Review of Blanket Bog Management and Restoration

TECHNICAL REPORT TO DEFRA

PROJECT No. CTE0513

H O’Brien, J C Labadz & D P Butcher
Nottingham Trent University
School of Animal Rural & Environmental Sciences
Brackenhurst
Southwell NG25 0QF
jillian.labadz@ntu.ac.uk
01636 817017
CONTENTS
1 Introduction ................................................................................................................................. 9
1.1 Principal Aims .......................................................................................................................... 9
1.2 Objectives ............................................................................................................................... 9
2 Methodology ............................................................................................................................... 10
2.1 Published Literature ................................................................................................................. 10
2.2 Grey Literature ....................................................................................................................... 10
2.3 Interviews .............................................................................................................................. 10
3 Blanket Bog: Definition, Classification and Characteristics .................................................. 12
3.1 Introduction ............................................................................................................................ 12
3.2 Definition of Blanket Bog ........................................................................................................ 12
3.3 Classification of Blanket Bogs .................................................................................................. 14
3.4 Blanket Bog Formation ............................................................................................................ 16
3.5 Hydrology of Blanket Bogs ...................................................................................................... 18
   3.5.1 Infiltration and infiltration-excess overland flow .............................................................. 19
   3.5.2 Saturation-excess overland flow ....................................................................................... 20
   3.5.3 Pipe flow and macropore flow ......................................................................................... 20
   3.5.4 Subsurface flow through the peat matrix ........................................................................ 21
   3.5.5 Runoff generation in blanket bogs ................................................................................... 21
3.6 Peat Accumulation ................................................................................................................... 22
3.7 The Age and Origin of Blanket Bog in the British Isles .......................................................... 23
3.8 UK Distribution of Blanket Bog .............................................................................................. 24
3.9 UK Status – Protection and Designation ................................................................................ 25
3.10 Common Standards Monitoring and Condition Assessment .............................................. 26
   3.10.1 Common Standards Monitoring ..................................................................................... 26
   3.10.2 Condition Assessment .................................................................................................... 27
4 Management and Values of Blanket Bog .................................................................................. 28
4.1 Introduction ............................................................................................................................ 28
4.2 The Value of Peatlands .......................................................................................................... 28
   4.3 Ecosystem Services of Blanket Bog ..................................................................................... 29
      4.3.1 Regeneration and Production Services of Blanket Bog ................................................ 30
         4.3.1.1 Production: Harvesting of Peat for Fuel ................................................................. 30
         4.3.1.2 Production: Forestry ............................................................................................... 31
         4.3.1.3 Production: Grazing for Livestock ......................................................................... 32
         4.3.1.4 Production: Grouse Shooting ................................................................................. 33
      4.3.2 Regulation and Stabilisation Services of Blanket Bog .................................................. 33
         4.3.2.1 Physical and Hydrological Function ........................................................................ 33
         4.3.2.2 Potable Water Supply and Water Quality ................................................................. 34
      4.3.3 Habitat Provision Services of Blanket Bog .................................................................. 35
         4.3.3.1 Wildlife Conservation Value ................................................................................ 35
      4.3.4 Cycling Services of Blanket Bog: Carbon Sequestration .............................................. 35
      4.3.5 Information/Life fulfilling Services of Blanket Bog ...................................................... 38
         4.3.5.1 Landscape, Culture and Education Values ............................................................... 38
         4.3.5.2 Visitor Access ....................................................................................................... 38
      4.3.6 Purification and Detoxification ....................................................................................... 39
5 Blanket Bog Management and Causes of Degradation ........................................................ 40
5.1 Introduction ............................................................................................................................ 40
5.2 Measurement of Blanket Bog Degradation ......................................................................... 40
5.3 Causes of Blanket Bog Degradation – Natural Factors ....................................................... 43
   5.3.1 Wind Action ...................................................................................................................... 43
   5.3.2 Frost Action ..................................................................................................................... 43
   5.3.3 Drought .......................................................................................................................... 44
   5.3.4 Flowing Water ............................................................................................................... 46
      5.3.4.1 Gully Erosion ......................................................................................................... 47
   5.3.5 Climate Change ............................................................................................................. 48
5.4 Causes of Blanket Bog Degradation Associated with Land Use and Management .................. 49
   5.4.1 Controlled Burning ........................................................................................................ 53
5.4.1.1 Methods of Controlled Burning.............................. 53
5.4.1.2 Guidelines for Controlled Burning on Blanket Bog........... 54
5.4.1.3 Extent of Controlled Burning on Blanket Bog............................. 56
5.4.1.4 Impact of Controlled Burning on Blanket Bog ................. 56
5.4.2 Accidental or Wildfires............................................. 60
5.4.3 Livestock Grazing ...................................................... 61
5.4.3.1 Overgrazing ......................................................... 61
5.4.3.2 Cattle .................................................................... 66
5.4.4 Drainage (Gripping) ................................................... 67
5.4.4.1 Effects of Drainage (Gripping) on Vegetation............... 71
5.4.5 Afforestation ............................................................. 73
5.4.6 Liming and Fertiliser ................................................. 76
5.4.7 Recreation ............................................................... 78

6 Restoration of Blanket Bog ............................................... 80
6.1 Introduction ................................................................ 80
6.2 Blanket Bog Restoration ............................................... 81
6.2.1 Objectives of Blanket Bog Restoration ......................... 81
6.2.2 Principles of Blanket Bog Restoration ......................... 81
6.3 Restoration of hydrological function .............................. 84
6.3.1 Grip/Drain blocking .................................................. 85
6.3.1.1 Methods of Grip Blocking ...................................... 85
6.3.1.2 Results of Grip Blocking ....................................... 93
6.3.2 “Natural” Gully blocking ........................................... 96
6.4 Re-vegetation of bare ground ........................................ 100
6.4.1 Lime and Fertiliser Applications ................................. 104
6.4.2 Sphagnum revegetation ............................................. 106
6.5 Prescribed burning ....................................................... 108
6.6 Grazing ....................................................................... 109
6.7 Mitigation of Forestry Practices and Restoration of Afforested Sites ... 111
6.8 Recreation .................................................................... 113
6.9 Agri-Environment Schemes and Policy .......................... 114

