on river banks. Part Three of this report provides illustrated case studies of the impacts of intensive grazing and increased **runoff** rates on river banks (see Figure 15).

Understanding the controls on river bank **erosion**, however, is extremely difficult as they arise from interactions of form and processes that are not only complex but variable on long time scales; the relative importance of high magnitude low frequency events (flood discharges in the case of **channel morphology**) has long been and still remains a fundamental research question (Wolman and Miller, 1960). These difficulties compromise the generality of much research.

The major controls on bank **erosion** remain unclear at present (Hasegawa, 1989) and this is reflected in the range of conclusions concerning the dominant mechanisms of bank retreat. e.g. "banks retreated primarily by mass failures of over heightened and over steepened banks" (Little *et al.*, 1982), "the shearing of bank material by hydraulic action at high discharges is a most effective process, especially on non-cohesive banks and against bank projections" (Knighton, 1984), "the **erosion** of a river bank is not the result of **erosion** by high velocity water......rather, for effective **erosion** to occur, the material must be loosened" (Leopold, 1973 and similarly Lawler, 1993). Evans (1996) considers the rate of **channel** bank **erosion** and **channel** incision to be largely dependant on the bank material.

Despite the great differences in the findings of studies done of banks made from different **alluvium**, at different downstream positions and different hydroclimatic regimes it is generally apparent that bank **erosion** is the result of the resistance of bank material and the force to which it is subjected.

In many cases, peak discharge and antecedent moisture (the water status) of banks are the primary natural variables of bank **erosion** with a combination of high discharges and wet banks being the most susceptible (Hooke, 1979; Wolman, 1959).

Recent vigorous research activity on the measurement and modelling of bend flow and the distribution of fluid stresses on river banks (e.g. Ikeda and Parker, 1989; Pizzuto and Mecklenburg, 1989) has not been matched by a similar level of interest in the resistance side of the bank **erosion** equation. Lawler (1992) makes the case that the relative neglect of bank erodibility, and especially the patterns and controls of spatio-temporal change in erodibility, urgently need to be addressed.

It is these changes in erodibility that are most directly influenced by the impacts of grazing. Research has, however, been unable or has not been directed to provide evidence of a consistent role for many factors, including grazing, in altering erodibility.

This is not to say there is no evidence that grazing can control bank **erosion** (e.g. Orr, undated; Stephen, 1989) but the evidence is mainly anecdotal and/or empirical (refer to Part Three of this report). However, anecdotal evidence is extremely important as its timebase tends to be the length of human memory rather than the 2 or 3 years of the typical research project. Anecdotal evidence is presented in subsequent sections of the report.

Empirical evidence arises from situations where grazing has been stopped, Such as the introduction of fencing at one site whilst grazing continues at an adjacent or nearby site. In some cases, the results of this type of action have been written up as experiments but in many, they remain as anecdotal evidence of an **erosion** management practice.

One very good example of this is work undertaken by The Tweed Foundation. Nichol (Pers. comm. 1996) suggests that the protection, restoration and management of degraded riparian belts is a major factor central to the success of salmon habitat restoration schemes. To achieve this, they have fenced off significant lengths of riparian corridor from stock. However, their findings are applicable to a wide range of other river management aims. This philosophy is reflected by the fact that a large proportion of the work undertaken by The Foundation concentrates on 'soft engineering' practises and raising awareness of land management issues with land owners. Unfortunately the time and expense associated with actively managing buffer zones discourages many agricultural landowners, particularly when the benefits to them do not appear to be tangible (Campbell, Pers. comm.). Better incentives for landowners therefore need to be found (e.g. MAFF's Countryside Stewardship Schemes).

The best **solution** to the problem of bankside **erosion** suggested by the Foundation is the physical exclusion of livestock from the riparian corridor. The most common method employed is fencing, and its effects on riparian stability have been well documented (e.g Platts 1991; NRA, 1995). The type of fence used will depend on whether livestock graze the adjacent land or if it is used for arable purposes. A mixture of barbed wire and wire netting is best to deter grazers from leaning on the fence. The longevity of fences is believed to be around 25 years, after which they have to be renewed. Resources should be set aside for this purpose. In the majority of cases, a nominal fence is still needed to prevent accidental damage to the riparian community even if grazing activity is not present, as it identifies the land as being protected. In this way, people are kept from using the bankside for leisure pursuits (such as picnics or angling) which can flatten vegetation and it deters other would-be riparian users from encroaching onto the managed land (Crompton, 1994).

In some cases (e.g. the River Rhiw, Wales) hedges can be developed by layering lines of scrub on the bankside. These can perform the same role as fences, preventing access to the bank. They also provide additional habitat by acting as a windbreak, thus protecting the more fragile riparian plants. In addition their root system helps to bind the soil together. Hedges are preferable to fences from a conservation perspective, but require maintenance, and if allowed to grow unchecked, will become inefficient barriers (Lewis and Williams, 1984). In the majority of situations fences are a more pragmatic option, especially if time and resources are limited.
One North American method is to isolate a bankside 'paddock' from the herd or flock and allow

vegetation to recover over a period of about five years. Once recovered, the cattle are only allowed to graze on it for short periods of time, to minimise the effects of unrestricted 'seasonal-on' grazing, which leads to physical habitat degradation. In this manner, the grazing of bankside vegetation can be seen as a management tool, achieving an interrupted climax community and, if controlled, the length of the sward and overhanging foliage can be maintained at a density where it fulfils a beneficial role with regard to salmon habitat and **channel** stability.

A second method currently utilised in the USA is mounted cattle drivers which can prevent a herd from settling along **channel** margins and allow them to be directed towards a less sensitive area of pasture. UK shepherds would have historically fulfilled a similar role, ensuring that a flock was kept on the move and utilised all areas of available pasture and not just the more succulent areas adjacent to rivers and streams; this allowed the development of a well established riparian plant community. Today, an absence of control over livestock grazing allows them to concentrate in valley bottoms, typically alongside the **channel**, which is used as a source of water.

The provision of food such as agricultural feeds accentuates this concentration of livestock and "honey-pots" such as ring-feeders are typically located on flat tracts of land. In many situations, such as in the Tweed system (Scotland), this is invariably on flat land alongside rivers. As there is no incentive to feed elsewhere, the herd will remain within a small area, with a detrimental effect on nearby vegetation. Such feeding policies need to be reviewed and possibly include the introduction of multiple, small feeding sites in order to disperse the livestock situated away from the vulnerable riparian areas.

Empirical evidence, whether rigorous or anecdotal, offers sufficient evidence to demonstrate a causal link between riverbank **erosion** and grazing (refer to Part Three of this report). Without further research into processes, prediction - of susceptible reaches, of optimum stocking densities and shepherding, and of the most effective remediation practices - will remain largely a matter of trial and error which may not be the most effective strategy. Some R&D work is being undertaken at Lancaster University (Orr, undated) which is attempting to assess processes operating in the River Lune catchment including variations in **channel morphology** and sites of active **erosion** and deposition. Statistical analysis of rainfall and discharge data is also being carried out to determine trends and significant events.

Information has been released by the Environment Agency (NRA, 1995) which discusses riverbank **erosion**, the potential causes of **erosion**, the effects of it on the rest of riverine ecosystems and its impacts upon man. Although this publication deals with riverbank **erosion** both in lowland and upland regions, it does describe the effect of high grazing densities, particularly where livestock are allowed right up to the water's edge (e.g. for grazing, and access to water) and especially when this occurs through the winter or in drought periods. The suggested remedy for this is the fencing off of river banks (apart from drinking areas), especially if vegetation such as bankside scrub or trees is to be encouraged. This document also recommends riparian management techniques. More details of specific management techniques can be found in Schiechtl and Stern, 1997 and Ward *et al.*, 1994.

Some idea of the scope of research work needed and the complexity of the interactions between grazing and bank **erosion** is given by Trimble (1994).

Trimble's five year experiment on the **erosional** effects of cattle in Tennessee is important as there is limited information about the long-term effects of cattle on the **erosion** of stream banks. Most published research has been concerned with the biological effects of seasonal grazing along mountain and piedmont streams of the semi-arid western United States (Trimble, 1994), and is mostly oriented toward effects on fish habitat and wildlife.

Trimble showed that cattle are important geomorphic agents in the **fluvial** environment, with grazed streambanks being seen to erode 3 to 6 times faster than ungrazed, the **erosion** rate being approximately 40 m^3 yr^{-1} km^{-1}. However, although this result seems straightforward, the following points should be noted:

- Cattle did not directly increase streambank scour, most of the increased **erosion** resulted from the formation of "ramps" for stream access.

- Much of the streambank scour in the ungrazed reach occurred in only two high discharge events. It seems likely that the effects of the ungrazed, and therefore woody, vegetation on bank erodibility are discharge dependent and under high discharges may become negative (Zimmerman *et al.*, 1967; Thorne, 1990).

- The reduction in grass cover which, according to Zimmerman *et al.*. (1967) is the most **erosion**-resistant vegetation, as a result of shading by woody growth may also be partly responsible for the lack of resistance to bank scour.

- Though fine tree roots have been reported to be very effective in protecting banks (Smith, 1976; Hickin, 1984), the root zones of the poorly rooted red cedar, once exposed, suffered from increased scour.

- Ramps were susceptible to further **erosion** during high discharges but smaller **channel** forming discharges partially replaced material lost.

It is apparent from the above that the time-scale over which measurements are made is of crucial importance. For example, it appears that there is unlikely to be any difference in the amount of **erosion** between grazed and ungrazed banks resulting from a flood with a 200 year return period. However, in contradiction to this, anecdotal evidence may suggest otherwise (refer to Part Three of this report). Evans (1996) studied the impacts of a flood occurring after a high magnitude precipitation event in the central Pennines and concluded that where trees and shrubs lined the river banks, no or far less **channel** bank **erosion** occurred than locations where the field was grazed right up to the river.

At present in the UK there are no general legal restrictions on grazing on river banks although, MAFF runs an incentive scheme to reduce stocking close to the water's edge and the Environment Agency has byelaws as part of the Land Drainage Act, 1930. The "Countryside Stewardship Scheme" has an option for development of "waterside landscapes" for which annual payments per hectare are available to offset the loss of income due to reducing stocking rates and extensive land management. There are, therefore, likely to be a number of sites suitable for rigorous controlled experiments whereby the effects of different bank side treatments can be assessed. Laboratory and modelling work will also be necessary to simulate conditions that rarely occur but may be of crucial importance.

3.2.7 Conclusions

A surface that is devoid of vegetation, or is colonised by vegetation that presents little foliage to intercept rainfall (e.g. a tightly grazed sward), may facilitate a more rapid rate of **runoff** of water. In turn, this increased rate of runoff may decrease the response time of rivers to storm events, thus increasing the instantaneous discharge and erosive energy of the river.

This section of the report has shown that grazing pressure from livestock will, in many circumstances, lead to a change in vegetation type and, in some cases may lead to the loss of vegetation altogether and creation of expanses of bare soil. If the stocking density is not below the **carrying capacity** of the land at which soil **erosion** occurs then it will perpetuate accelerated **erosion**. The other salient points from this section of the report are as follows:

- There is a wide range of information existing on the changes in productivity and ecological diversity of upland vegetation which occur as a result of **intensive grazing pressures**.

- This report illustrates a lack of information regarding the relationships between grazing animals, **erosion** and **runoff**. In addition, little is known about the effects of these upon groundwater recharge. There is an obvious need for further research to be undertaken (see Part 5 of this report).

- If the stocking density of grazing animals exceeds a specific **carrying capacity** of the land (this is different for livestock productivity and the prevention of the exposure of bare soil), changes will occur in the vegetation structure, in some situations resulting in the exposure of bare soil. These bare areas are very susceptible to further **erosion**.

- Many organisations report degradation of the British Uplands. Some attribute this degradation directly to high stocking densities of sheep (in Scotland, Red Deer as well). In localised areas, there has also been a noted increase in rabbit populations. This high concentration of grazing animals reduce vegetation cover and leads to **erosion** of the soil. This may also lead to a greater abundance of rabbits, increasing the **erosion** problem further.

- Sheep stocking densities as low as 4 ha per sheep can seriously retard the flowering and fruiting of plants. Stocking densities of 2 ha per sheep can cause a decline of heather moorland and initiate **erosion** in the form of sheep scars. Sheep stocking densities less than 0.1 ha per sheep have been recently recorded in parts of England. Where grazing occurs in the dormant season (winter) the effects will be more pronounced as the sward is not able to repair the damage and is also susceptible to frost action.

- Where winter grazing occurs, the effect on the sward becomes even more pronounced as the plants are not growing at this time. The impact of frost and rain on the soil are exacerbated.

- Once **erosion** has been initiated, it is exacerbated both by other agents of **erosion** (refer to Section 2.3.5 of this report) and by grazing animals. In some environments, it has been shown that bare soil can only be revegetated if grazing animals are excluded entirely.

- Grazing pressure can remove effective rainfall intercepting vegetation, replacing it with short grass. Trampling from animals can also reduce the **infiltration capacity** of a soil. Both of these mechanisms can result in increased rates of **runoff**. This has direct ramifications for flooding and **channel erosion** (exacerbated by grazing and trampling close to the edge of river banks) However, more research needs to be undertaken on this subject as there is little published evidence.

It is recognised that there are many other factors involved in the **erosion** of the uplands. The dynamics of a drainage basins are intricate and many different processes are interrelated. The following sections of this report will assess the impacts of some of the other factors which have been identified as playing a critical role in accelerated upland **erosion** in Britain. The factors which will be considered are: fires, control of bracken, land drainage, air pollution, recreation, forestry and climate.

3.3. The Impact of Burning on Upland Erosion and Runoff Rates

3.3.1 Introduction

Evidence suggests that some form of burning in upland areas has taken place for many years. Jacobi *et al.* (1976) suggest that mesolithic populations in the Peak District routinely burnt the vegetation to attract populations of game. The use of fire and grazing livestock to clear expanses of woodland is also an ancient practice. However, the burning of vegetation as a management tool to encourage vigorous regrowth of more nutritionally important shoots and saplings for use as food for sheep (e.g. Farey, 1815) or for the management of grouse moors or lowland heaths is a more recent event (only a couple of centuries old).

Heather dominated moors are particularly susceptible to accidental fires although, as already stated, the use of fires in the uplands is largely as a management tool (Figure 17). This is especially true on grouse moors, to maintain the diversity of age structure of heather (*Calluna*), and to improve grazing for livestock. However, accidental fires do occur and, with dry weather conditions, the likelihood of their occurrence is increased.

After the removal of vegetation by fire, there is scope for regeneration. Indeed, this is the basis for the use of fire as a tool in grazing and grouse management. While this is occurring, the bare, scorched earth will be subject to mechanical and chemical impacts from rain, wind, frost and the sun. This alone can lead to a loss of material, especially in exposed locations. However, if livestock are allowed onto these areas, the impact can be substantial; the regeneration of vegetation may be halted and extensive **erosion** initiated.

The reasons gamekeepers or farmers burn hill land include:

a) to create uneven aged stands of heather to encourage nesting of grouse in the longer, older heather and to encourage new growth of younger heather on which the grouse can feed, in order to promote a good population of grouse on the moor for shooting.

b) to remove unpalatable and surplus vegetation.

c) to improve the nutrient status of the vegetation for sheep/grouse/deer.

d) to reduce colonisation by trees which maintains hill grazings.

e) to reduce the risk and impact of accidental fires.

Reviews of suitable methods of moor burning can be found (e.g. Rowell, 1988; RSPB, 1985). Moor burning on its own, if light grazing is not introduced, maintains the dwarf shrub heath and prevents the succession to forest.

Where grazing is introduced, the resultant plant succession occurring after the fire will vary greatly depending on the type of burn (see Hester and Sydes, 1992), its temperature (see Gimingham, 1972; Hobbs and Gimingham, 1987 and Coulson *et al.*, 1992), periodicity of burning (see Watson and Miller, 1976) and the time of year burning takes place (Hobbs and Gimingham, 1987). The age of heather when it is burnt will also affect the impact of grazing.

Legislation controls the period of the year during which moorland burning can be carried out (The Muirburn Code: Phillips, Watson and MacDonald, 1993). This restricts burning to between late autumn and early spring although burning outside this period does occur (either due to accidental or illegal burns, or through the use of special licenses). MAFF (1992) have produced a Heather and Grass Burning Code which gives advice on best practice.

If a low number of small burns in heather are produced, the likelihood is that they will be grazed very intensely, to the point where heather may never re-establish itself (unless stock is excluded). An occasional large burn has the effect of attracting large numbers of sheep from the surrounding area with the same effect. However, a large number of small burns over several years will spread the intensity of the grazing impacts and it is this which is recommended by the Peak District Moorland **Erosion** Study (Phillips *et al.*, 1981).

Drewett (Pers. comm., 1997) identifies that a long rotation of a small burn size used for grouse management, with low grazing levels, will reduce the risk of **erosion** and increase diversity for wildlife. However, he feels that there is too much burning taking place and believes that there is scope for using mature unburnt heather, if it is managed, to reduce the risks of accidental burns.

Gimingham (1972) states that "provided the standards of burning are good, there is no evidence that significant botanical or mineral-nutrient changes take place between one rotation and the next". However, Mabey (1980) argues that burning itself may promote and maintain a heather monoculture on the moorland which (if natural regeneration was allowed) could be far richer in its biodiversity. This argument is currently being raised again by conservation bodies.

3.3.2 Accidental fires

Accidental or even deliberate fires are fairly commonplace. Tallis (in Phillips *et al*, 1981) state that the potential for accidental fires has risen due to the increase in numbers and mobility of people visiting the moorland areas (see Figure 18). Such fires can be started in a variety of ways, such as by dropped cigarettes or matches, picnic fires or by the concentration of the sun's rays through broken glass. A study on the occurrence of accidental fires in the Peak District and their ecological impacts is detailed in a report for the Peak District Moorland Restoration Project (Anderson, 1986).

Accidental fires are more likely to occur during and after periods of hot dry weather in summer and have serious consequences. These "unmanaged" fires have a tendency to burn for longer and the temperature of the burn may be high enough to combust aerial plant foliage and surface peat layers. If the fire occurs after a period of drought, the peat may have dried out sufficiently to facilitate combustion to a significant depth, even burning the peat away completely, exposing the mineral soil. Controlled burning in autumn and winter can also get out of hand and has resulted in extensive areas being burnt, sometimes into the peat itself.

Ultimately, the peat will be converted to ash. Even where fires occur on damp peat, they may smoulder for many days but, eventually, they too reduce the peat to a fine ash. This is readily removed by rain and wind. Bare soil or regolith (shattered rock) may then be exposed over extensive areas to give what can be described as a "desolate, totally sterile, lunar landscape" (Phillips *et al.*, 1981). If the peat is not totally removed, the remainder can evolve to a pot-holed, powdery deposit which is very susceptible to **erosion** by running water (see Radley, 1965).