7 Qualitative Analysis and Evaluation of Interviews .................. 115
7.1 Introduction ................................................................ 115
7.2 The Definition of Blanket Bog and its Condition .............. 116
7.3 The Value of Blanket Bog ............................................. 117
7.4 Threats to Blanket Bog ............................................... 119
7.5 Influence over Threats to Blanket Bog ......................... 123
7.6 The Restoration of Blanket Bog .................................. 125
7.7 The Restoration of Hydrological Function and Appropriate Techniques . 127
7.8 The Monitoring of Land Management and Restoration ....... 128
7.9 Raising Awareness and Publicity .................................... 130
7.10 Knowledge Gaps and Future Research Needs .................. 131
7.10.1 Future Research Needs: Generic Questions ................. 131
7.10.2 Future Research Needs: Review of Definitions .......... 131
7.10.3 Future Research Needs: Climate Change ................. 131
7.10.4 Future Research Needs: Atmospheric Deposition .......... 131
7.10.5 Future Research Needs: Carbon Cycling ................. 132
7.10.6 Future Research Needs: Hydrological Processes ......... 132
7.10.7 Future Research Needs: Prescribed Burning .......... 132
7.10.8 Future Research Needs: Grazing ......................... 133
7.10.9 Future Research Needs: Recreation ......................... 133
7.10.10 Future Research Needs: Deforestation .................. 133
7.10.11 Future Research Needs: Restoration ....................... 133
7.10.12 Future Research Needs: Review of Monitoring Techniques ........ 133
7.10.13 Future Research Needs: Feasibility Studies ........... 134

8 Conclusions and Recommendations for Further Research .... 135
8.1 Introduction ............................................................... 135
8.2 Threats to Blanket bog ................................................. 135
LIST OF FIGURES

Figure 3.1: Conceptual Model of Peat Development (Charman 2002) .................. 16
Figure 3.2: Schematic diagram to illustrate water pathways in a blanket bog .... 19
Figure 3.3: Distribution of Blanket Bog Habitat Type in England and Wales © Crown Copyright. All rights reserved (2006) ......................................................... 24
Figure 3.3: The activities practised on blanket bog deemed responsible for causing the feature to be in unfavourable condition. (Chart and data from JNCC 2006b) .................................................................................................................. 27
Figure 5.1: Example of frost-heave and subsequent erosion of peat (Labadz 1986) .................................................................................................................. 44
Figure 5.2: Peat desiccation and cracking resulting from drought conditions (O'Brien 2006) ................................................................................................. 45
Figure 5.3: Steep gully wall of bare peat approximately 1.5m deep over paler solifluction "head" deposit in the Peak District (O'Brien 2005) ............................. 45
Figure 5.4: Gully formation in deep peat, south Pennines, UK (O'Brien 2003) .... 47
Figure 5.5: Reasons for Adverse Conditions and Percentage of Unit Area of SSSIs not meeting Favourable Condition (Adapted from English Nature 2006b) .... 50
Figure 5.6: The activities practised on blanket bog deemed responsible for causing the feature to be in unfavourable condition. (JNCC 2006) (NB this is the number of features and not percentage) ..................................................................... 50
Figure 5.6: The activities practised on blanket bog deemed responsible for causing the feature to be in unfavourable condition. (JNCC 2006) (NB this is the number of features and not percentage) ..................................................................... 51
Figure 5.7: Less Favoured Areas in England and Wales (MAGIC 2006) ............ 62
Figure 5.8: Positive and Negative Effects of a Lowering of the Water Table and Hydraulic Conductivity (from Schumann and Joosten 2006) .............................. 69
Figure 5.9: Scatterplot of estimated cumulative particulate carbon loss against the age of drainage (Holden 2006). ................................................................. 71
Figure 6.1: Eroded Grip in the Ashop Catchment, south Pennines, Derbyshire (O'Brien 2004) ................................................................. 86
Figure 6.2: Recommended Dam spacing Along a Ditch (adapted from Evans et al 2005) ............................................................................................................. 88
Figure 6.4: Plastic piling dam with lower section in centre of dam (O'Brien 2005) 91
Figure 6.5: Plastic piling constructed with a Box configuration or deep V configuration (Grove 2005) ................................................................. 91
Figure 6.8: Soil Shrinkage by Grip Block (Plastic Piling) (Grove 2005) ............ 94
Figure 6.11: Recolonisation of E angustifolium at Within Clough Gully Blocked Site (Summer 2006) (O'Brien 2006) ................................................................. 98
Figure 6.12: Vegetation cover of Treated and Untreated Plots at Bleaklow Restoration Sites (Buckler et al 2007) ................................................................. 103
Figure 6.13: Nurse crop establishment on Sykes Moor – treatment 2004 (Buckler et al 2007) ......................................................................................... 103
Figure 6.14: Nurse Crop and Heather Cover at Bleaklow Sites in 2006 (Buckler et al 2007) ......................................................................................... 104
Figure 6.15: Vegetation on Treated and Untreated Areas of Geojute (Buckler et al 2007) ......................................................................................... 104
Figure 6.16: Grass Growth with the Application of Lime and Fertiliser at Black Hill, Derbyshire (Caporn et al 2006) ................................................................. 105
Figure 6.17: Soil Respiration of Treated and Untreated at Holme Moss, October 2006 (Caporn et al 2006) ................................................................. 106
Figure 7.1: Distribution of Specialists ................................................................. 115
LIST OF TABLES
Table 2.1: Key words used in literature searches.................................................. 10
Table 2.2: Individuals and Organisations Interviewed ........................................ 11
Table 3.1: Peatland Classification (Adapted from Moore 1984)............................ 14
Table 3.2: Classification and Characteristics of Blanket Bog............................ 15
Table 3.3: Hydrological Processes and Peat Initiation (Adapted from Charman 2002) ................................................................. 18
Table 3.4: Blanket Bog Category Type and NVC type (based on Shaw et al 1996) 25
Table 4.1: Categorised Peatland Values................................................................ 28
Table 4.2: Functions, services, products uses and values of peatlands (adapted from Immirzi 1997) ................................................................. 29
Table 4.3: Ecosystem Service Categories (eftec 2005) ........................................ 29
Table 4.4: Peat cover and production of energy peat (World Energy Council 2001) ................................................................................................. 31
Table 4.5: UK Forestry Plantations on deep peat (Cannell, Dewar and Pyatt, 1993) ........................................................................................................ 32
Table 4.6: Estimates of Global Soil Carbon Accumulation (Adapted from Adams and Lioubimtseva 1999) ................................................................. 36
Table 4.7: Soil Carbon in Organic Soils in England and Wales ......................... 37
Table 5.1: Impacts on Blanket Bogs associated with Land Use and Management. 52
Table 5.2: Summary Table of Burning Recommendations for Blanket Bog .......... 55
Table 5.3: Summary of advantages and disadvantages for nature conservation of prescribed burning on blanket bog (from Shaw et al 1995, and Tucker 2003) ........................................................................ 57
Table 5.4: Hydrological and Hydrochemical Effects on Peatlands from Artificial Drainage of Peatlands ................................................................. 72
Table 5.5: Afforestation and the Changes on Blanket Bog (adapted from Anderson et al 1995, Anderson 2001, Brooks and Stoneman 1997) ................. 74
Table 5.6: Advantages, Disadvantages, Effectiveness and Duration of Catchment Liming ......................................................................................... 77
Table 6.1: Peatland Classification According to the Level of Disturbance. Adapted from Warner 1996, Charman 2002 and Schumann and Joosten 2006) ....... 82
Table 6.2: Factors to Consider When Setting Conservation/Restoration Objectives (Adapted from Adamson and Gardener 2004) ................................. 83
Table 6.4: Recommended Gully Blocking Sites on Deep Peat (adapted from Evans et al 2005) ................................................................. 99
Table 6.5: Methodologies for Re-Vegetating Peat Surfaces .............................. 101
Table 6.6: Grazing Recommendations for Blanket Bog in England.................... 111
Table 6.8: Summary of Recreational Management (adapted from Backshall et al 2001) ................................................................................................. 113

APPENDICES
APPENDIX I – Case Studies ........................................................................... 1644
APPENDIX II – Interview Questions .............................................................. 1811
EXECUTIVE SUMMARY

In the last 20 years a significant programme of restoration has been undertaken on blanket bog within the UK, focused upon restoration for conservation and wildlife functions. More recently the recognition of these areas as a carbon store and their potential to combat the effects of climate change through carbon sequestration has increased perceived urgency to restore these sites. Much of the work has previously been done on an ad hoc or pragmatic basis, with little science-based evidence either to support the choice of techniques used or to demonstrate the consequences of such programmes. In view of the very great costs in time and resources to restore extensive areas of degraded blanket bog, Defra has commissioned this research with the principal aims:

- To review the current knowledge of the management and restoration of blanket bog mires, particularly with regard to the restoration of hydrological function and Sphagnum growth
- To analyse prevailing issues
- To identify priorities for possible future field-based research.

The report has used published peer-reviewed and “grey” literature together with interviews and consultations with a wide variety of specialists. The perceived ecosystem drivers of blanket bog, the main threats to its active state and the range of techniques used to conserve or restore blanket bog were investigated. Recommendations and priorities for future field-based research are discussed within the report.

Main Findings

- Climate change is considered fundamental to influencing changes in the restoration of hydrological function and re-vegetation of bog plant species. It is considered to be the over-riding threat to the continued existence of blanket bog and may affect the success of projects should the forecast changes in climate occur.
- Wildfire is a major threat with increases in the number of incidences being linked to “abnormal” seasonal fluctuations of climate and increased recreation access to these areas.
- Afforestation is largely no longer considered a threat due to changes in planting regimes and polices adopted by the Forestry Commission.
- Sheep grazing is considered less threatening because of reduced stocking densities. However, the legacy of intensive grazing remains with erosion scars, failure of re-vegetation and localised degradation.
- Prescribed burning on “active” blanket bog does not generally occur, whilst the continued burning of “degraded” sites through a system of agreed burning consents effects vegetation, peat hydrology and carbon losses.
- Recreation may threaten only selected areas of blanket bog and the perceived threat of open access following the CRoW Act (2000) has not materialised.
- Re-establishment of hydrological function is seen as fundamental to the recovery and restoration of blanket bog. “Active” blanket bog should contain wet mossaes including sphagnum which should be encouraged by natural re-colonisation or re-introduction.
- Grip and gully-blocking are key techniques in aiding hydrological function, but there is a lack of science-based evidence to conclusively determine their effectiveness. Long-term data, pre-monitoring of sites and publicising innovative techniques are required to determine if hydrological integrity of a blanket bog can be re-established.
- Agri-environment schemes are essential in supporting and manipulating land management practices. Removal or reduction of payments may encourage farmers and landowners to sell-up resulting in a loss of knowledge base and potential for scrub invasion.
Recommendations

- Definition and mapping is required to define blanket bog and assess its “active” or “degraded” state. Assessments at local, regional and national scale should assess changes using tools such as remote sensing.
- Restoration projects should commence with an Environmental Impact Assessment (EIA) as a means of collating and assessing the significant environmental effects of restoration.
- Scientific monitoring should be a condition of securing funding for restoration schemes and so further the knowledge and understanding of techniques and processes. Pre-restoration monitoring should be enforced. Strategic restoration should encompass plot and catchment scale monitoring of chemical, physical and hydrological processes.
- Climate change monitoring needs precise, long-term monitoring techniques of carbon budgets appropriate to upland sites to measure long-term response to climate change.
- Further investigation of the impacts of the frequency and intensity of prescribed burning on vegetation, soil and hydrological processes are required. Plot and catchment scale responses need to be assessed to determine the local and regional cumulative impact. Continued development in the use of digital infrared (IR) photography is recommended to determine the vegetation composition and recovery rate under cool/hot burns.
- A national database of strategic moorland plans and fire prevention strategies needs further development to combat wildfire.
- Optimum stocking rates and breeds of sheep require further research to determine the effects on the hydrological and hydrochemical processes of peat soils with long-term research sites set up to determine the time required for blanket bog to recover following removal or reduction in livestock.
- The long-term effectiveness of changes in bog restoration projects adopted by the Forestry Commission requires assessment as most have occurred recently (within the last 10 years or so). Research on nutrient availability and release, hydrological processes, stream flow and sediment flux is required. The displacement of conifer with broad-leaved species also requires further investigation to determine the soil, hydrological, hydrochemical and vegetation impacts of such planting schemes.
- A national resource base of best practice of footpath repair on heavily used, sensitive sites and the economic feasibility of restoring popular pathways is required.
- Sustainable catchment management (potential changes to prescribed burning, grip/gully blocking, manipulation of grazing) requires further research with replicate long-term studies on a catchment and plot scale required to understand the hydrological and hydrochemical processes responsible.