The ignition of peat waxes during intense fires can effectively seal the surface of peat as it can lead to the formation of a skin of tarry bitumen (Shaw ***et al.***, 1996). It can be argued that this helps to reduce **erosion**, but it may also prevent recolonisation by "desirable species" and its impermeability can prevent **infiltration** of rainwater and therefore increase **runoff**. The lack of vegetation can lead to desiccation (from the sun and wind). The aeolian transport of desiccated peat and mineral soils is a real problem in some parts of the country (e.g. Devon and the North York Moors).

The change in **albedo** to a dark peat surface from a relatively light vegetated cover may have impacts on the micro climate. Darker peat surfaces absorb more heat, and therefore moisture loss is exacerbated. The reduction in **albedo** also increases the likelihood of freeze-thaw processes and therefore **erosion** (NYMNP, 1996).

If underlying mineral soils are exposed, then re-vegetation of such areas is extremely difficult. Seeds have to be brought in from outside the local area and the substrate is often nutrient deficient. Any propogules which do become established are quickly uprooted by grazing animals or frost-heave. The Peak District Moorland **Erosion** Project (Phillips *et al.*, 1981) refers to several areas (Pike Low, burnt 1939; Arnfield Flats, burnt 1947; Burbage Moor, burnt 1959 and 1976) which in 1981 were still "noticeably bare" and may be permanently unfavourable for revegetation. Attempts have been made to recolonise such areas (refer to Peak District Moorland Restoration Project: Phase Two, 1983). For example Cabin Clough which was devastated by fires in 1887, still had bare ground after 100 years (but in exclusion plots, heather became re-established after 3 years).

Radford (in Bunce, 1989) describes that in Wales, a combination of severe burning and sheep grazing has resulted in the disappearance of much of the heathland as well as heather from blanket bog. Rawes and Welch (1969) identify that under a free grazing regime, an early growth of *Eriophorum sp.* occurs after a winter fire, which attracts sheep. Densities of 0.33 sheep per hectare can be supported on such vegetation.

Unfortunately, grazing and burning can reinforce and accelerate each other's effects, including an increase in the extent of bare ground (which is a very hostile environment to recolonise) and changes to the vegetation structure. Shaw *et al.* (1996) describe an enclosure on the North York Moors which was constructed in an area severely damaged by fire. It demonstrated how a reduction in grazing pressure leads to faster recolonisation by moorland species (refer to NYMNP, 1981). Even so, such regeneration will still take between five to ten years, possibly longer (Rees, Pers. comm., 1997).

3.3.3 Conclusions

Many authors document an association between peatland **erosion** and either burning or grazing, or both (e.g. Mallik, Gimingham and Rahman, 1984; Fullen, in NYMNP, 1986; Anderson, 1986; Anderson and Yalden, 1981; Tallis, 1987; Ratcliffe, 1959). However, Grieve, Davidson and Gordon (1995) describe how 6% of upland Scotland comprised eroded peat, but they could not find a clear correlation between land management and **erosion** (suggesting that at a local scale a combination of factors are operating). Anderson (1986) cites Farey (1815) who describes how (in the late 1700s) some moorland in the Peak District had burned for a number of weeks and then collapsed. Bad burning practice is, therefore, not a new phenomenon.

- Controlled seasonal burning can lead to the regeneration of vegetation which, in turn, can sustain a larger population of sheep (or grouse). However, the resultant exposed surface from this practise (or from light uncontrolled fires) can be degraded by natural agents of **erosion** and the mechanical effects of trampling by livestock. Grazing of these areas can lead to reduced levels (or an absence) of vegetation. The removal of stock increases the likelihood and rate of natural regeneration of vegetation.

- The more devastating impacts from large accidental fires can lead to the ashing of the peat layer and the exposure of the mineral soil which, due to its physical and chemical characteristics, is extremely hostile to recolonisation. This can be compounded by the presence of livestock.

- Once a bare surface is exposed, "natural **erosion**" (e.g. from frost heave) can be far more effective. This can be enhanced by the presence of grazing livestock who have been reported to target such areas due to the ease of access to vegetation at the margins of the burnt area.

- The Phase 1 Report of the Moorland **Erosion** Study (Phillips *et al.*, 1981) concluded that fire damage was the most important factor in disrupting the vegetation cover of 500-600 ha of the Peak District. Other factors (intensive grazing, hostile climate, recreation) were also important.

- Due to little vegetation being present to intercept rainfall and prevent the potential desiccation of peat (from droughts and wind), the ability of exposed peat to retain moisture is severely diminished. As a result, rainfall (particularly if it is intense) will exacerbate the loss of material as **rills** and gullies develop. In addition, **runoff** rates may increase.

- Research has suggested that the severe burning of the peat surface reduces the water storage capacity of the soil and lowers dry weather flows. It may also increase the rate of **runoff** in drainage ditches. This has negative consequences for water resource management in potable water gathering areas such as moorlands. Peat and other eroded materials are transported into reservoirs, thus reducing their storage capacity. These materials also colour the water which then requires treatment.

This section suggests that burning can be detrimental at varying scales and that good practice needs to be developed and linked more to stocking rates of individual sites. The prevention of uncontrolled fires will also depend on current management and historic management. Therefore, management needs to focus upon reducing the risk.

3.4 The Impact of the Control of Bracken on Upland Erosion and Runoff Rates

3.4.1 Introduction

Typically, the control of vegetation in the uplands focuses upon the maintenance of a good age structure in heather, for the benefit of grouse populations and grazing animals (mainly sheep). Where this does not occur, the heather community becomes dominantly mature and unpalatable (although is has a natural ability to regenerate). The effect of the development of mature unpalatable stands of heather is to reduce the areas of land sheep prefer, effectively encouraging the intense grazing of more palatable areas. The prevention of this is usually achieved by controlled burning (please refer to Section 3.3 of this report) and has already been discussed. In addition to heather management, a great deal of attention has been given in the uplands to the control of bracken (*Pteridium aquilinum*) due to its aggressive and encroaching nature. It is regarded as a weed by agriculturists and foresters and its consumption by domestic livestock may have indirect implications for human heath (Anderson, 1988). It is also a habitat for the sheep tick, which is a vector for Lymes disease. However, it does provide habitat for other animals and plants, and it could be argued that bracken helps to stabilise slopes (via its extensive rhizome network, and retardation of trampling in dense stands of bracken by animals and people), reduce **runoff** rates and limit **erosion** (Penman, 1963, STOG, 1988). An Environment Agency R&D project "P2-076 "Using Asulox for Bracken Control" will assess the full implications of bracken management for the Agency and the wider environment.

3.4.2 The effect of bracken control in the uplands

Rymer (1976) identified bracken in the fossil records of the Quaternary although it appears that it was part of the woodland herb layer. It was not until large-scale clearance of the forests and woods by Neolithic man that bracken began to expand out to the hills (Rymer, 1976). Anderson in her "Review of the Role, Status and After-Treatment of Bracken on Moorland" (1988) quotes an encroachment rate of 120 ha per year in the North York Moors National Park (Brown, 1986) or 1% per annum. Johnson (1986) considers that this rate could be extrapolated to the rest of Northern England. Bracken expansion is also noted in Wales and Scotland (Taylor, 1986).

Recent figures from Rhône-Poulenc (1997) suggest that a total area of 975,000 hectares of open upland and heathland are dominated by bracken in Britain. Each stand of bracken has the capability of expanding its area by as much as 1% to 3% per year. Rhône-Poulenc also believe that bracken management programmes are not keeping pace with the rate of spread. Pakeman *et al.* (1993) discuss the problems associated with the spread of bracken in Britain.

The encroachment of bracken onto upland grazing areas is detrimental to both the farmer and the livestock (Figure 19). Bracken reduces the quality and quantity of available grazing land and presents a risk to stock as it has toxic effects when eaten by sheep and cattle (Birnie, 1985). Bracken also makes stock control difficult and it creates a habitat for parasites such as ticks (which also affect grouse chicks). There is also evidence that bracken may act as a carcinogen to humans.

Upon the finding of bracken toxins in cow milk, MAFF recommended that milking cows should never be allowed contact with bracken (Anderson, 1988).

In addition, the control of bracken by the use of chemicals may have serious negative impacts for receiving water courses (Knapp, Yorkshire Water Plc., Pers. comm. 1997). An excess of only 0.1 μl of asulox in water is required before the limit for herbicide concentrations set in the EC Drinking Water Directive is exceeded.

The encroachment of bracken onto the surrounding vegetation can restrict the effective grazing area, with the potential result of concentrating grazing effort, leading to a deterioration of the sward and exposure of bare soil. This can then be exacerbated by the activity of animals or vehicles and other agents of **erosion** (refer to Section 2.3.5).

Therefore it is apparent, that the control of bracken is highly desirable. The extent and nature of any control should be assessed prior to its implication and guidelines are often issued (a current Environment Agency R&D project will assess the use of "Asolux" spray for Bracken Control;

Code of Practice for Bracken Control in the Peak District National Park; Bracken Management Handbook,Rhône-Poulenc).

Methods of control include spraying (e.g. using asulam, which will only kill fern species), cutting and crushing (when there is potential of any spraying killing valuable conservation species, cutting can also affect ground nesting birds), and burning (this is not generally thought to be effective and can increase the danger of soil loss and **erosion**- refer to Section 2.3 of this report). Pickett (1994) provides a comprehensive review of the methods for the control of bracken.

In any situation it is vitally important that after-treatments are initiated, these reduce the risk of the bracken returning and helps to prevent **erosion**. The loss of the bracken cover will remove the stabilising qualities of its rhizome network, and presents a surface that is devoid of vegetation to the elements and grazing animals or, at best, will develop into a sward of grass. In areas with a deep bracken litter layer, recolonisation by other vegetation can be limited, as it presents a hostile environment and seedlings are often disturbed by **erosion** (Barber, 1986) (Figure 20).

Anderson (1986) describes such a situation in the North York Moors. An area of 8 hectares was sprayed to control bracken in approximately 1971. The control of the bracken was good but the resultant underlying litter layer was deep, and instead of being recolonised by heather or other moorland plants, the litter gradually became washed away, exposing the peat. The peat then began to be blown or washed away, leaving gullies behind. This resulted in the occurrence of many areas of bare ground. The landowner has had to fence the area and attempted to restore the heather moorland, which in 1997 is only just beginning to show signs of recovery.

Johnson (1986) has arrived at four conclusions which describe the effect of a lack of follow-up treatment, with uncontrolled grazing, after spraying for bracken control.

1) If the initial degree of control is poor, a full ground cover of bracken may be re-established.

2) Surface **erosion** may result especially where there is no undergrowth of grass, heather or bilberry as the bare ground encourages sheep to congregate (as they can gain easy access to marginal vegetation). Little vegetation is able to develop due to constant disturbance by the animals.

3) Heather areas colonised by bracken regenerate slowly and seedlings tend to be pulled out by sheep, with established plants being subjected to **intensive grazing pressure**s and unable to produce seeds.

4) Stands with an undergrowth of bilberry and grass may not be recolonised by bracken as these plants are extremely competitive and regenerating fronds can often be damaged by trampling.

The types of aftercare required are largely dependant on the topography and vegetation associated with bracken. Details of these can be found in many publication (e.g. Rhône-Poulenc, Bracken Management Handbook; MAFF leaflet, "Bracken and its Control; Code of Practice for

Bracken Control in the Peak District National Park; Anderson, 1988; Robinson, 1984).

3.4.3 Conclusions

The control of bracken is promoted for several reasons including its toxicity to livestock, the control of sheep ticks, the encroachment upon grazing land (leading to localised intensive grazing- refer to Section 3.2 of this report) and an obstruction to recreational activities.

The control of bracken can be achieved through a variety of mechanical and chemical methods. These methods can themselves have negative impacts (either upon other vegetation or the soil) but essentially it is the exposure of non-vegetated areas of land which has serious ramifications on upland **erosion** and **runoff** rates.

- Expansion of bracken onto upland grazing areas will have the effect of concentrating livestock grazing effort. Some consequences of this are the removal of vegetation, trampling and compaction of the vegetation and soil, and ultimately, the exposure of bare soil and its **erosion**.

- One result of bracken control is the formation of a deep litter layer which presents a inhospitable habitat to recolonising plants. The litter layer can also be washed or blown away, revealing bare soil. **Erosion** of the bare soil can then proceed, exacerbated by livestock trampling through the cleared area and grazing on any plant regrowth.

- The decline of cattle and rise of sheep in the uplands has exacerbated the problem of bracken litter suppressing other forms of vegetation. Cattle are better than sheep at trampling down bracken litter and thinning out frond densities (Oates, undated).

- The presence of roots and decaying litter usually improves soil structure, promoting the **infiltration** of water. Close growing plants may detain water long enough to make its absorption into the soil complete and almost any kind of vegetation (especially those with a large foliage surface area), will impede surface flow and reduce **erosion**.

- The loss of bracken foliage has the impact of reducing the surface area available for the interception of precipitation, and despite a layer of bracken litter, **runoff** may become accelerated, especially where the bracken grew on steep slopes.

- Fencing greatly enhances the natural regeneration of bare areas following bracken spraying.

The control of bracken has been promoted in the past, and still continues today, although the practise is perhaps more restricted due to concerns about **erosion** of moorlands stemming from loss of substantial areas of bracken cover (Thomas, Pers. comm. 1997). However, this is more likely to be due to the cost of bracken control, the lack of available grants and an increasing restriction on herbicide use (Rees, Pers. comm., 1997).

3.5 The Impact of Air Pollution on Upland Erosion and Runoff Rates

3.5.1 Introduction

Lee (1981) established a plausible link between atmospheric pollution and **erosion** via the reduction in vegetation in uplands. He describes how historical atmospheric pollution (particulate and precipitate) has contributed to the loss of sensitive plant species. For example, the contamination of the Peak District by soot is correlated to a change in the vegetation of the bogs and Tallis (1964), describes a resultant loss of sphagnum cover coinciding with an increase in the rate of peat **erosion**. Such trends have also been observed in South Wales, probably as result of the Industrial Revolution (Chambers, Dresser and Smith, 1979).

Current air pollutants which are thought to cause ecological concern include nitrogen oxides (from transport and power stations, non-methane volatile hydrocarbons (from industrial processes, solvents and petrol) and black smoke (from domestic fuel and transport). Increased levels of ozone are also a cause for concern (Caporn in Anderson, *et al.*, 1997).

3.5.2 The impact of air pollution

Acid rain resulting from precipitation through gaseous pollutants such as sulphur dioxide and nitric oxide is potentially more important than particulate pollution (Caporn, 1997). Air pollutants can directly reduce the growth or competitive vigour of plants. Indirectly, they may reduce the tolerance of plants to stresses such as frost, drought, intensive grazing or pests.

High altitude sites may receive a greater proportion of wet-deposited pollutants than valley bottoms. Typically, high altitude sites receive more rain which contains greater concentrations of pollutants than its lowland counterpart. In addition, at elevation, cloud may persist for longer and according to RGAR (1990), cloudwater droplets contain even higher concentrations of solutes than rain. Therefore, chronic or acute injury to plants at elevation is a real problem, if the contributing air pollutants are present in concentration.

Where this does occur, a reduction in the vegetation cover may result, especially where the environment is hostile to recolonisation by other species. The impact of the loss of vegetation cover (as discussed elsewhere in Sections 2.5, 3.2.4, and 3.2.5 of this report) will lead to the exposure of bare ground and hence, result in **erosion**. Indeed, revegetation of established bare ground can also be retarded due to a range of effects from pollutant groups (Anderson *et al.*, 1997).

- active sulphur and nitrogen compounds which cause soil acidification
- acidity in rain and mist directly affecting plant aerial organs
- toxic gases (SO_2, NO_x and O_3) which are taken up by the aerial organs of plants

It is a combination of these impacts that have in the past (as a direct result of industrialisation), led to severe effects upon most vegetation, and it is thought (Phillips, Yalden and Tallis, 1981; Anderson *et al.*, 1997) that some of the **erosion** we see today was encouraged by a historic dieback of surface vegetation affected by smoke and acid precipitation (Evans, 1996).

Concentrations of $S0_2$ are likely to decline further in the future, but the levels of other phytotoxins (e.g. NO and NO_2) may actually rise. In addition, exposure to ozone (again in greater concentration on hill tops than in valleys) may pose a problem for vegetation, especially if already stressed (Caporn, 1997). Foot *et al.* (1996), whilst undertaking experimental work to assess the impact of ozone on heather, found that heather became more susceptible to frost action as a result of elevated ozone concentrations.

3.5.3 Conclusions

Air pollution, especially in the form of acid precipitation (rain or mist) has a deleterious effect on upland vegetation. This is exacerbated by harsh environmental conditions already found in such areas. If the stress exerted upon the vegetation is too great, plants will die, revealing areas of bare ground that is difficult to recolonise (especially if subjected to air pollution). These patches of bare ground will then be affected by other processes of **erosion** (e.g. frost heave, rainsplash, trampling, grazing etc.) and may expand in size. **Intensive grazing pressure** may make the vegetation more vulnerable to other stresses such as acid rain.

- Air pollution encourages **erosion** through its effect on the vegetation cover and acid rain especially affects the lower plants, particularly Spagnum moss (the main peat forming species) but, it is not a direct cause of **erosion**.

- The extent to which air pollution has and is affecting **erosion** rates in the UK is not known. In certain local areas it has been established that air pollution is significant in retarding the revegetation of bare soil (e.g. the Peak District). In other areas (e.g. the Lake District) this is probably not the case as robust areas of vegetation which are out of reach of grazing stock are not affected in this manner. However, specific aspects of air pollution are interrelated in the overall denudation of the landscape and unlike the control of grazing density, are difficult, if not impossible to modify.

- European agreements to reduce the emission of sulphur, nitrogen and volatile compounds should result in the improvement of air quality and accordingly, reduce the impact on vegetation and **erosion**.

- More research is required to identify the links between air pollution, upland **erosion** and **runoff** rates, especially on vulnerable habitats (e.g. blanket bogs and montane heaths).

3.6 The Impact of Recreation on Upland Erosion and Runoff Rates

3.6.1 Introduction

Recent figures (e.g. Country File, BBC 4/5/97) suggest that more and more people are visiting the countryside for recreation purposes. In some cases, the attraction of the uplands exceeds the "honeypot" effects of the coast. This is undoubtedly connected with a desire to have a break from urban life, as rural areas especially those in the uplands, are visualised as being remote from other humans, a last bastion of wilderness in which refuge from modern life can be sought.

The growth of "outdoor pursuits" is another major factor which attracts people out of the cities. Sports such as climbing, cycling and running can all be accommodated in urban settlements but, the challenge undertaking them in locations such as the Lake District and Snowdonia adds vastly to their appeal.

The result of both these factors has led to an increase in the numbers of people using the hills. The range of activities include walking, running, scrambling, climbing, mountain biking, horse riding and All Terrain Vehicle (ATV) driving (these are also used by farmers). If a parallel is drawn between impact of people concentrated onto the hills and the impact of sheep herds, then it is easy to extrapolate the link between recreation and **erosion.**

3.6.2 The impact of recreation

Liddle (1975) identified the general ecological principal that "the effect of the degree of impact from feet, hooves or tyres is inversely related to the potential productivity of the sward" (i.e the greater the trampling pressure the lower the plant biomass). Anderson (1990) describes how, according to Grime (1979), competitive plants characteristically grow rapidly in productive soils in summer. These plants are not evergreen, but typically dieback. They are the only plants which can be regarded as being reasonably tolerant of trampling, although there are significant differences between individual species.

Plant communities that grow in stressed environments (e.g. acid and infertile soils/ peat) or on steep slopes are will tend to be more intolerant to the impacts of recreational activities than, for example, improved grasslands. Harrison (1981) undertook a trampling experiment and discovered that recovery was slow on neutral and basic grasslands. Substantial damage occurred on heather covered heath and acid grasslands, and their recovery was even slower. Anderson gives a relative guide to the sensitivity of plant communities (Table 4, below):

Less Sensitive	Common bent/crested dogs tail (inbye land)
	Wavy hair grass/ sheep's fescue (mineral soils)
↓	young heather
	Mat grass (drier, thin peats, peaty-mineral soil)
↓	Purple moor grass (wetter, flushed peaty soil)
	Bracken
↓	Old heather (brittle, easy to break)
	Crowberry/bilberry (on peat)
More Sensitive	Cottongrass bog (on peat)

Table 4. The relative sensitivity of plant communities to trampling (Anderson, 1990).

The effects of trampling have been discussed elsewhere (please refer to Section 3.2.2 of this report). Footpaths have the effect of concentrating walkers to linear tracks which tend to be perpendicular to the contour on slopes. However, paths do tend to spread out when the edges are indistinct, and the adjacent surface is easier to walk on than the path (Huxley, 1970), this is apparently more so on steep routes.

Where the **carrying capacity** of the vegetation marginal to the paths is exceeded by the trampling pressure, areas of bare paths are likely to develop. Even if the pressure is reduced, recolonisation of this bare ground may be inhibited. As described earlier, (see Section 2.5 of this report) **erosion** is easily initiated once the vegetation cover is removed (Figure 21). The footpaths also act as a **channel** for the conveyance of overland flow, promoting rapid **runoff** and vertical incision.

An exceedence of the **carrying capacity** of the sward is not only limited to linear footpaths or bridleways, but is also found at locations such as viewpoints, where "family walkers" gather at central points, often close to their vehicles. Shimwell (1981) describes this in a review of **erosion** on the Pennine Way. He notes that four of the most severely affected sites along the Pennine Way where footpath widths have increased considerably happen to coincide with major attractive features. Two of these sites suffer as linear routeways, one site possesses a magnificent landscape view, the other is a highly reputable climbing spot.

As stated earlier, the impact of other forms of recreation (horse riding, ATV driving) can have the same ultimate result; **erosion**. Variations do exist as the **carrying capacity** of vegetation will vary for different activities and their location changes. For example ATV transit across wet bog will be more destructive than walking over healthy grass moor, mountain biking is not simply restricted to linear paths, scree/fell running and scrambling can dislodge loose material on slopes and climbing can damage rock faces.

In the same manner, other activities can have similar impacts. Anglers fishing at discrete fishing pegs during competition matches or along favoured parts of a beat can, with time, trample vegetation away and initiate bank **erosion**. The launching of canoes from banks can result in the same thing. In some cases, river bank erosion results in the diversion of activities as a result of bank collapse. One example is the River Brock (NW England) where over a period of eight weeks in 1997, a well vegetated forest habitat was completely denuded by erosion.

3.6.3 Conclusions

Essentially, the role of recreation in eroding the uplands tends to be linear and is modest in comparison to other agents (**overgrazing**, fires, climate etc.). Loxham (Pers. comm. 1997) has the view that when compared, the extent of **erosion** caused by recreational pressures is far superseded by that initiated and exacerbated by grazing pressures. Yalden (1981) describes the overall area of bare ground produced in the Peak District National Park by trampling as being 2% of the total bare/ half-bare ground. However, Anderson *et al.*, (1997) sees this 2% as being "a very conspicuous example of damage to the moorlands".

- Short grazed swards encourage people to spread out from linear pathways, taking shortcuts and, can result in a wider spread of footpath **erosion**. Impacts from this include loss of surface vegetation, and soil/scree **erosion**.

- Intensively grazed swards are already stressed. The extra trampling from people can tip the balance and cause soil **erosion**. Repair and regeneration is also more difficult.

- Vigorous, well developed vegetation will contain the spread of footpath **erosion** and paths running through them are more favoured by walkers than the rougher areas adjacent to them.

- Incised, gullied footpaths can act as a route for rainfall to run off down a slope as the path usually follows a direct route to the bottom. As well as increasing localised **runoff**, the water flowing down such paths can transport loose material and cause further **erosion**.

- Attention needs to be given to the chronic effects of footpath **erosion**, rather than the visible, acute effects.

- The politics of recreation e.g. "The Right to Roam" may well affect **erosion** caused by grazing animals. More visitors, wandering away from defined paths can have the effect of dispersing herds, causing further damage from trampling.

Due to its acute nature, **erosion** from recreation attracts large sums of money to affect its repair. This is far more then the amounts of money directed into stock control management (e.g. shepherding) or other methods of reducing the occurrence/impact of grazing animals and uncontrolled fires. This should be reviewed.

3.7 The Impact of Afforestation on Upland Erosion and Runoff Rates

3.7.1 Introduction

Approximately 25% of the uplands of the UK are under forest cover and this has been prospected to rise to 50% over the next 40 years (Centre for Agricultural Strategy, 1980).

Afforestation (typically non-deciduous plantations) is a particularly common management practice in reservoir catchments in the UK, and it gives some commercial value to land that must be protected from the effects of agriculture and industry on water quality. Consequently, afforestation has often been undertaken to improve water quality (Newson, 1980).

3.7.2 The impact of afforestation

Forestry plantations have impacts on **erosion**, these not only occur due to the presence of trees but also the artificial drainage systems found in plantations. In Northern Europe, forests are normally planted on soils requiring drainage but, in the UK, almost all the new land for forestry is on upland soils which first have to be ploughed. Studies on the impacts of forestry have often been undertaken on sites without artificial drainage. The impact of a lot of forestry is a combination of the effects of drainage and the trees themselves, the predominant impact changing over time. In the early years of a plantation the drains will exert the dominant hydrological effect.

In mature forests, because of protection by the forest canopy and the surface litter layer, rainsplash **erosion** and rapid **runoff** are reduced, therefore, limiting the silt supply from forested slopes when compared to unforested (Douglas, 1969). Forests have also been held responsible for reduction in water yield due to higher evapo-transpiration losses, and in flood peaks due to reduced storm flows (Calder, 1982). Forests have, therefore, been shown to reduce **erosion** within catchments and within streams.

Forestry drainage, however, was shown to be responsible for large increases in **bedload** transport in certain sites in mid-Wales (Newson, 1980), this was a result of increased **erosion** in the drainage **channels** within the plantation. In a catchment of immature forest, Robinson (1986) has found drainage to be primarily responsible for a doubling of baseflow and, following rainfall events, shorter response time and higher peak discharge. These in-stream changes will result in increased stream power and thereby **erosion** downstream, perhaps away from the forest plantation.

Increased bank **erosion** may also result from the lower root density and lack of vegetative cover provided by typical plantation trees compared to grass (Murgatroyd and Turnan, 1983). Shade from trees will discourage ground flora. Ideally, a buffer strip should be placed between trees and water courses. Grassed banks can remain intact when undercut, effectively reducing the erosive power of the stream by increasing the area over which it acts. Forested banks, however, are more liable to collapse when slightly undercut, furthermore, slumped material is easily broken up whilst slumped grassed banks are highly resistant to breaking up and can give good protection to the toe of the bank.

Channel widening in forested catchments is also a result of the development of temporary debris dams in the stream; these are formed from the material eroded from the banks and branches and twigs from fringing trees. Streamflow around these obstructions causes the **channel** to be further widened introducing more debris into the **channel**.

It is important to note that the importance of the processes mentioned above depend on the size of the stream. Only in small catchments will debris and log jamming cause **channel** widening, in rivers of 10-60m bankfull width, narrower **channels** are associated with forested rather than grassed banks (Charlton, 1978).

It should also be noted that the more open nature of mixed woodland allows the development of a good protective turf along stream banks. Any dams that may be associated with fallen branches or roots that extend into the **channel**, do not cause **channel** widening in mixed woodland, and often remain as stable features which become overgrown with vegetation (Murgatroyd and Ternan, 1983). If treeless buffer zones dominated by grass and scrub are introduced alongside **channels**, light will be admitted, promoting further development of such vegetation, which then helps to stabilise river banks.

The Forestry Commission produces guidelines for protection of watercourses from the impacts of forestry (Forestry Commission, 1993) which if followed, addresses all the issues mentioned above. The extent to which the guidelines are followed for new plantations and the degree to which older plantations can be said to comply has not been assessed.

3.7.3 Conclusions

- Forests have been shown to reduce **erosion** within catchments and streams due to protection from the canopy and surficial litter layer. **Runoff** can be reduced in a similar manner, as forests have a high evaporation rate and also reduce storm discharge peaks by retarding the surface flow of water.

Forestry drainage does increase **bedload** transport if plantation drainage **channels** become eroded. Such drainage **channels** have been found to reduce response times to rainfall events and increase peak discharges, thereby causing **channel erosion.**

3.8 The Impact of Land Drainage on Upland Erosion and Runoff Rates

3.8.1 Introduction

The UK is one of the most extensively drained countries in Europe (Green, 1980). Since 1940 and until 1985, grants have been available for agricultural drainage from MAFF (although these have now ceased) and records of all types of drainage carried out have been kept. The broad pattern of drainage has been controlled by economic rather than physical factors reflecting the distribution of high value crop growing (the most intensive draining being in the relatively dry East Anglia and East Midlands). The majority of MAFF research has, therefore, been into lowland rather than upland drainage.

3.8.2 The impact of upland drainage

A large amount of upland drainage (or moorgripping) has been undertaken since the 1970's when 70% grants became available, this subsidy fell to 60 % in 1983, 30% in 1984 and was not available after 1985. The objective of this drainage was to lower the water table so improving the growth of heather (which prefers to grow in dry conditions) for grazing by sheep and grouse. This drainage work was based on the assumption that peat would dry out as a result of a reduction in the water table, it was not based on the findings of research.

Artificial drainage is described as being either arterial (referring to the alteration of water courses), or field. Field drainage is of essentially two types; open drainage or moorgripping (Figure 22) and underdrainage, the former being unlined trenches and the latter being lined or unlined tunnels.

Drainage causes a variety of potential effects upon river flows, flood risks and erosive power, many of these have been reported by researchers at some time or place. There are essentially two conflicting hypotheses:

i) Drainage leads to faster **runoff** resulting in higher peak discharges and shorter response times subsequent to rainfall events. For example, Conway and Millar (1960) and Robinson (1986) reported an increase in peak flows subsequent to gripping of peat moorland.

ii) Drainage removes water from the soil so increasing moisture storage capacity and buffering storm **runoff**. For example, Newson and Robinson (1983) reported a reduction in surface waterlogging, greater soil moisture storage and moderation of flood risk subsequent to emplacement of lined underdrainage in both clay soil and peaty soil.

It is apparent that the impacts of drainage may be controlled by:

- Site characteristics - slope, and soil type.

  Various authors (e.g. Thomasson, 1975; Bailey and Bree, 1981) have suggested that the artificial drainage of permeable soils, having a high water table due to external factors such as drainage from upslope, would generally increase the moisture capacity of the soil and reduce the incidence of high discharge and flooding, whilst the opposite would occur in clay soils.

It should be noted that water only moves freely through the upper 10 cm of hill peat, the underlying humified layers conduct water at only a few metres per year.

- Type of drainage

  Whilst the field drainage component of a drainage scheme may reduce peak discharge, it might be necessary to deepen and clear arterial drains in order to allow the field drains to intercept them. This may counter the effect of the field drains in peak discharge reduction.

- Location of drained area within a catchment.

  The findings from a study site cannot be extrapolated to the catchment that contains it. For example, delaying **runoff** from areas whose peak flows normally occurred before the catchment peak would tend to build up the overall peak discharge, and the erosive power of the receiving stream.

- Climate and rainfall regime.

  The input / output relationship of a drainage system may be constant across a range of rainfall inputs but is likely to change at certain thresholds.

The complexity of the interactions between drainage and **erosion** and some idea of the scope of research work currently needed in upland environments can be illustrated by consideration of the "Hall Moor" study (Newbourne and Booth, 1991).

The "Hall Moor" study is one of the best examples of research into the effects of moorland drainage in association with other upland management practices. The drainage studied was of the standard form for moorland gripping, open trenches, 36 cm deep following the contours at 22 m intervals.

The study showed, amongst other things, that the drainage had no effect on the water table other than within 0.5 m of the drain, this was because of the poor water conduction of peat as previously mentioned. There were, however, pronounced effects on peat **erosion** due to the rate of **runoff** increasing once the water was in the moorgrip.

Over the three year study period, 56% of the length of drains had eroded through the peat to the mineral horizon, and the cross sectional area of the drains increased by 98 %. Maximum **erosion** rates occurred in rainfall events subsequent to dry periods which had caused the peat in the drains to crack, allowing the peat to be moved in large pieces. Denudation rates were measured in two ways, by sediment trapping and by measurement of the change in profile of the drains. The former method suggested 7kg of peat was removed from every metre of drain over three years, whilst the latter suggested a much higher rate of 300kg (which is probably more accurate as fine material was not collected in the sediment traps). If an area of peat was drained at the usual density there would be a resultant loss of 319 - 13,650 tonnes of material per square kilometre over the first three years.

The removal of such a large amount of material will undoubtedly change the ecology of the moors themselves as well as disrupting the aquatic habitat of the receiving waters. Furthermore, though the drainage system may be having little effect on lowering the water table *per se*, this will no longer be the case when the moor becomes radically altered by the loss of peat, exposing bare mineral soils. Problems due to increased acidity as a result of the exposure of such deposits may result, impeding the recolonisation by plants. The impact of **intensive grazing pressure** is also likely to slow down recolonisation. In areas where stocking rates have been reduced, some moorgrips are revegetating and filling in, due to the recovery of the existing vegetation.

3.8.3 Conclusions

- Moorgripping has been shown to be ineffective in lowering the water table, other than immediately adjacent to the drain. To undertake successful drainage of peat moors, the density of drains would be so high that it would dramatically retard the desired use of the land.

- Drainage will exacerbate the rate of **runoff** from areas of uplands where it is employed. This is accentuated where the sward is short and compacted due to the impact of grazing animals (refer to Section 3.2.5 of this report).

- Once in the drains, any water and sediment is rapidly conveyed to receiving arterial watercourses. In many cases, vertical incision of such 'moorgrips' is apparent. In this manner, moorgripping increases sediment input to riverine systems during storm events. Reservoirs are also affected and their storage capacity is reduced by infilling of eroded sediments.

- MAFF, English Nature and the Game Conservancy Trust are currently involved in blocking many moorgrips to reduce their detrimental impact. In addition, some landowners have also realised the problems associated with upland drainage and are blocking grips.

- In addition, drainage of the uplands has serious negative implications for water collection and recharge to groundwater resources. Water quality problems can also occur (e.g. discolouration and acidity) from peat **runoff**, these can cause serious problems for the water companies.

3.9 The Underlying Control of Climate

3.9.1 Introduction

This chapter will attempt to show the relative importance of climatic changes compared to cultural changes in altering **erosion** rates in upland catchments.

Though climate has long been known to be both a qualitative and quantitative control on **erosion**, only its action in differentiating **erosion** between regions has been studied. However, since the recognition of the potential for rapid anthropogenically induced climate change in the early 1980's, it became apparent that **erosion** processes within a region might alter even during times of cultural stability.

In the context of this report the questions that must be addressed are, therefore:

i) is global warming occurring?
ii) what are the consequences of global warming for climate?
iii) have changes occurred that could affect **erosion**?
iv) has climate changed sufficiently to account for the observed changes in **erosion**?

3.9.2 Is climate change happening?

The basic principles behind the greenhouse effect are well established and are reviewed by the Climate Change Impacts Review Group (1991). Theoretically anthropogenically increased concentrations of greenhouse gases (primarily CO_2 from fossil fuel combustion) will result in enhanced energy retention by the atmosphere, this is termed "global warming".

Analysis of global temperature records since 1900 indicates an average warming of 0.5^0C, however, this may only be variability around an unstable mean or a manifestation of long time-scale variability associated with solar radiation. Essentially, the detection of anthropogenic global warming is very difficult because of the masking of any signal by year to year climate variability.

3.9.3 The climatic consequences

The consequences of increased energy retention are complex and, therefore, have been the focus of an enormous amount of research. Potential feedback mechanisms have been identified that may help to maintain the present climate and these include enhanced cloud formation (causing more energy to be reflected from the earth, or accelerate any warming) and the enhanced release of the greenhouse gas methane from warming tundra soils. There remains, therefore, uncertainty about the effects of enhanced energy retention at the global scale.

Uncertainty about the impacts of enhanced energy retention increases further when regional temperatures are considered and additional complications arise on consideration of other measures of climate such as precipitation (Fiering & Matalas, 1990).

Thus, while it is logical that atmospheric warming will increase general precipitation in temperate oceanic locations (Warrick & Farme, 1990), actual rainfall amounts are very sensitive to the tracks taken by airmasses across Britain (Wheeler, 1990). The characteristic rainfall patterns of the British Isles are largely controlled by the regional circulation pattern, and changes in the location and efficiency of the rainfall bearing elements of this pattern are not, as yet, predictable.

At present the best predictions of climatic models only allow the broad conclusions that as global warming occurs the North of Britain will become wetter in winter and the South drier in summer. A further complication for erosive events is the importance of the relationship between snowmelt and **runoff** in Britain. This is highlighted by Johnson (1975) who listed 53 gauged catchments where the maximum recorded floods were influenced by snowmelt. Under a warmed climate, if there is an accumulation of snow, the potential would therefore exist for higher melt rates. At present, therefore, climatic modelling is unable to predict variability and intensity of the short-term precipitation / **runoff** events which are often those most effective in causing **erosion**.