Overall, the report has highlighted a number of areas where existing policy may need to be altered to more clearly define blanket bog and the options available for its management. It has recognised the major drivers for the continued conservation and restoration of blanket bog and the perceived threats to its continued existence. In addition, there remain a number of information gaps relating to the complex processes and interactions occurring on blanket bog from the combination of land management, air pollution, climate and restoration. Further work is obviously required and key recommendations have been made to further our understanding and support management and restoration projects in a more effective manner in the future.
1 Introduction

This report relates to DEFRA research project CTE0513, undertaken by Nottingham Trent University in 2006/7. Section 1 outlines the aims of the project. Section 2 outlines the methodology applied. Section 3 defines blanket bog, outlines its spatial distribution, its value and subsequent protected status. The processes leading to blanket bog formation are discussed, followed by the causes of degradation, which include climatic processes and anthropogenic factors and how they influence the functioning of an active blanket bog. Section 4 outlines the values and functions of blanket bog. Sections 5 and 6 contain the main literature review related to the aims of the project. They explain the current guidance on blanket bog management and restoration and attempt to identify the science-based evidence to support such guidance. Case studies of past and present management and restoration are used to illustrate the "success" or "failure" of these practices. On-going restoration projects with any associated monitoring are discussed. Section 7 analyses interviews held with a selection of main stakeholders and suggests options available for sustainable land use. The report concludes by identifying current gaps in our knowledge and recommendations for appropriate field-based research to support sustainable upland management and restoration projects in the future.

1.1 Principal Aims

The principal aims of this project are:

- to review current knowledge of the management and restoration of blanket bog mires, particularly with regard to the restoration of hydrological function and *Sphagnum* growth;
- to analyse prevailing issues;
- to identify priorities for possible future field-based research.

The project seeks to take a holistic view, recognising the many and varied demands upon this habitat.

1.2 Objectives

The objectives of the project are:

- to undertake a review of peer reviewed academic literature on the historic and current management practices and restoration of blanket bog;
- to undertake a review of "grey" literature to examine the historic and current management practices and restoration of blanket bog by organisations, landowners, farmers and other stakeholders, and to consider options available to ensure more sustainable use of this habitat;
- to conduct interviews with a selection of the main stakeholders in order to evaluate the perception, opinions and priorities of these individuals or groups in managing, conserving and/or restoring blanket bog;
- to identify gaps in the knowledge and to recommend appropriate field-based research to support sustainable upland management and restoration projects in the future.
2 Methodology

2.1 Published Literature

A comprehensive search of published literature on blanket bog, its formation, climatic influence, effects of land management and restoration has been conducted using the following English language databases: JSTOR, ISI Web of Knowledge (comprising BIOSIS previews via EDINA, CAB Abstracts, ISI Web of Science), Index to Theses Online, and the British Library Catalogue.

The reference lists from papers and reports were checked to identify relevant literature with particular relevance to blanket bog, its management and its restoration. Much recent literature was already available through the team’s personal knowledge and specialisms, and further references were followed up from suggestions made by interviewees and contributors to the project. The Harvard system has been used to reference the material used in the report.

A list of keywords was used to search each of these databases. If search returns were over 200, the search criteria were narrowed by combining keywords e.g. bog and restoration, allowing searches to be more focused and of relevance to the project. Table 2.1 shows a list of the most commonly used key words.

Table 2.1: Key words used in literature searches

<table>
<thead>
<tr>
<th>Active</th>
<th>Blanket</th>
<th>Blocks</th>
<th>Burning</th>
<th>Bog</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calluna</td>
<td>Carbon</td>
<td>Climate</td>
<td>Controlled</td>
<td>Degraded</td>
</tr>
<tr>
<td>Drainage</td>
<td>Eriophorum</td>
<td>Erosion</td>
<td>Fire</td>
<td>Grazing</td>
</tr>
<tr>
<td>Grip</td>
<td>Grouse</td>
<td>Gully</td>
<td>Heather</td>
<td>Humic</td>
</tr>
<tr>
<td>Humification</td>
<td>Land use</td>
<td>Management</td>
<td>Moorland</td>
<td>Moss</td>
</tr>
<tr>
<td>Muirburn</td>
<td>Organic</td>
<td>Peat</td>
<td>Peatland</td>
<td>Prescribed</td>
</tr>
<tr>
<td>Restoration</td>
<td>Sheep</td>
<td>Sphagnum</td>
<td>Upland</td>
<td>Wetland</td>
</tr>
<tr>
<td>Wildfire</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2.2 Grey Literature

Web databases such as Google, Google Scholar, and Yahoo have been searched for reports, management plans and general unpublished or non-peer reviewed literature. Persons interviewed were requested to provide literature where possible and many have been able to contribute relevant literature in the form of internal reports, management plans and draft articles.

2.3 Interviews

A list of possible contacts was compiled from the team’s contacts and advice from Defra. The literature review provided information on additional contacts. An introductory letter was sent to all potential interviewees, containing brief details of the review and a request for interview. Arrangements were made with individuals to be seen at a convenient venue and time. Follow-up requests were made by email and telephone to clarify details and interview procedures. Where individuals did not reply to written, email or telephone correspondence, it was accepted that they did not wish to take part in the review and records were annotated as such.
Structured interviews were then conducted with a selection of key individuals to evaluate the perceptions, opinions and priorities of individuals and organisations involved in the management, conservation and/or restoration of blanket bog. The interviews were recorded and transcribed by agreement with contributors who have been invited to make changes through the addition or deletion of comments.

The interview questions were in a set format and divided into three types according to the individual being interviewed. These categories were:

i) researchers/academics (mostly from universities and research institutes),
ii) policy makers (largely government agencies)
iii) practitioners (e.g. land managers, non-government organisations, consultancies).

Additional questions were asked where clarification was required of certain points made by interviewees.

A total of 22 people were interviewed for the project and the information provided during the interviews has been evaluated and analysed to identify differences between perceived and actual science-based evidence of the causes of degradation to blanket bog (including current land use) and restoration of blanket bog (including the methods and techniques used by practitioners). Interviewees were asked questions relating specifically to the restoration of hydrological function and the regeneration of sphagnum on blanket bog. In addition, researchers and academics were asked about their own and other related research (recent and current). All individuals were asked to identify what they considered to be gaps in the knowledge of current management and restoration of blanket bog and what they considered to be the priorities for future research.