Consideration of past records in order to demonstrate the existence of changes in climatic parameters, perhaps a more obvious method than modelling, is also fraught with difficulties. In the case of precipitation this is primarily because the most widespread, available and long-term records are of daily rainfall.

However, despite problems with data, Perry and Howells (1982) suggest that heavy daily falls of rain have increased in Wales since the 1920s. Lawler (1987) reviews several studies and focuses on the apparent change in the seasonal distribution and location of the heaviest daily falls. Higgs (1988) supports the hypothesis that 1925 is a significant breakpoint in daily rainfalls at both an upland and lowland site in mid-Wales, In addition, 1968 is also identified as a breakpoint marking a shift from heavy upland (depression) rainfall to a more frequent convectional origin for the heaviest falls and hence a larger number occurring at the lowland station.

3.9.4 Climate and erosion

Erosion is a consequence of the interaction of the material and physical relief of the Earth's surface with the overlying atmosphere. The erosive action of the atmosphere is largely controlled by climate which, therefore, has profound effects on **erosion** rates through a wide variety of mechanisms. A review of research into these processes and their consequences can reasonably be divided into two classes:

i) Alteration in the occurrence of geomorphologically significant discharges in rivers.

Change in the occurrence of high magnitude low frequency discharge events is driven by changes in precipitation intensity, precipitation duration and coincidence of precipitation and / or snowmelt events. Study of such discharges in Britain and elsewhere have confirmed their important role in producing landform change (Lewin, 1989), and that floodplain landforms should not be regarded as adjusting to relatively frequent *circa* bankfull discharges.

ii) Alteration in sediment / regolith mobilisation as a result of changes in ***weathering*** *regime.*

Rates of sediment mobilisation and type of material mobilised will alter as climatic change results in changes in the quality and quantity of vegetation cover, soil moisture regime, temperature regime, and rainfall intensity.

It should be noted, however, that the division is somewhat artificial, in as much as a river **channel** is part of a catchment and, therefore, i) could be treated as sub-class of ii). That these two classes are often separate research areas is a result of a history of academic sub-division of environmental science between hydrologists and earth scientists.

Evidence of the occurrence of i) and ii) as a result of climate change generally and as a result of contemporary climate change in particular are presented below.

3.9.5 Climate change and fluvial erosion

Newson & Lewin (1991) conclude from the evidence of catchment research that though cultural effects are sometimes spectacularly apparent on the hydrology and **fluvial** response of basins (eg. Robinson, 1986), these changes tend to be local and transient. It should be noted that most reported studies are on small catchments and when measurements have been possible further downstream, the flood record is dominated by the changing incidence of heavy rainfall. There is little indication, therefore, of an enhanced cultural imprint on extreme events. Geomorphological surveys following extreme floods in Britain have seldom identified a specific land-use or land- management effect and the British Isles Flood Study (NERC, 1975) detected no significance in the use of cultural data as independent variables in flood prediction (except for urbanisation influencing hydrograph "time to peak").

Though British **fluvial** sedimentary data analysed by Macklin & Lewin (in press) favours a climatic drive behind the processes of **fluvial** change with only local variability attributable to cultural effects ("cultural blur"), research on valley floor deposits often specifically identifies a cultural influence (eg. Saunders *et al.* 1986). This is most apparent in low order basins where there is no floodplain and **colluvium** and **alluvium** interdigitate. It is in such cases that the separation of i) and ii) mentioned above becomes most artificial.

Schumm (1977) identifies the mechanism of valley sedimentation as a property of drainage basins but not of rivers, and Knox (1989) estimates that more than 70% of source area sediments end up in the colluvial store. Therefore, in a **fluvial** landscape, the cultural imprint is likely to be much more manifest in **colluvium**. However, the effects of a cultural change on the contributing slopes on the sediment dynamics of the entire basin will only be large if the planform of the **channel** is disrupted (this is regarded as unlikely by Newson & Lewin (1991), as a result of cultural change under UK conditions).

On the scale of large basins, therefore, **fluvial** action is dominated by climatic signal and that cultural signals are less significant in temperate climates, such as that of Britain. However, the transport of sediments by river **channels** is not the sole component of **fluvial** change, and the colluvial record (and **alluvium** in headwaters) is more liable to show cultural effects.

3.9.6 Climate change and sediment mobilisation

It has been suggested by Evans (1993) that though climate has changed since woodland clearance began, in comparison to land use these changes have had little impact in altering geomorphological thresholds and the sensitivity of the land to **erosion**. Periods exceptional to this general finding have been recognised, particularly during the Little Ice Age when mass movements of slopes were more frequent and, when wetter or more stormy climatic conditions prevailed (1000 BC to 0 AD, 1200 to 1300 AD and 1500 to 1750 AD) exacerbating the surface washing of slopes under arable cultivation (Lamb, 1982). Furthermore, climatic change to wetter conditions around 300 BC and 1000 BC may have triggered peat growth and the associated instability and **erosion**.

A wide variety of reports in both scientific journals and popular periodicals can be offered as a counter to the above argument, in as much as low frequency high magnitude weather events can be regarded as climatic. The effects of such events within catchments has sometimes been shown to be profound and long lasting particularly in the uplands where weather can be most extreme (eg. Tallis 1981; Manchester Guardian, 1834).

3.9.7 Conclusions and further work

- Climatic records are too short or, in other ways inadequate so as to preclude correlation with geomorphological changes that have occurred over the last 70 years. Cultural change is less ambiguously recorded and recognised and may, therefore, be a more easily implicated agent of change over this period.

- Palaeohydrological and sedimentary records present a fairly consistent picture of "climatic drive" and "cultural blur". The same is true when large catchment studies have been undertaken rather than those at the smaller scale of most experimental catchments.

- At the smaller scale (eg. small catchments, short time periods, or closer to the source of **erosion** eg. within colluvial rather than alluvial deposits) it appears that this cultural blur is resolvable into significant impacts.

- That both climatic and cultural factors affect **erosion** is certain but it seems the predominance of each is determined by scale. For example, long time scales would mean the consideration of effects of the next glacial period which would strongly affect **erosion** rates. Another example of this is that the planform of river **channels** (and other geomorphological features) subsequent to a long return period flood may be identical regardless of prior cultural influences.

- Though identification and further analysis of detailed meteorological records is already being done (Sefton & Boorman, 1997; Orr, 1996) this should be a fruitful area of study which could be expanded, paying particular attention to catchments thought to be suffering enhanced **erosion**.

- Given that detailed (eg. records at 15 minute intervals) meteorological records cannot be created retrospectively there is an urgent requirement for a wide variety of catchments thought to be at risk to become fully instrumented. The instrumentation scheme used must overcome the problem of limited spatial extent that has confounded previous studies, preventing unqualified conclusions being drawn concerning the relative impacts of climatic and cultural controls on **erosion**.

PART THREE

4. A QUALITATIVE ASSESSMENT OF THE LOCAL, REGIONAL AND NATIONAL EXTENT OF UPLAND EROSION IN ENGLAND AND WALES

4.1 Introduction

Part Two of this report has concentrated on the findings of published literature and research to describe and assess the impacts of grazing animals and other types of upland management. In contrast, this section of the report utilises unpublished information or "grey literature", questionnaire responses, and visits to upland sites reported to be suffering from **erosion**. This facilitates the regional and national assessment of the nature of the problems which are occurring and the spatial distribution of them.

The site visits were aided by information gained from appropriate organisations based in the relevant areas, and the accompaniment on the visits by key persons from these organisations. The areas used in the case studies are: North York Moors, Yorkshire Dales, English Lake District, Snowdonia, the Peak District, and Devon.

Time constraints placed a restriction on the number of upland areas. However, a questionnaire was sent to the National Parks of England and Wales and farmers who work in a National Trust Estate in North Wales. The questionnaires enabled an assessment to be made of the perceptions people have about the impact of **erosion**, on a national, regional and local scale.

In addition, discussions held with members of the National Parks Authority, National Trust, Game Conservancy Trust and English Nature staff and other organisations (refer to Appendix 1 of this report) have helped to assess the nature and perception of **erosion** problems in some of the areas not visited.

4.2 Case Studies of Upland Erosion in England and Wales

Due to the highly complicated inter-relationships between the different factors which contribute to upland **erosion** (discussed separately in Part One and Part Two of this report), it is deemed important to discuss specific aspects of upland **erosion** in a more localised context. This is hopefully achieved in this next section by describing a range of processes occurring in the locations visited and by using photographs to illustrate these processes and their effects. The actual mechanics and impacts of these processes have been discussed in detail earlier in this report (Sections 2.3 and 3). Colour figures illustrating the case studies can be found in Appendix 4.

4.2.1 Lowland England

By way of introduction and comparison, sites in Devon and Wiltshire were visited. This allowed for the comparison between problems of **erosion** in the lowlands and uplands. The occurrence and impact of soil **erosion** in the lowlands has been a topic widely researched (e.g. Evans, 1980a, 1981, 1990, 1993, 1996, 1997; Holy, 1980; Higgitt, 1991; Morgan, 1985; Quine and Walling, 1991; Boardman, 1988, 1994; Biot and Lu, 1995). Typically, problems centre around; untimely cultivation of crops (e.g. winter wheat) which can present expanses of bare soil during periods when adverse weather conditions are more common, methods of tillage (increasing the risk of soil compaction, promoting **runoff** and flooding) and methods of feeding livestock (including **overgrazing**). Problems tend to be exacerbated if the land farmed is on a slope (even a gentle one) and consists of a light, friable soil.

- **The Impact of Free Range Piggeries**

Figure 23 shows a piggery located in Devon, near to Exeter. The pigs are allowed to feed on whatever grows in the field until the field is turned into a nutrient rich mud. The period of time for conversion to this state is approximately one year (Smith, Pers. comm. 1997). The resultant exposure of bare earth to the elements and compaction and "puddling" from hooves encourages the surface **runoff** of rain which transports the nutrient enriched soil (from the pigs) downslope. A small buffer strip serves to protect the receiving watercourse, but such is the rate of **runoff** during a storm event it is ineffective, with consequential negative impacts upon water quality and river habitat.

- **Rilling of Slopes**

Water running over an impermeable soil will form small **anastomosing channels** which, with time, join. The consequential effect is a vertical incision of the soil. This can create a **rill** (seen left of the character in Figure 24). Once the more resistant soil surface has been penetrated, more friable soils can be easily eroded away and the **rills** can develop into gullies, impeding harvesting and spraying operations. The eroded soil will be transported downslope, typically onto roads where further **runoff** rapidly transports it into streams.

- **Runoff of Water and Soil into Watercourses**

Figure 25 shows a stream which flows at the bottom of a sloping field in a Devon catchment. Soil and organic matter from the field is entering the stream, especially when there is a rain event. The stream (originally culverted, but now diverted due to localised siltation) is **channel**led across the road where it entrains more nutrient enriched sediment. it then proceeds to flow back into the stream **channel**. The stream used to be of good enough quality for salmon spawning; now, the gravel beds are silted and the watercourse is eutrophic, a direct consequence of the **erosion** of soil.

- **Grazing on the Wiltshire Downs**

Sheep are grazed in high numbers on the Wiltshire Downs. Figure 26 illustrates the use of fodder crops (such as curly kale) to supplement the stock. A local resident (Ridgers, Pers. comm., 1997) described how, in times of storm, the road in the foreground of the picture is covered by a "chalky river" of **runoff**. This type of **runoff** finds its way into rivers and is partly responsible for a problem known as "Chalk Stream Malaise" which particularly affects salmon and trout spawning habitats.

4.2.3 The English Lake District

Situated in the North West of England, the Lake District is a popular destination for many people. A mixture of tourism, agriculture and light industry fuel the economy, but it is the mountains and lakes which have captured the imagination of locals and visitors alike. A mixture of geology is found throughout the region (sedimentary, igneous and metamorphic) which gives rise to the differences in form and appearance of the landscape.

- **Recreation Erosion on the Langdale Pikes**

Figure 27 illustrates the visible scars left behind from scree running (the light grey linear trails). The impacts from this were at one time so severe local properties were at risk from rockfalls. The National Trust has controlled this **erosion** by using fences and signs to discourage people from using the "runs", and by planting the lower slopes. This material will however, be still be susceptible to **erosion** from natural agents (such as frost and rain). Furthermore, grazing pressures from livestock could exacerbate the problem through trampling and a reduction in the abundance of stabilising vegetation.

- **Footpath Erosion in Great Langdale**

Footpaths are constantly put under pressure from walkers (Figure 28). Typically these can be seen as linear tracks, slowly getting wider as the surface becomes more uncomfortable to walk on. In this manner, the margins of paths get worn and damage to vegetation occurs. Water uses such paths as routeways for rapid overland flow as the lack of vegetation reduces interception of flow. Therefore, vertical incision of paths from **runoff** can also be a problem.

- **Stable Boulder fields on the Slopes of Helvellyn**

Figure 29 illustrates a classic example of a structure in equilibrium with its environment. Boulder fields, such as the one shown in Figure 29 may have remained *in situ* for thousands of years and are often colonised by lichens and bryophytes (indicating stability). With time, shrubs and trees will also colonise.

- **Unstable Eroding Scree on the Slopes of Helvellyn**

The scree slopes of Helvellyn are particularly affected by **erosion** (Figure 30). Evidence of grazing is apparent. The surrounding vegetation is cropped close to the ground, sheep scrapes and hoof marks are commonplace and there is an abundance of contour trackways. Essentially, sheep graze these slopes and because of a reduction in available food, are concentrated together, putting additional pressure on remaining vegetation.

More sheep are getting "crag-fast", accessing remote, untouched areas of the hills. The impact of the livestock and natural agents of **erosion** is to make the scree unstable. Where remobilised scree moves on top of vegetation it will bury and kill it off. Thus, the impact is perpetuated as the area of unstable, unvegetated slope is always increasing in area.

In one particular location (Dry Gill) material is fed into the **channel**, it builds up with time until enough rain falls to carry it down-slope (Figure 31). In February 1997, such a rain event did occur. The material in Dry Gill and more from surrounding scree slopes was mobilised downslope. The spate flow of the Gill carried the coarse debris through a forestry plantation (Figure 32) and blocked the main arterial road from Ambleside to Keswick in three places for the best part of a week, subsequently roadside highway repairs were required during April and May 1997.

This road blockage has occurred before, in Jan, 1995 (Loxham, Pers. comm. 1997). The cost to the Highway Authorities, local economy, owners of the plantation and reservoirs below the gill is not insignificant. The pattern of events has become established and is threatening to repeat itself again. In this case a reduction in the number of stock and prevention of access to these slopes would have a beneficial impact.

- **Full Blown Upland sheet erosion. A Terminal Situation**

As described in Section 3.2.4 of this report, one consequence of intensive pressure from grazing animals on slopes is **upland sheet erosion**. Where this occurs, (as illustrated by Figure 33) large expanses of hillslope become devoid of vegetation (being grazed out or buried) and as a consequence, the soil and rock are very mobile. The combined effects of trampling and other mechanisms of **erosion** (rain, frost-heave) perpetuate this situation. It is widespread throughout the Lake District and in terms of restoring the hillslope to its past condition in a human lifetime, this problem can be considered to be terminal.

- **Ennerdale, Cumbria.**

Longmoor Common (Figure 34,) near Ennerdale Bridge village has not been grazed for at least 15 years. In the late 1960s, when the Commons' Registration was being completed, many individuals lost their grazing rights. The recovery of the vegetation has been so dramatic that the National Trust have had to remove willow as it was able to colonise so rapidly.

Kinneside Common (Figure 35,) is approximately 2000 hectares in size and there are common grazing rights to 10-11,000 sheep. In order to qualify for the ESA scheme (refer to Section 2.7 of this report) this had to be reduced to less than 4000 sheep. There is also a conflict with recreational uses as approximately 35 fell ponies roam this area. Short, grazed vegetation dominates this area with the effect of grazing and trampling being obvious (sheep scrapes and scars, even on shallow slopes).

In 1989, the National Trust began rebuilding an old stone wall which encapsulates an area known as The Side. This was completed in 1991, effectively removing the grazing pressure from the adjacent common-land. The Side is a SSSI and to enter Tier 2 of the ESA scheme, grazing had to be reduced to a maximum of 250 sheep (a maximum stocking density of 1.6 ha per sheep or 0.6 sheep per hectare).

When the wall was completed in 1991, several exclosures were also created. The Side could be described as a long-term experiment to determine the effects of grazing and low grazing pressure on fell vegetation. Another area of The Side has zero grazing. The vegetation of The Side can be described as spectacular. Ranging from high montane, through dense, robust stands of heather and bilberry (Figure 36) to old, stable woodland (Figure 37). Throughout The Side, there are no signs of **erosion**, only stability. A window to the past showing what would have grown naturally on the majority of fells in the Lake District.

4.2.3 Yorkshire Dales

The Yorkshire Dales sit astride the central Pennine watershed. Typically, it is limestone country (sandstones and shales are also found), with exposed gorges, rock pavements and subterranean cave networks. Much of the tops are covered with heather, although grazing pressures have reduced its relative abundance, with some locations losing their heather communities entirely.

- **Rabbit Erosion in Littondale**

Rabbit populations are said to have soared in the Dales (Sykes, Pers. comm. 1997). This could be a result of the recent dry weather and the friability of much of the alluvial soils, and the reduction in the length of grass (by sheep grazing) to one which is favoured by rabbits. Scenes such as that shown in Figure 38 are common-place. Large warrens can provide intrinsic weaknesses in river bank structure, the excavated material ready for transport away in the next flood.

- **Riverbank Collapse**

Figure 39 illustrates a graphic example of river bank **erosion** which is occurring in the Dales. At the volume of discharge shown in the photo, water cannot negotiate a large bar deposited by storm flows (to the left of the picture), instead it follows a pathway which hugs the bankside. In doing so, it undercuts the bank which is composed of reworked glacial drift and **alluvium**. As a result, turf-mats overhang the retreating bank, ultimately collapsing into the **channel** below. In times of flood, the main current will follow the easiest line available to it, bisecting the bar. Sheep are permitted to graze up right to the bank edge, and **poaching** is evident. The vegetation is short, grazed grass which has very shallow roots, providing no real protection or stabilisation to the bank material.

Figure 40 illustrates the effect of large flood events upon river **channels**. Banksides are eroded away whilst large volumes of coarse material are deposited elsewhere. In this manner, over a relatively short period of time, the path of a river migrates across valley floors. The rate of this being dependent upon a number of parameters, including rapid **runoff** rates, precipitation intensity and frequency, and bank stability.