Table 2.2 shows the names and organisations of those interviewed. Many other individuals were contacted during the review and provided relevant information to assist with the report and can be referred to in the acknowledgements section. Analysis and evaluation of the interview is discussed in section 7.

Table 2.2: Individuals and Organisations Interviewed

<table>
<thead>
<tr>
<th>Name</th>
<th>Organisation</th>
<th>Name</th>
<th>Organisation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mrs Penny Anderson</td>
<td>Penny Anderson Ass.</td>
<td>Dr Mike Billett</td>
<td>CEH, Edinburgh</td>
</tr>
<tr>
<td>Dr Aletta Bonn</td>
<td>Moors For the Future</td>
<td>Mr Matt Buckler</td>
<td>Moors For the Future</td>
</tr>
<tr>
<td>Mr Ian Condliffe</td>
<td>RDS, Leeds</td>
<td>Mr Alistair Crowle</td>
<td>English Nature</td>
</tr>
<tr>
<td>Dr Martin Evans</td>
<td>Manchester University</td>
<td>Mr Geoff Eyre</td>
<td>Landowner/farmer</td>
</tr>
<tr>
<td>Dr Sarah Gardener</td>
<td>Consultant</td>
<td>Mr David Gaves</td>
<td>RDS, Exeter</td>
</tr>
<tr>
<td>Dr Joe Holden</td>
<td>Leeds University</td>
<td>Mr Mike Innerdale</td>
<td>National Trust</td>
</tr>
<tr>
<td>Prof Rob Marrs</td>
<td>Liverpool University</td>
<td>Mr Richard May</td>
<td>Moorland Association</td>
</tr>
<tr>
<td>Mr Martin McGrath</td>
<td>United Utilities</td>
<td>Mr Richard Pollitt</td>
<td>English Nature</td>
</tr>
<tr>
<td>Dr Kate Snow</td>
<td>United Utilities</td>
<td>Mr Steve Trotter</td>
<td>New Forest NPA</td>
</tr>
<tr>
<td>Mr Simon Thorpe</td>
<td>The Heather Trust</td>
<td>Mr Andrew Warren</td>
<td>Severn Trent Water</td>
</tr>
<tr>
<td>Dr Fred Worrall</td>
<td>Durham University</td>
<td>Dr Adrian Yallop</td>
<td>Cranfield University</td>
</tr>
</tbody>
</table>
3 Blanket Bog: Definition, Classification and Characteristics

3.1 Introduction

This section considers the definition of Blanket Bog as *ombrotrophic peatland not confined by the surrounding topography* and states that, for the purposes of this review, the JNCC definition of blanket bog has been used (JNCC 1999). This encompasses all areas of blanket bog supporting semi-natural blanket bog vegetation, whether or not it may be defined as ‘active’. The section goes on to outline the formation of blanket bog, including the role of *Sphagnum* mosses and the importance of hydrological processes, before describing the distribution, status and assessment of blanket bog habitat in the UK.

3.2 Definition of Blanket Bog

The meaning and connotations of the term “blanket bog” require some investigation prior to considering the current policies and future options available to manage and restore this environment. The Oxford English dictionary defines bog in the broadest terms as “an area of soft, wet, muddy ground” (AskOxford 2006) and it has been suggested that the term is derived from the Irish Gaelic word “bogach” meaning “soft” (Wheeler and Proctor 2000). Rydin and Jeglum (2006, p 11-12) state, in a more scientific definition, that bogs are “*ombrotrophic peatlands with the surface above the surrounding terrain or otherwise isolated from laterally moving mineral-rich soil waters*”. They do recognise, however, that “bog” is an old vernacular term and that, even in scientific papers of the 1960s, it was often used rather loosely for any *Sphagnum*-dominated peatland.

Blanket bog is accepted as falling within the umbrella term of wetland, which was defined at the Ramsar Convention (1971) as “an area of marsh, fen, peatland, or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt”.

“Mire” is a generic term for a wetland which supports vegetation that is capable of peat-formation through the incomplete decay and steady accumulation of dead material in a largely waterlogged environment (Scottish Natural Heritage 2006). The term “bog” and “mire” are stated to be inter-changeable within the context of describing blanket bog in the UK Biodiversity Action Plan (BAP) (UK Biodiversity Group 1999).

The JNCC (1999) *Habitat Action Plan for Blanket Bog* also notes that the term “blanket bog” strictly applies only to that portion of a blanket 'mire' which is exclusively rain-fed. The Peak District National Park in its local BAP describes blanket bog as developing as an unconfined, ombrotrophic mire type *“where cool, wet climatic conditions prevail which favour water-logging of the ground and the accumulation of plant remains as deep peat”* (PDNPA 2001, section 6.4 p 2). They also noted that, whilst strictly the term refers to ombrogenous (precipitation-fed) areas only, they would use the term “blanket bog” to encompass some areas of wet heath, raised bogs, bog pools and basin bogs as well as various flush and fen vegetation types occurring within the wider expanses of blanket bog.

Gore (1983) suggested that raised bogs (confined by the surrounding topography) could be distinguished from blanket bogs, which are not so confined. JNCC (1994, p4) in its *Guidelines for selection of SSSIs* indicated that in blanket bog “the conditions necessary for soil waterlogging favourable to *Sphagnum* growth and peat formation are such that bog development is no longer confined to level terrain but can occur on all but the more steeply sloping ground. It therefore covers many of the gentler uplands in a smothering mantle, hence the descriptive name.”
The JNCC (1999) Habitat Action Plan for Blanket Bog states that it is a globally restricted peatland habitat confined to cool, wet, typically oceanic climates. It is, however, one of the most extensive semi-natural habitats in the UK and ranges from Devon in the south to Shetland in the north. Peat depth is also very variable, with an average of 0.5-3 m being fairly typical but depths in excess of 5 m not unusual. There is no agreed minimum depth of peat which can support blanket bog vegetation.