Although some landowners may be losing land which they can farm when a river erodes into their land, others will not benefit from deposition in proportion to the losses upstream, for much of the fines will end up on coastal marshes or out to sea (Evans, Pers. comm., 1997). If a **channel** can remain stable, natural revegetation will occur, giving some natural stability to the margins, but only if stock are excluded. In other cases, hard engineering techniques may have to be employed (e.g. gabion mattresses, revetments etc.). The longevity of any of these techniques is limited, because with time, a flood of high enough magnitude will occur which will be powerful enough to move the position of the river banks again (NRA, 1995). In addition, hard engineering approaches are also capable of simply transferring erosion problems downstream.

Future floods may cover the cobbles in the picture with enough silt to allow re-vegetation by local plants. This will in turn promote local stability during the next flood. Alternatively, this material may be reworked in such a way that water continues to flow along the **channel** again, abandoning other parts of the braided **channel.**

- **Differential Grazing of Heather in Swaledale.**

In many regions of the Dales (and other parts of Britain), heather has been "grazed-out" or damaged (refer to Wildlife Trusts, 1996). Figure 41 illustrates the effect of grazing over different lengths of time. The top of the fell (dark colour) is grazed during the winter. Heather still survives here but is beginning to show sign of grazing stress. The middle flanks of the fell (light brown) have been grazed for 2-3 years. The bottom of the fell (green) has been grazed for 10 years and is purely grass. The heather could recover, even where grass grows today. If light grazing pressures were enforced and the stock was excluded during the winter, the heather could return in as little as 10 years (Newbourne, Pers. comm., 1997).

Figure 42 illustrates the colouration difference in vegetation on areas of land that are grazed heavily, and those left ungrazed and managed for grouse. The light green area on the left of the picture is land that is intensively grazed by sheep. The sward is reduced in quality and density. To the right of the picture (darker green) the vegetation is left to grow unchecked. The defined boundary between the two areas of grazing is marked by an obvious colour change. This shows the position of a fence excluding stock.

4.2.4 The Peak District

The Peak District lies at the southern end of the Pennines, between Manchester and

Sheffield. In the north of the area, the rocks are gritstone and shale. Large areas of moorland are found where heather and grasses dominate. Many of these moors are managed for grouse and are grazed by sheep. The southern area of the district is underlain by limestone. The landscape consists of plateau which are cut by steep dales **Erosion** problems have been noted here in the 1970's, 1980's and 1990's and much work has been undertaken to evaluate and restore the impact of it (refer to Section 3.2.4, 3.2.5 of this report).

- **Peat Erosion**

Figure 43 shows typical conditions which exist in many of Britain's peat moors. This particular photograph illustrates the continuing effects of fire damage. Once the vegetation was removed by fire, hostile environmental conditions (soil acidity, atmospheric pollution, frost action) and the presence of grazing animals have prevented the recolonisation of the peat. The bare surface is subjected to the effects of **weathering**. Frost heave and dry weather conditions have resulted in the upper layer of the peat flaking off (shown in the photo) exposing deeper layers of peat and mineral soils (see Figure 44).

- **Desiccation of Peat Bogs**

In some cases, areas of standing water in the Peak District have been lost. This is due to the effect of climate (long periods of dry weather), but could also be related to changes made to local hydrological networks as a result of the loss of vegetation, lowering of the water table and drainage.

Figure 45 depicts such an area of peat where desiccation cracks are evident, illustrating that previously saturated peat surfaces are now dehydrated and have contracted away from each other. This reduces the potential for the peat to become re-saturated and facilitates the removal of larger pieces of peat by **runoff**. The revegetation of such areas is difficult, especially where grazing pressure continues.

- **Incision of Peat Hags.**

Where surface drainage pathways combine into larger **channels**, the tendency for vertical incision into the peat surface increases (Figure 46). If **channel** margins are weakened from the effect of trampling, and loss of vegetation (grazing and atmospheric pollution etc.) then the **channel** may expand. If precipitation events are of a high magnitude, **erosion** by water may occur. In this manner, such **channels** (gruffs) can be deepened to the point that the underlying mineral soil is exposed. This is usually the only vegetated part of the system (if undisturbed) as the peat side-walls are too unstable to become vegetated so they continue to retreat. The mineral soil usually contains rock material which will also offer more resistance to **erosion** than peat.

- **Vegetation Control**

Figure 47 illustrates a mosaic pattern of vegetation. This is typical of areas of heather which have been burnt (Section 3.3) and areas of land where bracken has been controlled (usually by spraying). The ground can be covered by woody material after the bracken dies off (Figure 20). If this is removed (e.g. through the action of trampling) bare soil will be exposed. It is difficult for vegetation to recolonise such an area if a programme of aftercare is not instigated once bracken control is complete (see Section 3.4 of this report) having potential implications for slope stability and **runoff**.

4.2.5 The North York Moors

The North York Moors are found in North Yorkshire and form a large upland Plateau dissected by dales. The moor tops are dominated by heather moorland, but unlike the Peak District, there is a limited amount of blanket bog (less than 200 ha), but there is about 2000ha of dry bog where vegetation management or burning have changed the vegetation composition to one dominated by heather.

- **Footpath Erosion**

Footpaths and bridleways run across many upland areas. The photograph of the Lyke Wake Walk (depicted in Figure 48) shows how such paths often comprise of bare soil surfaces, which expand into the surrounding vegetation. As these paths degrade, they become more difficult to walk across (e.g. because of mud, ruts and boulders). As a result, walkers and cyclists will use the more comfortable margins of the paths, ultimately widening them.

- **Bracken Management**

The area shown in Figure 49 used to be dominated by bracken. About 12-13 years ago, it was sprayed to control the bracken. It has been fenced off from livestock for about 6 months and it is beginning to recover. Heather is starting to return , but the area is still susceptible to natural agents of **erosion** (frost-heave, rainfall etc.) and will not intercept much precipitation. Hence, local **runoff** rates could be influenced by such areas of land.

- **Moorland Erosion**

In many cases, the moorland vegetation is heavily stressed by eroding bare ground which threatens to encompass all, especially when severely damaged by fire. Frost heave, and desiccation attack the bare ground with greater effectiveness than when it was vegetated, breaking up soil aggregates which can then be transported away by the wind and rain. In places, streams can be found, stranding vegetation on small "islands" (Figure 50). Some of these **channels** are small, **anastomosing** across the surface but, where they join together, especially on slopes and footpaths, they can become incised, transferring soil and water at a rapid rate downslope (Figure 51).

4.2.6 Snowdonia

Snowdonia is an area of upland situated in the North West of Wales. It is dominated by hard rocks, which is reflected in the range of altitude the landscape has. High mountain peaks, upland moors and valleys are to be found throughout the region.

- **Grazed Upland Moors**

Grazing of the upland moors by sheep is prevalent throughout Snowdonia. Some of it on privately owned land, some on common land. If the grazing intensity is too high, changes to the vegetation will occur, in some cases exposing bare earth. Figure 52 shows how the heather community has receded due to grazing pressure. It has been replaced by grass communities. This has implications for the rate of **runoff**, potentially increasing it.

- **River Bank Erosion**

The slopes in the background of Figure 53 have grass that has been tightly grazed by sheep. The livestock are able to feed right up to the river bank. This in itself may cause local bank instability. The overall impact of reduced vegetation cover in the catchment, may increase **runoff** rates and increase the magnitude of floods. Such floods will have an erosive impact on these river banks, which have no protective or structurally enhancing vegetation. Figure 54 also shows river bank **erosion**. The impact here is from cattle. In the top left of the picture, a ring feeder can be seen. This has been placed close to the waters edge. Cattle will congregate around it, trampling the grass and breaking down the river banks. Sheep will also cause similar impacts (Figure 55).

4.3 Erosion in the Uplands of England and Wales: A Critical Analysis

4.3.1 Introduction

In order to attempt to assess the occurrence and perceptions of **erosion** in English and Welsh Uplands, it became necessary to gather information from outside the published literature ("grey literature"). The use of a questionnaire was deemed to be the most successful method of conducting a rapid review.

The standardised questions used were intended to stimulate a broad response which could facilitate further enquiries. The responses would also enable some insights to be made into the different perceptions about **erosion** held by different organisations and individuals. A single questionnaire was drawn up, the nature of the questions was directed by a member of Environment Agency staff at the Bangor office who had first hand knowledge of the types of questions required. The questionnaires were sent to the National Park Authorities to obtain information about regional and national perspectives on upland **erosion**, and to farmers in the Ysbuty Estate (National Trust) in North Wales.

Table 5. illustrates the layout of the questionnaire and the questions that were asked. Question one was altered to read "land you manage" for the National Park Authorities. Key personnel were contacted by letter. In addition, a summary of the project and its aims were

sent to them. They were then telephoned and aspects of the questionnaire were discussed, Where feasible, meetings were arranged and discussions were held in person.

QUESTIONNAIRE

ENVIRONMENT AGENCY RESEARCH & DEVELOPMENT PROJECT IN ASSOCIATION WITH THE NATIONAL TRUST

SUBJECT: SOIL/RIVERBANK EROSION IN UPLAND CATCHMENTS

1) Do you perceive there to be a problem on the land that you farm as a result of soil/riverbank **erosion**? If yes, could you provide brief details on how the land has been affected.

2) What, in your opinion, is the main cause of any soil/riverbank **erosion**?

3) Have you ever had to repair river banks and/or excavate debris (e.g. gravel) from rivers/fields as a result of flooding?

4) If the answer to 3) was "yes", did you receive advice on how to undertake these works from the National Trust, Environment Agency (formerly NRA) or any other source?

5) Could you describe, briefly, the method used to repair the damage to fields and/or riverbanks (e.g. the use of stone/concrete etc.)

6) In your opinion, how successful were those repairs or remedial works undertaken?

If you have any further comments or ideas please continue overleaf.

Thank you for your valuable contribution in completing this questionnaire which will assist in understanding riverbank **erosion** in upland catchments.

Table 5 The Soil and Riverbank Questionnaire

Two main recipient groups were targeted.

- **Tenant Farmers in the Ysbuty Estate (National Trust)**

The questionnaire was translated into Welsh at the Bangor office of the Environment Agency, and with the aid of the National Trust, the landowner of the Ysbuty Estate in Snowdonia, the questionnaire was disseminated to 50 of the tenant farmers who live and work in the estate. A free-post envelope was included to encourage returns. It was hoped that any answers would reflect the perceptions of individuals working on the land which may be suffering from **erosion**. A very local interpretation of potential problems would be obtained as a result.

- **National Parks Authorities**

A total of nine National Park Authorities were contacted: Exmoor National Park, Dartmoor National Park, Brecon Beacons National Park, Snowdonia National Park, Peak District National Park, Yorkshire Dales National Park, North York Moors National Park, Northumbria National Park and the Lake District National Park. These were the Authorities which held areas of uplands within their park boundary.

The National Park Authorities were chosen because the majority of regional upland blocks fall into their parks. Therefore, in addition to a good geographic distribution, by dealing with Authorities which have the same responsibilities, a consistency of approach to the questionnaire could be expected. The responses to the questionnaire would hopefully reflect regional problems, but also allow a crude evaluation of national trends in the perception of problems associated with **erosion**.

4.3.2 Response to the questionnaire:

A total of nine questionnaires were sent to nine National Park Authorities. All Authorities responded. Out of a total of 50 questionnaires sent to the farmers in the Ysbuty Estate, Snowdonia, a total of 12 were returned, despite encouragement by the use of free post envelopes and reminders to do so from the Environment Agency.

However, the information obtained from the assessment of the returned questionnaires is undoubtedly valuable as it enables some level of understanding of the types of problems encountered in different parts of the country, the potential causes of these, and whether any remedial action has been undertaken.

4.3.3 Questionnaire analysis

i) The National Park Authorities of England and Wales

The questionnaires returned from the National Parks were reviewed and the responses to the questions were categorised and tabulated. The positive responses were based from the questionnaire and telephone conversations with the recipients.

"Do you perceive there to be a problem on the land that you farm as a result of soil/riverbank erosion?

	Exmoor	Dartmoor	Brecons	Snowdonia	Peaks	Dales	N.York Moors	Northumbria	Lake District
YES	✓	✓	✓	✓	✓	✓	✓	✓	✓
NO									

What, in your opinion, is the main cause of any soil/riverbank erosion?

	Exmoor	Dartmoor	Brecons	Snowdonia	Peaks	Dales	N.York Moors	Northumbria	Lake District
Grazing	✓	✓	✓	✓	✓	✓	✓	✓	
Trampling	✓	✓	✓	✓	✓	✓	✓	✓	✓
Fire	✓		✓		✓		✓		
Recreation	✓	✓	✓	✓	✓		✓	✓	✓
Climate				✓	✓	✓		✓	
Air Pollution					✓				
Drainage					✓	✓			
Forestry									
Lack of Vegetation					✓	✓	✓		
Increased **Runoff**		✓				✓	✓	✓	
Spates/floods		✓				✓	✓	✓	
Other		✓				✓			

"If the Answer to Question 1 was yes, could you provide brief details on how the land has been affected".

	Exmoor	Dartmoor	Brecons	Snowdonia	Peaks	Dales	N.York Moors	Northumbria	Lake District
Vegetation change/ loss			✓	✓	✓	✓	✓		✓
Peat/ soil loss		✓	✓	✓	✓	✓	✓		✓
Agricultural land/ grouse moor lost			✓	✓	✓	✓	✓		
River channel erosion		✓		✓		✓	✓		
Slope failure					✓	✓			
Increased runoff					✓	✓	✓		
Flooding			✓		✓	✓	✓		
Low flows/ aridity			✓						
Siltation of habitat							✓		
Damage to flood defence works/ footpaths	✓	✓			✓	✓			

Have you ever had to repair river banks and/or excavate debris (e.g. gravel) from rivers/fields as a result of flooding?

Could you describe, briefly, the method used to repair the damage to fields and/or riverbanks (e.g. the use of stone/concrete etc.)

	Exmoor	Dartmoor	Brecons	Snowdonia	Peaks	Dales	N.York Moors	Northumbria	Lake District
YES	✓	✓	✓	✓		✓	✓	✓	✓
NO					✓				
Gabions			✓	✓		✓		✓	✓
Stone Blocks		✓		✓		✓	✓		✓
Revetments						✓			
Pitching				✓		✓	✓		
Fencing						✓	✓		
Reprofiling				✓		✓	✓		
Revegetation		✓				✓	✓		
Footpath Diversion	✓					✓			
Footpath repair	✓					✓		✓	

In your opinion, how successful were those repairs or remedial works

In your opinion, how successful were those repairs or remedial works undertaken?

	Exmoor	Dartmoor	Brecons	Snowdonia	Peaks	Dales	N.York Moors	Northumbria	Lake District
Temporarily	✓	✓	✓	✓		✓	✓		✓
Yes	✓	✓	✓	✓		✓	✓	✓	
No									

From a simple evaluation of the responses to the questionnaires, it has been determined that the National Park Authorities (NPA) perceive that 18.4% of accelerated upland **erosion** is caused by trampling. In addition 16.3 % is caused by grazing, and 16.3% by recreation. This is interesting as the trampling is linked to the passage of livestock (trampling from people is labelled as "recreation") and damage to the sward and soil from this is mentioned separately to impacts from grazing. If both of these are combined (as "impacts from livestock") then the percentage of upland **erosion** arising directly from livestock is 34.7%. If this is then linked as a cause for a lack of vegetation (6.1%) then the total percentage is 40.8%.

In reality, recreation will have an effect upon the stability of vegetation cover, as does fire. As described in Section 3 of this report, there are many agents responsible for upland **erosion**. The majority of these agents of **erosion** have inter-relationships with one another. Therefore, interpretations drawn from the questionnaires are fairly limited in terms of assessing the responses to the questionnaire as being causative or exacerbatory. The questionnaires do allow a compartmentalisation of ideas and perceptions which helps to facilitate discussion.

Climate, **runoff** and spate-type flow in rivers are seen to be a cause of upland **erosion** (8.2% in each case). There are interrelationship here as increased precipitation, can give rise to increased run-off rates (especially if the vegetation is diminished, and the soil is parched or poached), which in turn, can cause spate-type flows in rivers.

Other factors felt to be involved include drainage (4.1%), air pollution (2%), military activity, and poor management of infrastructures (e.g. riverbanks) (4%).

If the number of NPAs which expressed a positive indication that a particular agent of **erosion** was active in their Park is assessed, the following trends can be identified. All of the parks identified trampling as a cause, 90% of NPAs identified grazing and recreation. In comparison, 44% of NPAs perceived that climate, fire, increased **runoff** and spate-flows were involved, and only 33% felt that a lack of vegetation contributed to upland denudation. Twenty two percent of the NPAs noted other factors. Clearly, the impact of livestock and recreation can be perceived as being important factors causing and exacerbating upland **erosion**. In addition, several other issues such as fire and the climate are also involved in the overall denudation of the uplands.

Almost 20% of the effects of erosion that are perceived by the NPAs are losses in soil and peat, in addition, 16% of NPAs describe a loss or change in vegetation. These are also reflected by

13.5% of effects being perceived as loss of agricultural land or grouse moor. The impacts of **erosion** are not limited to moortops or slopes, 10.8% of the effects are thought to affect river banks (**erosion**), 10.8% affects flood defence structures and 10.8 % of the effects is flooding. Interestingly, low flows and aridity are mentioned, suggesting a perceived link between climate, hydrology and **erosion**.

A variety of methods have been employed by the NPAs to repair damage to river banks which has arisen as a result of **erosion**. These include hard engineering techniques such as the use of revetments and gabions, and soft engineering (for example bank reprofiling and revegetating).

ii) Tenant farmers of the Ysbuty estate, N. Wales.

The questionnaires returned from the Farmers (F1-F12) were reviewed and the responses to the questions were categorised and tabulated.

"Do you perceive there to be a problem on the land that you farm as a result of soil/riverbank erosion?

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12
YES	✓	✓	✓	✓								
NO					✓	✓	✓	✓	✓	✓	✓	✓

What, in your opinion, is the main cause of any soil/riverbank erosion?

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12
Grazing												
Trampling												
Fire												
Recreation												
Climate												
Air Pollution												
Drainage												
Forestry												
Lack of Vegetation						✓						
Increased **Runoff**												
Spates/floods	✓	✓								✓		✓
Other				✓	✓			✓				

If the Answer to Question 1 was yes, could you provide brief details on how the land has been affected".

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12
Vegetation change/ loss												
Peat/ soil loss												
Agricultural land/ grouse moor lost	✓	✓	✓									
River channel erosion	✓	✓										
Slope failure												
Increased runoff												
Flooding	✓											
Low flows/ aridity												
Siltation of habitat												
Damage to flood defence works/ footpaths		✓										

Have you ever had to repair river banks and/or excavate debris (e.g. gravel) from rivers/fields as a result of flooding?

Could you describe, briefly, the method used to repair the damage to fields and/or riverbanks (e.g. the use of stone/concrete etc.)

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12
YES	✓	✓	✓	✓								
NO					✓	✓	✓	✓	✓	✓	✓	✓
Gabions												
Stone Blocks												
Revetments												
Pitching												
Fencing												
Reprofiling												
Revegetation												
Footpath Diversion												
Footpath repair												

In your opinion, how successful were those repairs or remedial works undertaken?

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F9	F11
Temporarily	✓	✓	✓	✓								
Yes												
No												

A total of 12 out of 50 farmers responded to the questionnaire, despite consistent efforts to encourage them to do so. However, the questionnaires returned did show an interesting difference in perception about the cause of **erosion**, compared to the National Parks Authorities, Snowdonia in particular. Only 4 out of the 12 recipients who returned the questionnaires felt that **erosion** was a problem for them. The causes of the **erosion** was seen to be flooding, although one individual identified the lack of bank protection (stones) as being contributory.

Those farmers who felt that **erosion** was posing a problem, mentioned the loss of agricultural land as being the main effect of it. These same farmers also had attempted to remove material deposited out of the **channel**, in some cases using this material to reinforce the river banks. However, they did not see this activity as being successful in the long-term, only a short-term **solution**.

At a local scale, the effect of **erosion** does not seem to be of particular concern to the majority of the farmers of the Ysbuty Estate who returned their questionnaire. However, this may be due to a lack of understanding about how **erosion** manifests itself. Several of the farmers did indicate that flooding was a problem. This may be linked in to the connection between, high levels of grazing and compaction and **runoff**.

4.3.4 Conclusions

The evidence presented from the questionnaire survey illustrates a number of important points.

- Differences in the perception of the causes of **erosion** are apparent both within the different National Park Authorities, between tenant farmers, and between the NPAs and tenant farmers. This affects how **erosion** is viewed and the urgency of control and remediation work.

- Generalised perceptions suggest that the NPAs believe livestock to be the greatest agent of upland **erosion**, followed by recreation.

- The questionnaires imply that other agents of **erosion** are also having an impact, suggesting that in fact, a mosaic of cause is occurring. The extent to which specific agents of **erosion** actually dominate, varies spatially.

- The anecdotal and photographic evidence presented in this section of the report is really a collection of individual examples of specific conditions found whilst undertaking the site visits. However, the number of similar sites found to be suffering from one or many **erosion** impacts (caused by a number of different factors) is of a scale which demands instant attention. Every upland region of the country visited gave cause for concern with regards to either loss of soil or vegetation and/or the effects of flashy catchments causing flooding, destruction of habitat or impacts on water quality.

- The spatial extent of the problem needs to be quantified further.

PART 4

5. THE IMPACTS OF UPLAND EROSION AND RUNOFF ON THE ENVIRONMENT AGENCY

This section provides some further detail of specific impacts of upland **erosion** and increased **runoff** which affect the Environment Agency.

- One effect of **erosion** is the increase in material readily available for transportation. Fine sediments transported in riverine systems are detrimental to both water quality and biota. Habitats can be smothered by deposited silt which can, for example, block voids in spawning gravels; preventing the flow of oxygen and water to fish eggs, alevins and food organisms; block sunlight from beneficial plants and, promote the growth of algae. If organic material is included in the fines, a loss of water column oxygen may ensue as the organic matter breaks down. Nutrient rich fines will also promote eutrophication. Contaminants (e.g metals) are often transported along with the fine material (often adsorbed on particles) and these can have acute or chronic effects on the biota, concentrating up through the food chain.

- **Runoff** from areas which have had bracken control sprays such as "Asulox" administered may well transport such herbicides and pesticides into water courses. In some cases, this may cause limits set by the EC Drinking Water Directive to be exceeded.

- Fine material will also have detrimental impacts upon potable water supplies, requiring settling prior to use. One result of this is the rapid siltation of storage reservoirs, reducing their longevity or causing the need for the removal of silt. If contaminants are transported with the silt, they will have to be removed. The use of such removal techniques is expensive.. In many cases, the aesthetic quality of water may also be affected, brown turbid rivers are less appealing than sparkling clear ones, they also need to be treated if water is abstracted for potable supply purposes.

- White *et al* (1996) have compiled and analysed a database of sedimentation information for 77 reservoirs in Yorkshire. The data indicate that sediment has reduced the original total capacity of these reservoirs by nearly 9000 million litres, (or 7.5%) since impoundment (a few are over 150 years old). To place this in context, the most recently constructed reservoir, Scammonden, has an original capacity of nearly 8000 million litres. Yorkshire Water Services have calculated that this loss has a value of approximately £74,000 000, £650,000/annum, or 25 days supply. The paper summarizes that catchment management is the only permanent solution to excessive reservoir sedimentation, and land use policies that encourage healthy, well managed vegetation of all types are likely to improve the water quality and the water holding capacity of the reservoir's catchment. The report concludes "The management of catchments to reduce erosion has a symbiotic and beneficial effect in reducing colour and *vice versa*. An holistic approach to the management of catchments will lead to cost savings and a combined management policy should therefore be achievable and beneficial."

- During flood events, the silt can act in an abrasive manner upon the biota, especially affecting fish by scouring scales and exposing areas of tissue which are then vulnerable to infection (e.g. Newcombe and Jenson, 1996). If silt is deposited on riparian areas, it may smother and kill short vegetation. However, the silts are often nutrient rich and can be beneficial to the sward.

- The degradation of incised stream **channel** aquatic habitats occurs when the sediment transport capacity (stream power) exceeds the sediment supply. This may be the response in some catchments to an increase in run-off. The **channel**s widen and often form a two-stage **channel** (or may become braided). Typically, such **channel**s are comprised of a low-flow **channel** flanked by sandy vegetated berms within an enlarged main **channel**. The low flow **channel**s are often very wide and shallow, devoid of riparian vegetation and dominated by sand, gravels and cobbles.. In many cases the passage of fish through such degraded areas of river is difficult or impossible.

- Much damage can occur when coarse material is transported by rivers in flood. Trees growing along river banks can have their bark stripped from them, riparian vegetation can be ripped up, flood defence structures, walls, and bridge supports can all be damaged or destroyed by the impact of boulders and trees in transport. Many tributary streams (e.g Joshua Beck, Lancashire; first order tributaries of the River Cover, Yorkshire Dales) have been completely blocked to fish passage by flood deposition of coarse deposits from eroded sources higher up the catchment. Any fish in the path of such material will be severely damaged or washed downstream, invertebrates will be crushed, and when the flood waters die down, habitats and organisms will be smothered under new deposits of coarse material. River banks and beds will be eroded more effectively when such material is being transported.

- The transport of bare soil and rock on slopes (created by any of the methods mentioned in this report) can have serious impacts on transport routes (roads and footpaths) if a rockfall, landslide or slump occurs. In addition, properties may also be at risk.

- If more water is running off the uplands instead or recharging aquifers, there are serious implication for water resources, unless the **runoff** is intercepted by storage reservoirs.

- There is a real risk of further decline in upland biodiversity from grazing pressure (changing the type and structure of vegetation) and/or the creation of bare, eroding areas (caused by a number of factors), devoid of much life. In addition, actively eroding hotspots may expand and smother previously stable, vegetated areas, killing plants and creating new zones of bare ground. The area of bare ground and scree appears to be increasing in many upland areas of Britain.

- A large number of sheep being dipped close to water courses may result in impacts on the river biota from synthetic pyrethroid dips (traditionally organo-phosphate dips). Sheep instinctively head for drinking water after being released from dipping. If this drinking water is a stream or river, remnants of the dip on the sheep may be washed into the water causing fish and invertebrate kills. Such watercourses should be fenced off from stock and alternative sources of water provided.

- Greater numbers of animals in the uplands results in a greater delivery of faeces and urine. **Runoff** will transport these downslope, and there may be a greater nutrient input to water courses, resulting in eutrophication. There may also be a greater risk of water-borne pathogens entering the potable water supply (e.g. cryptosporidium).

It is very difficult to pin a cost to such diverse impacts. Their implications are not just financial, but include aesthetic and wildlife considerations. The costs could be described as being a) direct (e.g. impact on flood defences); b) indirect (e.g. the cost of agri-environmental grants), and c) non-quantifiable (e.g. the loss of wildlife, aesthetic appeal).

The Royal Commission on Environmental Pollution (1996) describe some of the off-farm and on-farm costs of lowland soil **erosion**. The average cost of lost output as a result of soil **erosion** is estimated to be less than £100 per farm, far lower than off-farm costs. An example of the scale of difference between off-farm costs (higher) and on-farm costs is shown by £420,000 of damage to local property in Rottingdean, (E. Sussex) in 1987, during an **erosion** event. Farm losses in the same event were £13,000. The NRA have reported that in 1992 the remedial costs for the pollution of water courses and groundwater from **runoff** and **erosion** were around £4 million a year. Evans (1996) gives an estimate for the cost of water related pollution incidents in the uplands as £2 million and an estimated total cost of the impacts of **erosion** in the uplands and lowlands as £23 million to £50 million per year.

Evans (1996) makes an estimate of the cost involved in fencing off stock from actively eroding moorlands to allow vegetation to colonise exposed peat and mineral soils. It is likely that many hundreds of kilometres of fencing would be needed to reduce the risk of **erosion**. However, by excluding stock from these areas, they may become concentrated elsewhere and initiate **erosion** there.

Finally in all aspects, the old adage "prevention is better than the cure" is correct. Sustainable development appears to be the message put across by many of the major institutions and agencies. However, the current situation in Britains uplands is not deemed to be sustainable, and the time move towards a sustainable future is now.

PART 5

6. RECOMMENDATIONS FOR FUTURE WORK

6.1 Work Required

- Further research is required to quantify the impacts of grazing. There is a need for integrated studies to be undertaken which will link work connected with excluding stock and the revegetation of bare ground, to **runoff** and climate studies.

- There is a lack of quantitative evidence and any future work which proposes methods of best practice should be based on quantitative evidence. Currently, conceptual models are available to study **erosion**, these identify processes based on anecdotal and observational evidence. In order for these to be converted into mathematical models, high quality geographically extensive and temporally intensive data-sets are required to calibrate such models.

- There is a need to identify data-sets which are already available, and could be potentially useful.

- Different methodologies should be used to assess and analyse such data-sets. If the data is not available, its collection must be initiated now (as it cannot be re-invented).

- Therefore, there is an urgent need to set up fully instrumented catchments to obtain comprehensive data-sets for realistic environmental modelling and management.

6.2 Work in Progress

Also refer to Appendix 2. Of this report.

- In the 1990s, cheap processing power has become readily available with the consequence that electronic data collection has become highly cost effective. This will certainly be the primary source of the high quality data that is needed to pursue predictive modelling for the remediation of **erosion** impacts.

- This would facilitate the intensive assessment of wide spatial areas, sampling rates at parts of a second. Given the effect of flood impacts on equipment, the **attrition** rate of instrumentation is now acceptable, as the manufacturing cost of this type of instrumentation is reduced. Therefore, this type of assessment is now affordable.

- The project team are currently undertaking research which utilises such technologies and principles.

- Dr. S Boult (Intelisys Ltd, Manchester) is currently looking at the effects of big floods upon commercially important game fisheries in the Western Isles. The project is essentially a quantitative comparison of catchments (which are being continually measured for turbidity, dissolved solids, discharge and precipitation). The Western Isles Fishery Trust, N. Harris

Estate are producing man-power to undertake post-flood remediation, the efficiency of which, will be assessed.

- APEM are currently investigating the impact of stock exclusion and grazed vegetation recovery upon the ecological components of 1st order stream systems in Coverdale, Yorkshire Dales. It is hoped that the Coverdale catchment will be instrumented to the same degree as those in the Western Isles.

- Both studies are progressing towards having distributed networks of **erosion** monitoring devices on moortops and slopes.

- APEM and Intelisys are undertaking a 3-year monitoring project for the Environment Agency, NW Region. The Sustainable River Management Project will quantify the effect heavy grazing and poaching has upon river bank erosion and river channel sediment budgets. This will be undertaken along river reaches in the River Eden, River Ribble and River Weaver catchments, the top km of each site being vegetated, ungrazed and stable and the bottom km being grazed, poached and eroded. The bottom km will be fenced prior to monitoring to exclude grazing animals. Rates of bank erosion will be measured using erosion pins and electronic distance measurers and the in-channel suspended sediment flux will be recorded using an array of sensors and loggers. In addition, cross-sectional geomorphological surveys will be carried out as will River Habitat Survey and Habscore. The project will have a multimedia output, using cd-roms and interactive photo imagery to publicise the severe impact uncontrolled grazing has on river banks and the in-channel environment. Similar programmes of monitoring work need to be initiated in upland areas.

- MAFF have recently initiated a R&D study which will focus on the impacts of grazing on moorlands. However, it is not extending its study to other environments, which is desperately required. It is possible that **runoff** rates are increasing most on the steeper slopes (the in-bye land). This must represent a considerable proportion of the overall land area in the uplands and therefore has a potentially greater impact than **runoff** originating from the relatively flat moorlands. Removing sheep from the moorlands may well put additional pressures upon the inbye land.

6.3 General Recommendations

- Due to the severity of the **erosion** problem in the UK uplands, some steps need to be taken immediately in areas which are the most severely damaged or considered to be at extreme risk. This could be in the form of a simple system for recognising and remediating **erosion** which could be implemented by the busy landowner or farmer.

    - For example, the design of an index of **erosion** which is applicable on the ground where indicators (such as sheep scrapes per ha) show a vulnerable site, and therefore qualify it for rapid remedial action.

    - For example, there is a need for the re-vegetation of bare ground; the prime concern is the establishment of any vegetation prior to any attempt at manipulating it for desired species. This can be undertaken once stability has been achieved. Stock should be excluded from such areas.

PART 6

7. CONCLUSIONS

7.1 Introduction

- **Erosion** is a process which has been occurring throughout geological time, long before the presence of man. It is a series of processes which involve the breakdown of solid material and its transportation. The rates of **erosion** and **runoff** can be said to result from complicated interactions between physical, chemical and biological systems operating within drainage basin units.

- This Research and Development study has been primarily concerned with the potential relationships existing between grazing animals in upland areas and rates of **runoff**. Stocking levels, particularly of sheep, have increased significantly over the past 50 years. It is highly possible that this is contributing to increased runoff rates in upland areas for a variety of reasons that the report explores. The report includes an assessment of other land management issues which occur in the same locality as grazing, and which may also be contributing to the perceived problems.

- Evidence points to a realistic link between the high levels of grazing witnessed today and enhanced upland erosion and runoff. For example, Evans (1990), after examining the effect of a rise of sheep numbers in the Peak District, showed that the resultant intensive grazing pressure led to the exposure of bare soil and a compaction of the soil surface. These conditions promote both the erosion of soil material and an increased proportion of runoff. In America, Owens, Edwards and Van Keuran (1997), using experimental plots found that if a decrease in the intensity of grazing is initiated, then there will be a dramatic reduction in the yields of sediment and runoff from the grazed pastures. This is especially notable where grazing animals are not left to over-winter on moortops and slopes. Such academic evidence is supported by a wealth of anecdotal and empirical evidence.

- The impact of grazing animals, particularly in the uplands, is a topic which has been the focus of research for many academics and agencies for a number of years. It is a contentious subject as it potentially points the finger of blame at farmers and land managers and the systems of grazing utilised. In fact, the increases in stocking levels has been fuelled by the Common Agricultural Policy (CAP).

- In all aspects of upland management, good communication and interaction between organisations, farmers and landowners must be achieved. The way forward is through a partnership approach, and organisations such as the National Sheep Association and the National Farmers Union are more than keen to become involved in any future upland management objectives.

- The decline in the quality and diversity of Britain's uplands is reversible if action is taken immediately. However, some of the steeper areas (eg in the Lake District and North Wales) have already lost their vegetation and are now losing their soil at a rapid rate. The extent of these denuded areas is likely to increase with stock still grazing them, and ultimately, the sustainability of the farming community is at risk. Appropriate action is urgently required.

- CAP Reform will occur in some form and opportunities should not be missed to:

  - Increase the proportion of agri-environment payments in the uplands.
  - Change the headage payments to area payments.
  - Provide incentives to remove stock from the uplands during the winter.
  - Provide incentives to improve shepherding.
  - Provide incentives to protect common land.

- Agri-environment schemes could also include more grants to promote best practice, for example, protecting riverbanks from stock, blocking moorgrips.

- Whole catchments or areas (eg LFAs, National Parks) should be designated as sensitive areas or ESAs and be eligible for agri-environment scheme support. The whole farm approach should also be encouraged.

- Support for farm incomes and rural communities is essential if the present decline in upland farming is to be reversed.

7.2 Policy

- This project indicates that the underlying root of the problems arising from intensive grazing occur as a result of grazing management systems which are perpetuated by the CAP and the subsidy system it offers. In addition, other aspects of upland management, coupled with natural physical systems (e.g. climate, **weathering**, slope stability), cause and/or enhance the **erosion** of the uplands and the rate of **runoff**.

- There are approximately 40 million sheep in the UK, actual numbers may be declining slightly, but they are still far greater sheep now than have occurred in the past. The subsidies that arise from the Common Agricultural Policy and other agricultural schemes have encouraged this high level of stock. Unfortunately, farming does not have the human resources as it used to have and there are not enough farm employees to maintain the levels of shepherding needed. In the past, shepherding would prevent herds causing the concentrated grazing-out of vegetation and trampling damage witnessed today (pre-war ratio's of shepherds to sheep were 1:2-300, today the ratio can be as large as approximately 1: 1500; Spensley, pers. Comm.). In the past, shepherding would prevent herds from causing the concentrated grazing-out of vegetation and trampling damage witnessed today.

- In addition, the average age of sheep farmers is increasing all the time, and sadly recruitment into this type of farming appear to be in decline. With no support at all, it is likely that upland farming will not survive, and this would likely to produce negative consequences for the local economy, conservation and recreation.

- It is imperative that any potential changes in policy should support the rural upland community, not undermine it, perhaps by reducing the subsidy for stock and promoting environmental management through the use of alternative subsidies (perhaps based on an area payment instead of a headage payment, refer to Appendix Three). However, the international significance of many of Britain's sheep breeds to the sheep industry requires that some form of support for sheep farming in the uplands be maintained, not removed.

7.3 Impacts of Upland Management.

Research highlighted in this report shows that the level of **erosion** occurring in many upland areas is highly significant and is increasing with time. Habitats and species are threatened and there are severe water management implications, especially where **runoff** increases.