‘Active’ blanket bog is protected under the EC Habitats Directive as a priority habitat, the definition of active being given as “still supporting a significant area of vegetation that is normally peat forming” (JNCC 2006a). Typical floral composition includes the important peat-forming species, such as bog-mosses *Sphagnum spp.* and cotton grasses *Eriophorum spp.*, or purple moor-grass *Molinia caerulea* in certain circumstances, together with heather, *Calluna vulgaris*, and other ericaceous species. Thus sites, particularly those at higher altitude, may be characterised by extensive erosion features but may still be classed as ‘active’ if they support extensive areas of typical bog vegetation and particularly if the erosion gullies show signs of recolonisation (McLeod et al 2002). However, many areas that were once active blanket bog now support vegetation which is more characteristic of dry heath such as extensive stands of *Calluna* and/or *Molinia* and may not be readily identifiable as blanket bog even though they are still designated as such.

Despite these attempts to simplify the term, blanket bogs are in fact complex ecosystems that include ombrotrophic blanket bog on a large scale, but also include smaller areas of mineral flush, raised bog, valley mire, and wet heath each with their differing hydrology, soil structure and species composition and which together have blanketed the ground with a variable depth of peat to give the habitat type its name. In terms of micro-habitats, at the smaller scale, blanket bogs are made up of a mosaic of hummocks, hollows, pools and lawns that may require a range of measures to manage them effectively (Lindsay 1995, McLeod et al 2002). A number of sub-categories have been defined as, for example, saddle mires, watershed mires, and valley-side mires, but all are included under the definition of blanket bog (Lindsay 1995).

For the purposes of this review the JNCC definition of blanket bog has been used (JNCC 1999) encompassing all areas supporting semi-natural blanket bog vegetation, whether or not it may be defined as ‘active’.
3.3 Classification of Blanket Bogs

The development of blanket bog is a function of environmental factors (e.g., climate, geology and geomorphology) combined with the intensity and history of human impact (Steiner 1997). These factors create a range of regional bog types and so may influence local conservation issues. An awareness of what is the typical mire type for a region and the associated species composition may therefore assist in focusing restoration or conservation objectives.

Scientific classification of this ecosystem is essential in underpinning the understanding of its ecology and functioning. Such classification is based on scientific principles and characteristics, but as Moore (1984) indicates there are several criteria for classification which can be used separately or together to classify mires. These are: floristics, vegetation physiognomy, morphology, hydrology, stratigraphy, chemistry and peat characteristics (see table 3.1). Of these, shape (morphology), site hydrology, chemistry, plants (floristics) and structure are the most widely used and collectively referred to as hydromorphological peatland classification. It should be noted that such systems are used essentially for convenience and ease of communication within specialist areas such as forestry or conservation and are therefore subject to changes over time.

Table 3.1: Peatland Classification (Adapted from Moore 1984)

<table>
<thead>
<tr>
<th>Classification</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Floristics</td>
<td>The vegetation composition of the plant communities and often used as a proxy measure of other criteria such as chemistry and hydrology.</td>
</tr>
<tr>
<td>Vegetation physiognomy</td>
<td>The structure of the dominant plants on the surface. Used particularly in Russian and Scandinavian schemes</td>
</tr>
<tr>
<td>Morphology</td>
<td>The three-dimensional shape of the peat deposit itself and of the smaller scale features on the peatland surface</td>
</tr>
<tr>
<td>Hydrology</td>
<td>The source and flow regime of the water supply</td>
</tr>
<tr>
<td>Stratigraphy</td>
<td>The nature of the underlying peat deposits and their implications for development of the peatland</td>
</tr>
<tr>
<td>Chemistry</td>
<td>The chemical attributes of the water at the surface</td>
</tr>
<tr>
<td>Peat Characteristics</td>
<td>Usually specifically for energy, agricultural or horticultural use and based on simple assessments of botanical composition, nutrient content and structure.</td>
</tr>
</tbody>
</table>

Many authors (e.g. Daniels 1978, White and Doyle, 1982, Gore 1983, Lindsay 1995, Wheeler and Proctor 2000, Moore 2002) have reviewed the peatland classification system. Table 3.2 summaries the classifications and characteristics proposed for upland and lowland blanket bog found in the UK.
Table 3.2: Classification and Characteristics of Blanket Bog

<table>
<thead>
<tr>
<th>Type</th>
<th>Classification</th>
<th>Description</th>
<th>References</th>
</tr>
</thead>
</table>
| Blanket Bog          | Floristics     | Association: Vaccinio-Ericetum, Order: Erico-Sphagnetalia Schwächer, Class: Oxycocco-Sphagnetea  
Phytosociological classification – NVC types M1, M2, M3, M17, M18, M19, M20.  
Characterised by Calluna vulgaris, Empetrum nigrum, Vaccinium myrtillus,  
| Vegetation Physiognomy |                | Blanket. Open or with low trees, dwarf shrubs, bryophytes                                                                                                                                                | Doyle (1997), Daniels (1978)                 |
| Trophic (nutrient) Status |              | Ombrotrophic and oligotrophic with minerotrophic flushes. Mainly acidic and low in plant nutrients across blanket peat, with minor minerotrophic elements around springs and seepages | Charman (1993), Doyle (1997)                 |
| Morphology           |                | Unconfined peatland covering virtually all the landscape in an area. Mosaic of microforms, microtope, mesotope and macrotope landforms which may include ‘hidden’ raised mires within the blanket bog landscape.  
Minor areas of rock outcrop and exposed steep slopes not covered by peat are sometime present. | Ivanov (1981), Lindsay (1995)                |
| Hydrology            |                | Ombrogenous (rain-fed). Minimum annual rainfall 1200 mm, minimum 160 wet days (a wet day having >1mm precipitation in 24 hrs), a surplus precipitation over evaporation of at least 200 mm for a 6 month period Apr-Sept and a mean temperature below 15 °C for warmest month.  
| Stratigraphy         |                | Impermeable soils or bedrock strata e.g base poor granites and metamorphic rock on which peat layers form. Some podsolisation and formation of an impermeable layer within the mineral soil may result in mire development. | Moore (1984, 1989)                           |
| Chemistry            |                | Acidic (pH ~ 4), high C:N ratio (20:1), anaerobic conditions prevail in active bogs.                                                                                                                     | Heathwaite & Gottlich (1976), Clymo (1983)   |
| Peat Characteristics  |                | Raw peat, stagnohumic gley and stagnopodzol soils dominate upland blanket bog. Dark brown – black in colour, high water content, high organic matter content, high porosity, low hydraulic conductivity.  
0.4-6m depth (average 2-3m) on blanket bog. Accepted definition 0.4m depth (Scotland), 0.5m depth (Eng & Wales), 0.45m depth Forestry Commission (deep peat) | Jarvis et al (1984), Ragg et al (1984), Hobbs (1986), Heathwaite & Gottlich (1976) |
3.4 Blanket Bog Formation

Peatlands have been described as an example of a "living landform" which continues to grow laterally and vertically, changing its shape and character through time (Charman, 2002). This spatial and temporal evolution is an important concept in understanding the function of the ecosystem and incorporates the influences of major processes such as hydrology, carbon cycling and nutrient balance, all of which are important in terms of the management and restoration of this ecosystem.