7.3.1 Grazing

- There is an obvious need for something to be done about the impacts of grazing. However, a balance needs to be attained ensuring that the rural economy in upland areas is not disadvantaged by changes to agricultural policy and subsidy systems, and the traditional landscapes enjoyed by many people (many in our most beautiful areas such as the National Parks) are maintained.

- A stocking density can be set at a level where the vegetation and soil can withstand the impact of grazing animals. This is reflected by different definitions of "**overgrazing**" which: a) exceeds the ecological **carrying capacity** of the land and b) exceeds the livestock **carrying capacity** of the land. In addition, **erosion** can occur where stocking densities are lower than those which could cause ecological **overgrazing**, for example where concentrations of grazing animals cause local hotspots of **erosion**.

- The total number of grazing animals coupled with the area of grazing land available controls the density of grazing. The problem of grazing induced **erosion** is enhanced when the period of time upland areas are exposed to the impacts of livestock is extended over the winter, especially when overwintering in the valley bottoms is reduced. This is usually achieved through the use of feeds, driven up to the moortops by all-terrain vehicles. Unfortunately, winter is the time of year where the plants do not grow and therefore, grazing will remove the vegetation more quickly than it can regrow. Thus, all the benefits of the vegetation (including its **erosion** and **runoff** retardence as well as insulation properties) will be lost.

- Where grazing is maintained on eroding land, any recovery of existing vegetation and revegetation of bare areas will be significantly inhibited, and **erosion** and **runoff** enhanced. Therefore, in such cases the exclusion of stock is the only possible **solution**. If this approach were to be applied to all moorland areas without an overall reduction of stock numbers, then the density of animals grazing on slopes and low gradient land would be dramatically increased. It is the slopes which have the greatest potential to suffer from increased **erosion** and **runoff** due to the greater influence of gravity on mass movement and transport processes.

Therefore, the intensive grazing pressure exerted by stock on slopes would undoubtedly have greater deleterious consequences than on the moortops.

- In addition, the following conditions will potentially increase runoff:

- The reduction in biomass or surface area of heather/grassland due to intensive grazing pressure can lead to a reduction in the water storage capacity of the surface vegetation (e.g through evapotranspiration).

- A reduction in root depth and density in tightly grazed turf can reduce soil porosity and therefore reduce the volume of rain required to saturate the soil and cause runoff.

- Healthy robust vegetation provides good insulation against extremes of temperature (frost and heat). Frozen or sun-baked ground is likely to lead to increased runoff.

- Robust vegetation can store and insulate snow and therefore, the time taken for meltwater from snow to reach watercourses can be increased, reducing the flood and erosion hazard.

- **In all aspects of upland management, but especially where the farming community is involved, good communication and involvement between organisations and farmers/land owners must be achieved. The way forward is through a partnership approach, not a confrontational one. Organisations such as the National Sheep Association and the National Farmers Union are more than keen to become involved in any future upland management objectives (refer to Appendix Three).**

7.3.3 Burning

- In the majority of situations, controlled burning (used in heather management and the creation of fire breaks) will create very few problems. However, when fires become uncontrolled, either as a result of accidental or deliberate action, upland **erosion** and **runoff** can be significantly affected. The result is an ashing of peat and vegetation, and the creation of a barren environment, hostile to recolonisation by plants.

- When this occurs there is a far greater potential for the **erosion** of the ash and underlying mineral soils by wind and water. Evidence also suggests that severe burning affects the water storage capacity of peat, and **runoff** may therefore be enhanced.

- If sheep or other grazing animals are present, then recovery and revegetation may not occur and **erosion** can be accelerated. In fact, sheep appear to be attracted to areas which have been burnt as new plant growth can be stimulated by burning, providing choice foods. In addition, the perimeters of the burnt land provide an easy access to the non-burnt vegetation.

- When such fires occur, stock should be excluded until recovery begins. If at all possible, revegetation programs should be initiated.

7.3.4 Bracken control

- There are a multitude of health reasons why bracken control is desirable including the health of livestock and humans. In addition, encroachment effectively reduces the area available for grazing, enhancing pressure exerted by stock in other locations.

- The removal of bracken (usually achieved by mechanical or herbicidal means) should be followed by a programme of aftercare (e.g. the exclusion of stock, removal of the litter layer and revegetation) to prevent the development of potentially erosive environments.

- Trees, if they can be established, will provide an effective solution to the bracken problem once the trees are large enough to shade the bracken out. Trees will also grow on and stabilise steep slopes and could be encouraged by the National Park Authorities using woodland grant schemes to limit erosion in gills and gullies.

7.3.5 Recreation

- The uplands are a natural focus of attraction for many people and **erosion** occurring as a result of recreation is obviously visual and has made many headline features in newspaper and journal reports. However, the spatial extent of eroding footpaths and bridleways is less significant than the vast number of eroding sheep tracks, sheep scrapes and scree.

- Any additional pressure exerted upon vegetation, scree and soil by humans through recreational activities can cause a stressed environment to become critical and its failure can quickly ensue. Incised footpaths can also provide excellent routeways for **runoff** to follow, adding to the sediment transport budget and causing additional erosion.

- If some of the money spent on footpath repair were to be directed into stock control (e.g. shepherding, fencing) then the overall **erosion** problem could actually be reduced. Reducing stocking rates over areas as a whole is also likely to increase the success rate of footpath repair work where reseeding has been required.

7.3.6 Drainage

- Until 1985, grants were available to undertake upland drainage (moorgripping). This was intended to "dry out" wet moorland to promote better grazing conditions. However, moorgripping has been shown to be ineffective in lowering the water table.

- In fact, moorgripping exacerbates **runoff** and **erosion** as the runoff rate increases once the water is in the grip itself. The water and sediment is efficiently conveyed to arterial watercourses causing more erosion there. Anecdotal evidence suggests that catchments which still have functional grips tend to be very "flashy", and often suffer from dramatic floods. Many of these grips have become significantly eroded and enlarged over the years.

- Upland drainage has serious negative implications for surface-water collection and the recharge of groundwater resources as the residence time of rain or snowmelt on the moortops is drastically reduced by the presence of moorgrips.

7.6.7 Afforestation

- Forests can reduce **erosion** within catchments and streams due to protection by the canopy and surficial litter layer. **Runoff** can also be reduced in a similar manner, as forests have a high evaporation rate and, by intercepting rainwater with foliage, storm discharge peaks can also be reduced.

- However, forestry drainage does increase **bedload** transport if plantation drainage **channels** become eroded. Such drainage **channels** have been found to reduce response times to rainfall events and increase peak discharges, thereby causing **channel erosion**.

- In addition, where clear-felling occurs, the soil is disturbed and the absence of tree canopy and understory encourages the transport of soil material during rain events.

7.3.8 Air pollution

- Air pollution, particularly acid precipitation, has a deleterious effect on upland vegetation. When this is combined with the effects of grazing and other upland management practices, it can enhance the potential for **erosion** and **runoff** as the all-important vegetation cover may be lost.

- In the past 100 years, air pollution has created areas of bare uplands (e.g the Peak District during the Industrial Revolution) without the added impacts of other land practices. The extent of this today is not known, although areas of severe upland **erosion** which are not affected by air pollution have been identified (e.g. the Lake District), suggesting local variations in effect.

7.4 The Spatial Extent of the Problem

- The case studies presented in this report represent a coarse assessment of the spatial extent of upland **erosion** occurring in England and Wales. Regions which are suffering from upland **erosion** include: Lake District, Snowdonia, Brecon Beacons, Peak District, Pennines, Yorkshire Dales, North York Moors, Dartmoor, Exmoor. In addition, large areas of the country also suffer from soil **erosion** from arable land.

- All the National Park Authorities involved in the questionnaire survey perceived that they had problems resulting from upland **erosion**; in many cases these were caused by grazing and trampling. Many other individuals and organisations voiced similar opinions.

- **Every upland region of the country visited gave cause for concern with regards to either loss of soil or vegetation, and/or the effects of flashy catchments causing flooding, the destruction of habitats or negative impacts on water quality.**

- **The number of similar sites found to be suffering from one or many erosion and runoff impacts (caused by a number of different factors) is of a scale which demands instant attention and action.**

7.5 The Future

- Offer management agreements to graziers on specific catchments at risk, for the keeping of a sustainable and agreed number of animals on the site.

- Offer alternative subsidies to those currently available to reduce stock densities and promote the recovery of eroding sites.

- Exclude stock from areas which have areas of no vegetation or eroding soil to allow revegetation and recovery to occur (including areas suffering from fire, bracken control, clearfelling etc).

- Limit/cease the overwintering of stock on moortops and slopes, preventing the denudation of vegetation during a period of no-growth.

- Initiate a programme of education and integration to highlight the problems and objectives of sustainable upland management, and to involve the farmers, conservation bodies and statutory organisations in joint management policies. This can be achieved through using demonstration sites and a series of workshops.

- Initiate a programme of quantification. Instumented catchments are required to collect datasets that are viable for use in mathematical models which can provide results that are valid for management decision making.

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APPENDIX ONE

DIRECTORY OF RELEVANT INDIVIDUALS AND ORGANISATIONS

Anne Sansom. Environment Agency, North East Region. Leeds.

Martin Price. Environment Agency. Welsh Region. Bangor.

Richard Smith. Environment Agency South West Region. Exeter.

Bob Huggins. Environment Agency South West. Blandford.

Jim Walker. Environment Agency North West. Warrington.

Brian D'Arcy. Scottish Environmental Protection Agency. Edinburgh.

Jim Loxham. National Trust. Cumbria.

Rob Jarman. National Trust. Headquarters. Cirencester.

Alan Drewitt. English Nature. Peterborough.

Paul Carling. University of Lancaster. Lancaster.

Steve Boult. University of Manchester.

J. Milne. Herbivore Foraging Group. McCauley Land Use Institute. Aberdeen.

Malcolm Newson. University of Newcastle. Newcastle.

Des Walling. University of Exeter. Exeter.

Bob. Evans. Cambridge University. Cambridge.

Alan Woods. Country Landowners Association. London.

Grahame Brooks. Centre for Agricultural Evaluation Studies, Wye College, University of London.

Caroline Steele. The Wildlife Trusts.

Martin Gillibrand. The Moorland Association.

David Noble. Association of Drainage Authorities.

Arlyn Rickard.West Country Rivers Trust..

Ed. Moltby. Wetlands Ecosystems Research Group. Royal Holloway University. London.

Dave Newbourne. Game Conservancy Council. Gunnerside Estate. Swaledale.

Julie Smith. ADAS. Wolverhampton.

Richard Spensley. National Sheep Association. Leyburn.

Kevin Pearce. National Farmers Union. York.

Miles Fulger. Yorkshire Water. Bradford.

Kate Snow. North West Water. Warrington.

Roy Roads. North West Water. Warrington.

John Steele. RPS Clouston. Abingdon.

Terry Wells. Moor House National Nature Reserve.

Judy Palmer. Dales National Park Authority. Grassington. Yorkshire.

David Sykes. Dales National Park Authority. Grassington. Yorkshire.

Sue Rees. North York Moors National Park Authority. Helmsley.

Jan King. Brecon Beacons National Park Authority. Brecon.

John Ellis Roberts. Snowdonia National Park Authority .

Rhodri Thomas. Peak District National Park Authority. Bakewell.

Mrs S. Hasle. Dartmoor National Park Authority. Newton Abbot.

Keith Bungay. Exmoor National Park Authority. Dulverton.

John Toothill. Lake District National Park Authority.

Graham Taylor. Northumberland National Park.

G.A Tingley. The Centre for Environment, Fisheries and Aquaculture Science. Lowestoft.

Steven Gleave. MAFF. London.

Harriet Orr. HYSED. University of Lancaster. Lancaster.

David Hughes. University of Lancaster.

APPENDIX TWO

DIRECTORY OF RELEVANT PROJECTS

Best Management Practices to Reduce Diffuse Pollution from Agriculture. Environment Agency. R&D Project AO7(94)07.

CALSITE. Soil Erosion and Sediment Yield Prediction Software. HR Wallingford. Wallingford.

EC Sheepmeat Regime and the Natural Environment. SAC . Auchincruive. Ayr.

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Impact of Climate Change on Scottish Agriculture. Scottish Office Agriculture and Fisheries Department.

Land Care Project. Environment Agency.

Land Use Project. Environment Agency.

Monitoring Landscape Changes in the National Parks of England and Wales. Countryside Commission.

Moor Care Project. Dartmoor National Park Authority.

Moorland Regeneration Programme. North York Moor National Park Authority.

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Short Geomorphological Evaluation of River Trannon Focus Site. Environment Agency. North West Region.

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Vegetation for the Control of Water and Wind Erosion. AFRC/CIRIA.

APPENDIX THREE

COMMENTS FROM A SHEEP FARMER

These are personal comments extracted from a letter written by Richard Spensley, the Chairman of the Northern Branch of the National Sheep Association, June 1997.

The UK uplands have over the centuries been subject to action and reaction, be it recreation or farming. Should we not be trying to balance all interests?

We heard at the workshop (part of this R&D project) of utopian solutions to erosion and moorland management with little regard to the implications of these solutions on the "stratified sheep industry". The social structure of rural communities, the hill farmer and shepherd, are in danger of becoming a rare species just as much in need of nurturing as the environment in which they work.

The day-to-day maintenance of upland Britain relies on a viable agricultural use. The cost of this upkeep without agricultural input would be horrendous.

The only way to implement any of these proposals on a beneficial scale would to be to offer management agreements to graziers on specific catchments at risk; presently on a voluntary basis, for the keeping of a sustainable and agreed number of animals on the given site.

APPENDIX FOUR

COLOUR FIGURES

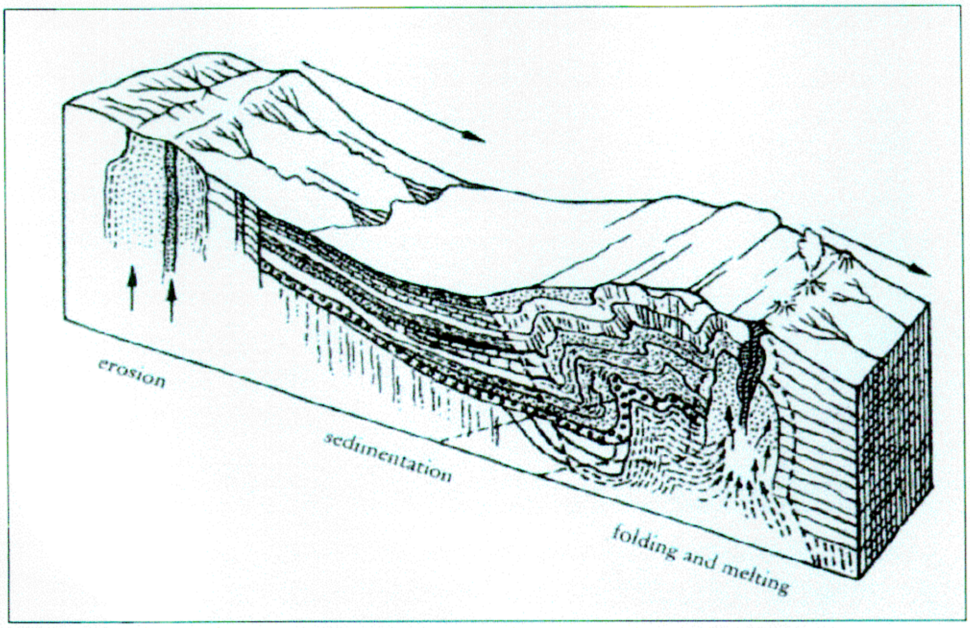

Figure 1. The cycling of rock material in the upper crust (From Lauterbach, 1983).

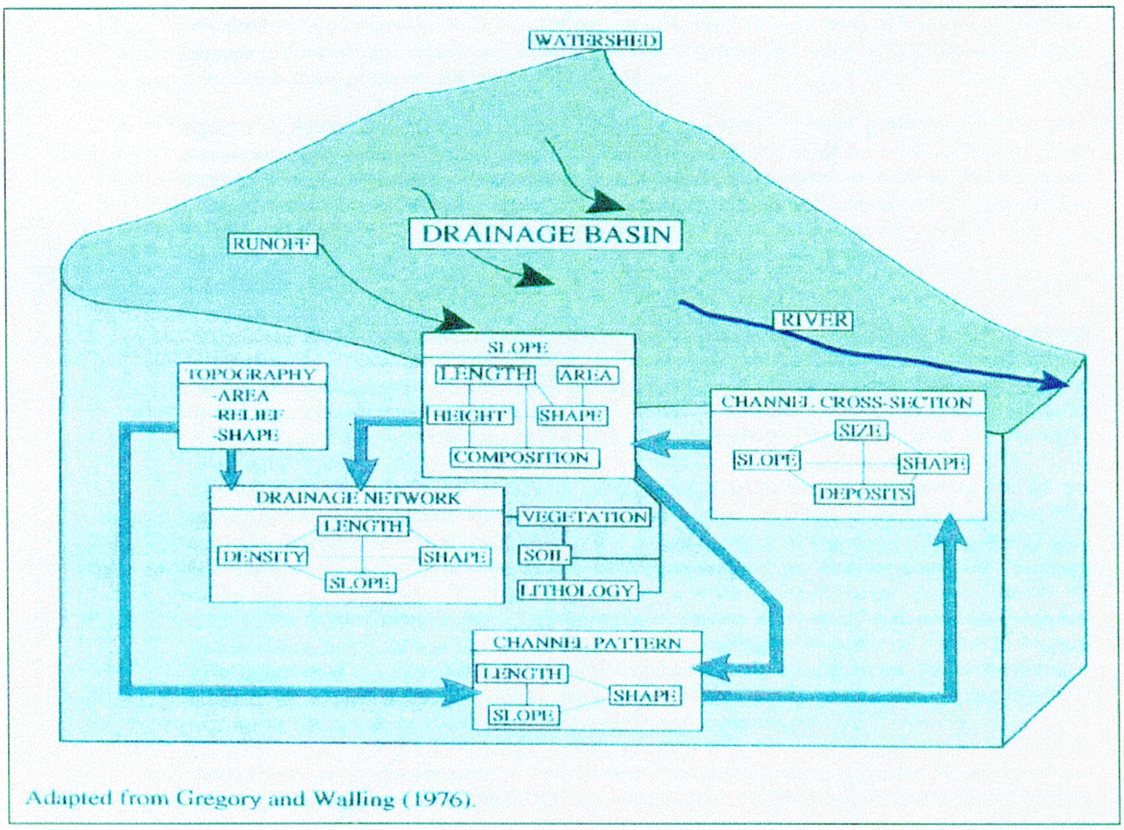

Figure 2. The interrelationships between drainage basin systems.

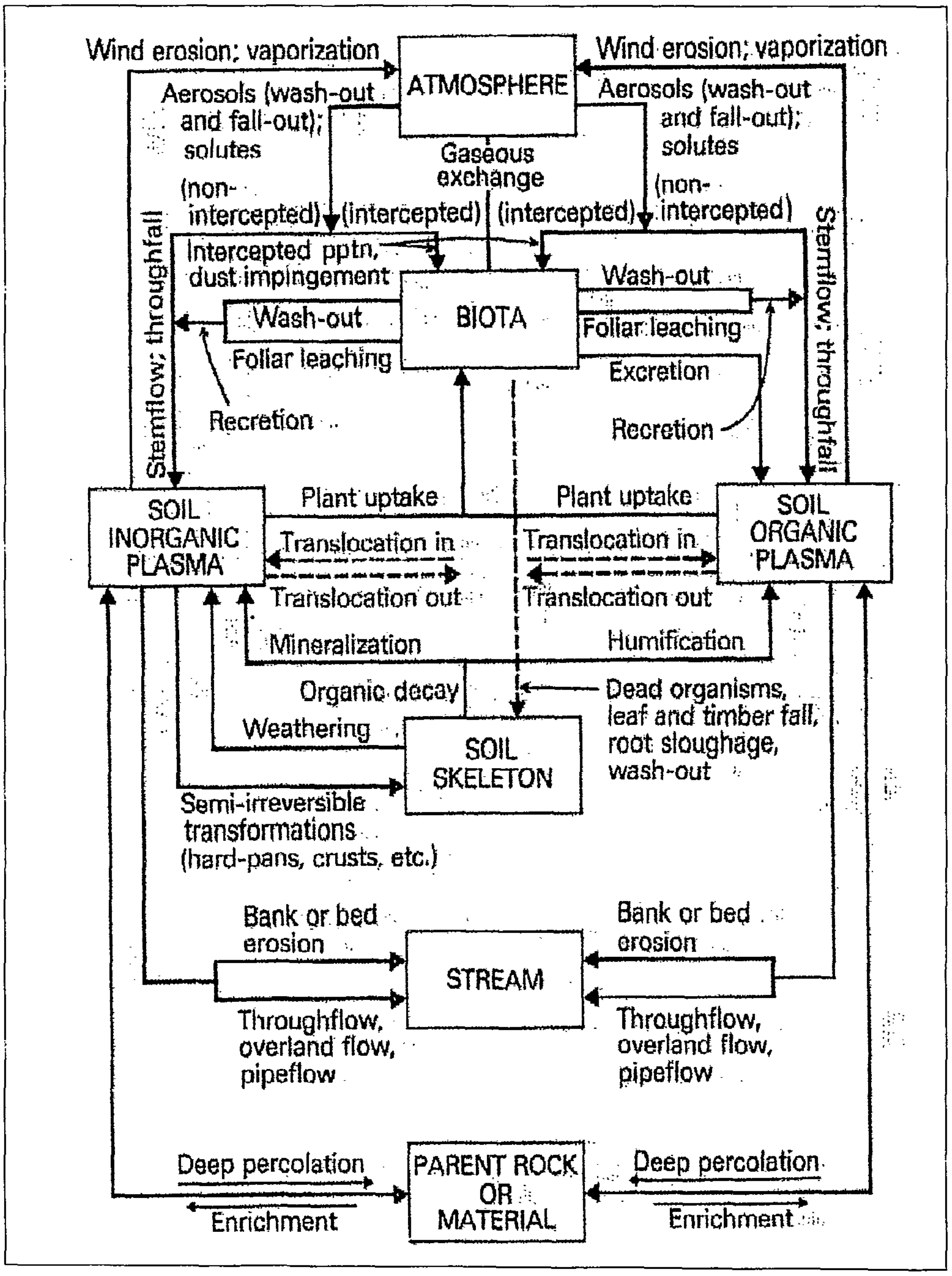

Figure 3. The complexity of a catchment biogeochemical cycle (from Huggett, 1980).

Figure 4. Frost-shattered blocks of rock.

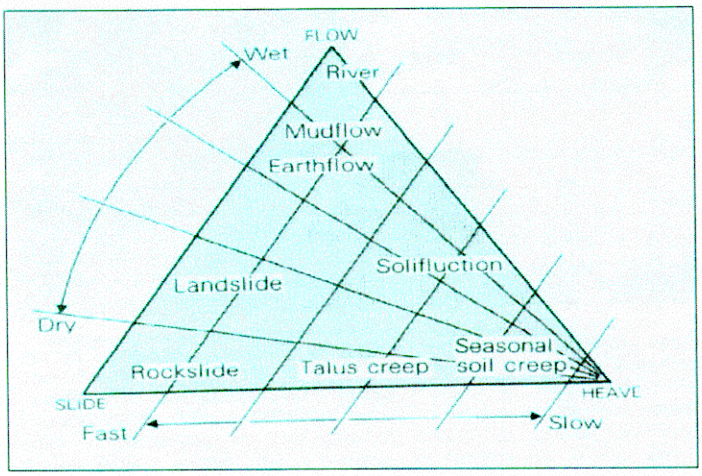

Figure 5. A classification of mass movement processes on slopes (After Carson & Kirkby, 1972).

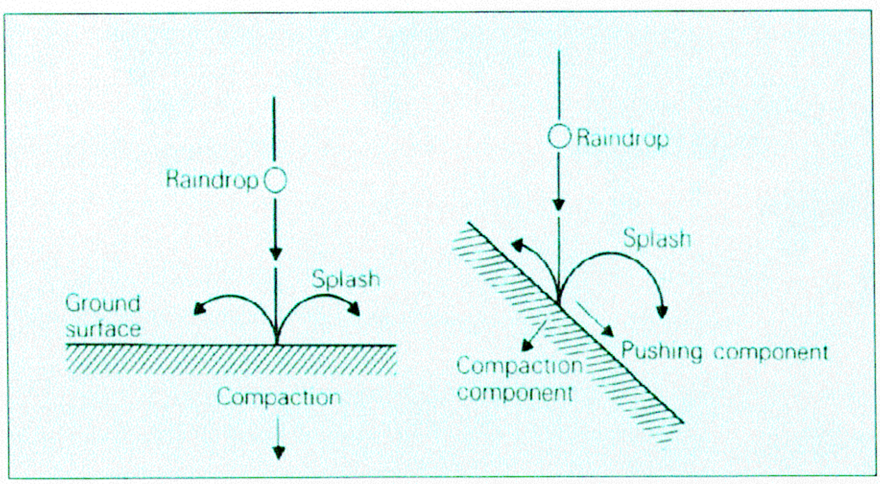

Figure 6. The effect of rainsplash on slopes. Net erosion occurs in the example on the right and accelerates as slope angle increases.

Figure 7. Surface runoff and puddling of water.

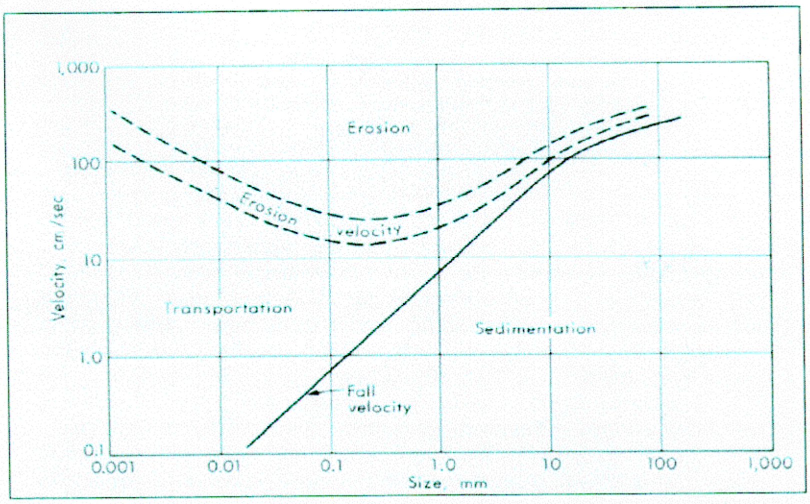

Figure 8. The relationship between erosion, transportation and sedimentation (After Hjulstrom, 1935).

Figure 9. A Lake District river in spate.

Figure 10. Corrasion and cavitation forming potholes

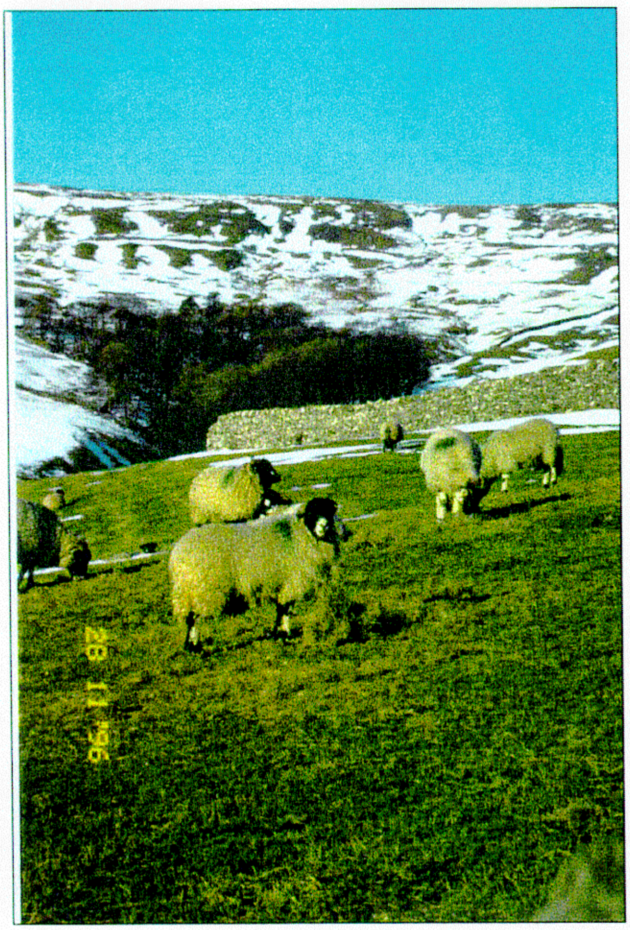

Figure 11. Greater numbers of sheep are overwintered and foddered in the uplands today than in the past.

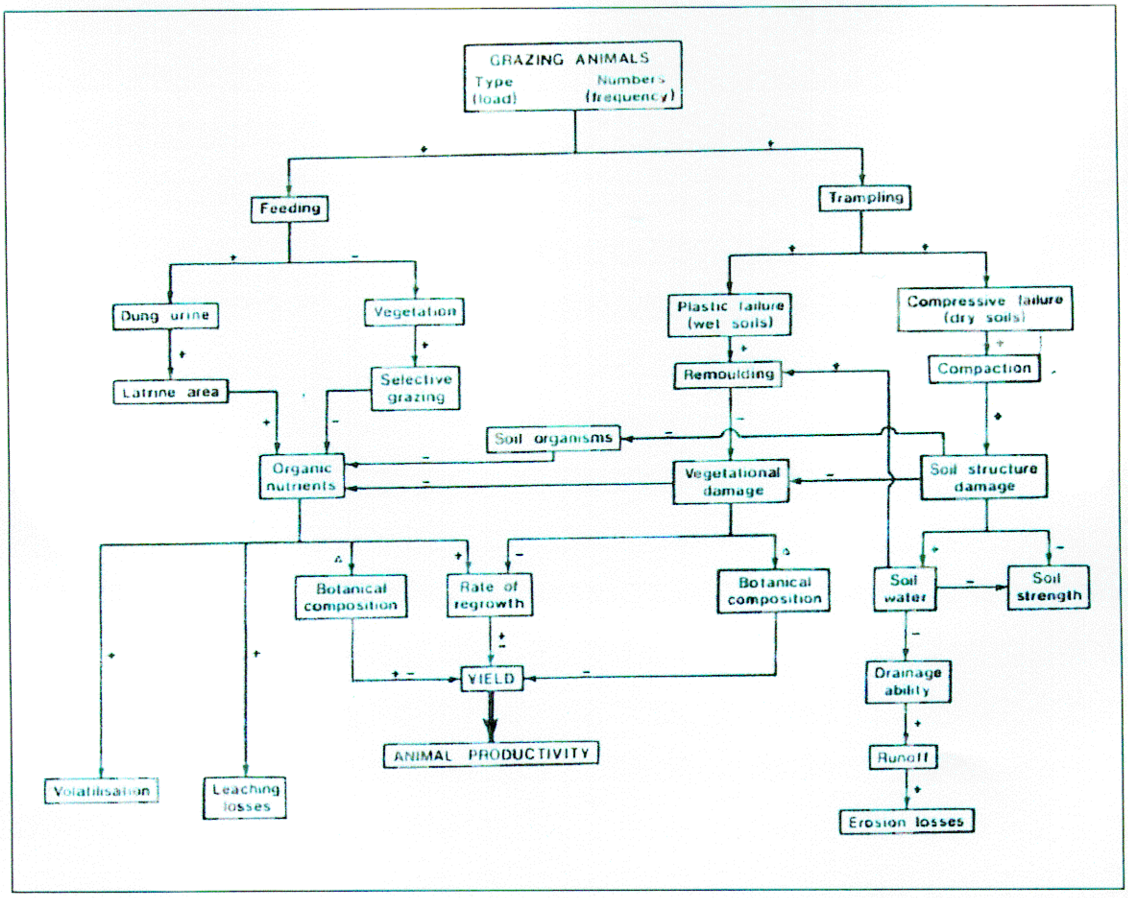

Figure 12. A model of the effects of trampling and grazing on soil, herbage and animals. (From Salmon, 1980). + is process or factor leading to an increase, - is a process or factor leading to a decrease, ▲ is a process or factor leading to a change.

Figure 13. Trampling and puddling resulting in erosion, increased runoff and possible contamination of water by cryptosporidium.

Figure 14. Effects of excluding stock from vegetation, the vegetation inside the exclusion plot is more robust and dense than outside.

Figure 15. River bank erosion in non-fenced areas. Where fencing is absent, stock can poach and erode the banks.

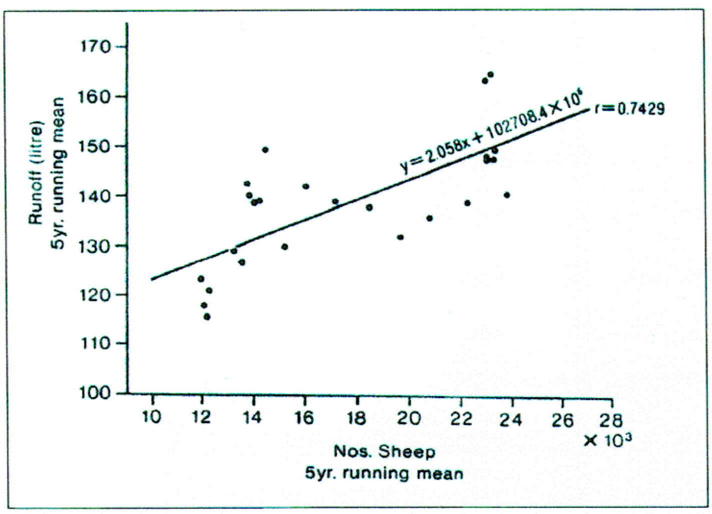

Figure 16. Runoff and sheep numbers in a North Derwent catchment. Evans, 1996.

Figure 17. Burning as a management tool, the freshly burnt heather is on the left.

Figure 18. The risk of fire is great in many upland areas, especially where people are found.

Figure 19. The appearance of bracken dominated slopes in the winter.

Figure 20. Areas of bare ground are left after bracken has been cleared.

Figure 21. The effects of recreational erosion on footpaths.

Figure 22. A moorgrip which is eroding beyond the fence-line as a result of the impact of grazing animals.

Figure 23. The impact of free range piggeries, Devon.

Figure 24. The rilling of slopes, Devon.

Figure 25. The runoff of water and soil into a stream, Devon.

Figure 26. Grazing on the Wiltshire downs.

Figure 27. Recreation erosion on the Langdale Pikes, Lake District.

Figure 28. Footpath erosion in Great Langdale, Lake District.

Figure 29. Stable boulderfields on the slopes of Helvellyn, Lake District.

Figure 30. Unstable eroding scree on the slopes of Helvellyn, Lake District.

Figure 31. Eroded scree being transported down Dry Gill, Lake District.

Figure 32. The impact of the movement of material along Dry Gill, Lake District.

Figure 33. Full blown upland sheet erosion on Lingmell, Lake District. A terminal situation.

Figure 34. Longmoor Common, not grazed, Lake District.

Figure 35. Kinneside Common, intensive grazing, Lake District.

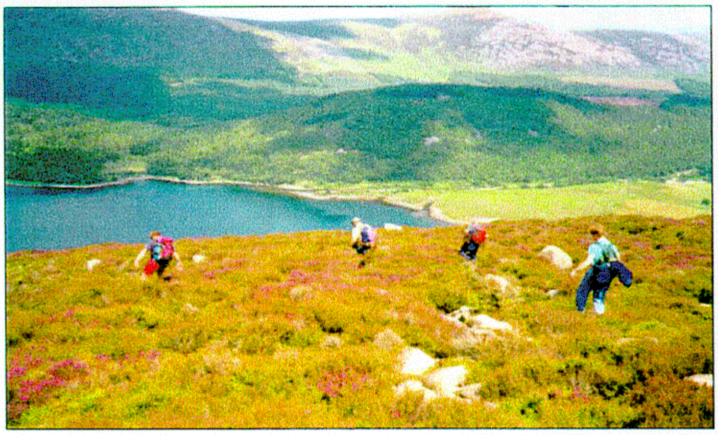

Figure 36. The Side, low levels of grazing resulting in robust vegetation and stability.

Figure 37. Side Wood, Lake District.

Figure 38. Rabbit erosion in Littondale, Yorkshire Dales.

Figure 39. Erosion of riverbanks where grazing occurs, Yorkshire Dales.

Figure 40. An abandoned river channel, the product of channel migration, Yorkshire Dales.

Figure 47. Heather management and bracken control can result in large surface areas of the uplands being temporarily devoid of vegetation cover, Peak District.

Figure 48. Footpath erosion in the North York moors.

Figure 49. Vegetation recovering after bracken control, North York Moors.

Figure 50. Islands of vegetation, isolated by eroding moorland. North York Moors.

Figure 51. Gully erosion along a long-distance footpath, North York Moors.

Figure 52. Grazed upland moors, Snowdonia.

Figure 53. River bank erosion, Snowdonia.

Figure 54. River bank erosion in Snowdonia, notice the poaching and erosion around the ring-feeder.

Figure 55. Sheep congregating at a ring feeder on moorland, causing poaching and erosion. Snowdonia.