The essence of peat development is for organic productivity to exceed decay. Such development is initially determined by allogenic factors such as climate and complex autogenic processes within the system (Heathwaite and Gottlich 1993). Blanket bog is an example of the combination of such processes. Figure 3.1 shows a conceptual model of the main influences on peat development, with external factors positioned on the outer rim of the model and key internal processes or those immediately impinging on the peatland represented by the four inner circles (Charman 2002).

Figure 3.1: Conceptual Model of Peat Development (Charman 2002)
A major role in the formation of the world’s boreal peatlands is played by *Sphagnum* mosses. Rydin and Jeglum (2006) noted that, like all mosses, *Sphagnum* lack leaf stomata but can transport water in a capillary network formed by spaces between the leaves and between the stem and the branches. In addition they state that peat mosses have a unique capacity to store water, both in the dead hyaline cells and between the leaves. If a bunch of *Sphagnum* is submerged and later drained, the water content can be as much as 15-20 times the dry mass. The consequences of this are enormous for the ecosystem: with stagnant and continuously high water tables, anoxic conditions will prevail. This in turn hampers decomposition and peat thickness gradually increases until the mire surface rises above the surrounding mineral soil. As the mire continues to grow it creates its own water table and the plants become isolated from minerotrophic influence (the process of *ombrotrophication*). They also noted (p66) that *Sphagnum* mosses exert an acidifying effect upon the waters of the bog as they grow, by continuously creating new cation exchange sites with uronic acids. These acids exchange hydrogen ions for cations in the mire water.

Peat can be created by the processes of terrestrialisation and paludification, both of which may contribute to the formation of blanket bog. **Terrestrialisation** is a process of hydroseral succession by which a shallow water body is gradually infilled with organic and inorganic sources until the water table is at or close to the surface enabling partial or permanent water logging to occur (Smith and Taylor 1989). The limnic (lake) sediments then provide a stable substrate on which the peat forming vegetation can grow, including *Sphagnum* mosses which require nutrient poor, water logged conditions (Walker 1970). Typical areas of formation include water-collecting sites such as flat plateaux, saddle-shaped cols and local basins, acting as a foci for progressive spread of peat to water-shedding sites (on sloping ground) (Edwards and Hirons 1982, Tallis 1998).

**Paludification** is a process by which mire systems form over a mineral layer such as previously forested land, burnt vegetated *Calluna* or grassland, bare rock (large, isolated glacial erratics as illustrated in north-west Scotland) or highly podzolised glacial tills (Brooks and Stoneman 1997, Tallis 1998). In cool, moist and mild climates, such ground can become waterlogged from constant precipitation allied with low evaporation rates which favour podzol formation and an iron-rich pan horizon, above which an impermeable layer of bleached sub-surface horizon peaty-gleyed podzols may form (Avery 1980). In these water-logged, anaerobic conditions, the decay rate of available biomass controls the production-decay balance sufficiently to enable peat formation to occur on the impermeable layer. The decay rate is primarily a function of moisture status and therefore the factors affecting the hydrological balance of peat initiation are critical to the initiation, conservation and restoration of blanket bog (Brooks and Stoneman 1997). Paludification is the dominant process in linking areas of terrestrialised peat, and so “blanketing” the topographically varied landscape.
3.5 Hydrology of Blanket Bogs

Charman (2002) explains that "standing on a peatland surface, one is supported by a giant bubble of water, held together by a mass of living and dead plant material". The fact that peatlands consist of over 95% water by weight (Heathwaite and Gottlich 1993) indicates that one of the most characteristic features of peatlands is that they are (or should remain) wet (Wheeler et al. 2002). However, there is no simple relationship between wetland types and the hydrological function they perform, partly because there is no simple classification of wetlands that consistently relates to hydrology, vegetation, substrate type and geomorphology. Maltby et al (1996) have developed a framework of functional analysis through characterisation of distinct ecosystem/landscape units (hydrogeomorphic units) and this is discussed further in section 7 when considering the systems available to monitor wetlands such as blanket bog in the future.

Table 3.3 shows five main factors which influence the hydrological balance at peat initiation, some or which may dominate or interact during the formation process.

<table>
<thead>
<tr>
<th>Table 3.3: Hydrological Processes and Peat Initiation (Adapted from Charman 2002)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Factor</strong></td>
</tr>
<tr>
<td>Climate</td>
</tr>
<tr>
<td>Geomorphology</td>
</tr>
<tr>
<td>Geology and Soils</td>
</tr>
<tr>
<td>Biogeography</td>
</tr>
<tr>
<td>Anthropogenic Activities</td>
</tr>
</tbody>
</table>

Rydin and Jeglum (2006, p4) noted that “the overriding physical condition controlling peatlands is the high water table”. It is now generally accepted that the basic functioning of a peatland system relies, at its simplest, on a diploietelic system that comprises of an upper ‘active’ layer of peat with a high hydraulic conductivity and fluctuating water table (the acrotelm), and a more ‘inert’ lower layer with a permanently saturated peat mass (the catotelm) (Ivanov 1981, Holden and Burt 2003c). These definitions were developed for raised bogs but have frequently been used in reference to blanket bogs also. In reality at a particular location there may well be a more complex stratigraphy within the peat, with alternating layers of higher and lower conductivity, but in broad terms the acrotelm is the upper layer that is periodically aerated and contains decomposing plant material whereas the deeper catotelm is anaerobic and permanently water logged (Ingram 1983). By definition, the water table always lies within the acrotelm and is temporally variable.
Evans et al (1999) considered variability of water tables in blanket bog and found the water table to be generally above or within 5 cm of the mire surface during the autumn and winter, falling to 20-25 cm in the spring and summer. This water level controls infiltration and surface runoff, with high incidences of saturation-excess overland flow dominating runoff production from peatlands during periods of high water table level due to the low hydraulic gradient and near-saturated state (Burt et al 1990).

Although large amounts of water are held within the peat of a blanket bog, it is important to understand that little of the incident rainfall is retained. Even intact blanket peat is highly productive of rapid (rainfall event) runoff and, by contrast, generates little baseflow during dry periods. Streams draining blanket bog are often ephemeral in their flow regime. Figure 3.2 is a schematic diagram illustrating the main water pathways in a blanket bog and these are discussed below.

**Figure 3.2: Schematic diagram to illustrate water pathways in a blanket bog**

![Schematic diagram](image)

### 3.5.1 Infiltration and infiltration-excess overland flow

Some rain is removed by interception and evapotranspiration from vegetation and some by evaporation from the ground surface. Much of the remainder passes through the surface of the soil and into the soil mass via pores or small openings, a process termed infiltration. Any given soil will have an infiltration capacity, a maximum rate at which the soil can absorb falling rain when it is in a specified condition. As soil becomes saturated, with continued precipitation input, infiltration capacity falls asymptotically to a final, minimum, constant level. Infiltration capacity varies with soil texture, such that sandy soils have much higher final infiltration capacity than fine clay soils or peats (see for example Shaw, 1994). Where precipitation is of greater intensity than the infiltration capacity of the soil, “infiltration-excess overland flow” will occur. Where rainfall is particularly intense or soil is particularly fine textured, this situation can occur long before the soil is actually saturated with water.

Burt et al (1990) discussed infiltration rates and infiltration-excess overland flow in peatlands. Studies using ring infiltrometers suggested that infiltration capacities on
cotton grass (Eriophorum spp.) moorland were as low as 2 mm hr$^{-1}$, whereas on crowberry (Empetrum nigrum) the mean infiltration capacity was just less than 30 mm hr$^{-1}$. However, experiments with sprinkling infiltrometers suggested rather higher infiltration rates, at least into the top few centimetres of decaying vegetation and peat. More recently, Holden et al (2001) used tension infiltrometers and produced an average figure of 12.4 mm hr$^{-1}$ for the surface layers of blanket peat, with Sphagnum-covered peat and bare peat giving slightly higher values than that covered by Calluna or Eriophorum. Holden and Burt (2002) used rainfall simulation in the laboratory to obtain rates from 2-6mm.hr$^{-1}$, increasing with the intensity of the incident rainfall. They concluded that saturation-excess overland flow is therefore more likely to be the dominant flow process in blanket peat catchments.

3.5.2 Saturation-excess overland flow

When the soil profile is completely saturated, excess water (added from above by precipitation, or laterally by overland or subsurface flow) cannot be accommodated. Hewlett and Hibbert (1967) first put forward the hypothesis that in many catchments the precipitation entering the soil by infiltration moves both vertically and laterally through the soil, and that as a result of the lateral movement the areas immediately around the stream channels become saturated. With time the ‘saturated wedge’ moves upslope and any rain falling onto this surface runs off as saturation-excess overland flow. Burt et al (1990) described the frequent occurrence of saturation-excess overland flow in peatlands, explaining how expansion of the saturated zone during precipitation leads in turn to expansion of the area experiencing overland flow.

3.5.3 Pipe flow and macropore flow

Macropore flow occurs in pores above capillary size which allow water to move by gravity, bypassing the soil matrix and providing rapid recharge for the water table. Macropore flow may be almost as rapid as surface flow and is most commonly observed in structured soils such as cracked clays where it has been shown to increase stormflow volumes and peak discharge (e.g. Robinson et al, 1987). The same phenomenon could occur where peat becomes cracked as a result of frost or desiccation. Thresholds with regard to macropore flow are thought to exist with regard to rainfall intensity and antecedent soil moisture: if the soil is too dry, or rainfall too light, then any flow which finds its way into macropores is rapidly absorbed into the soil peds (see, for example, Anderson and Burt, 1990). Baird (1995) stated that macropores are commonly assumed to exert 3 cm suction, which means that they are more than 1 mm in diameter. He found that they accounted for over 50% of flow even in a highly humified fen peat. Holden et al. (2001) investigated macropore flow in blanket peat in the Northern Pennines, England, and found that macropores accounted for an average of 36% of flow through the peat, with 51% in Sphagnum-covered peat. They also reported a change with depth in bare, Calluna- and Eriophorum-covered peats, such that macropores were most significant in the 5 cm zone, accounting for 47-53% of flow, and had reached a minimum (13-22%) by 20 cm below the surface.

Rapid subsurface flow also occurs in larger features known as “pipes” in many blanket peat-covered catchments. For example, Jones and Crane (1984) found that almost half of the ‘stormflow’ from a blanket peat catchment in mid-Wales originated in discrete pipes. These pipes can be up to hundreds of meters in length and vary greatly in diameter from a few centimetres to more than a meter, but typically form branching subsurface networks which undulate throughout the peat profile (Jones 1981, Holden and Burt 2002b, Holden 2005c). The precise boundary between pipes
and macropores is difficult to define, but pipes may exhibit a greater degree of connectivity in the downslope direction. The precise role of pipes as sites for gully extension and stream channel initiation remains unclear, but they can play a significant role in the hydrology of some peat-covered catchments by providing linkage from distant source areas to the stream network.

### 3.5.4 Subsurface flow through the peat matrix

Most soil or rock matrices will be permeable to water to some extent, giving rise to both lateral and vertical flows within the ground. The term ‘throughflow’ is widely used for shallow subsurface flow, particularly downslope flow through soil profiles and is therefore analogous to lateral shallow flow through the peat matrix. It is used in this context in the present report (Figure 3.3). The rate of flow in any rigid medium is controlled by three factors according to Darcy’s law:

\[ Q = kIA \]

where:

- \( Q \) = groundwater discharge (m\(^3\) s\(^{-1}\))
- \( k \) = hydraulic conductivity (m s\(^{-1}\))
- \( I \) = hydraulic gradient (dimensionless, also known as “head” per unit distance)
- \( A \) = cross-sectional area across which flow occurs (m\(^2\))

The hydraulic conductivity of a material, \( k \), reaches a maximum when all available pore spaces are already filled with water. This is known as the saturated hydraulic conductivity, sometimes abbreviated to \( k_{\text{sat}} \).

It is generally considered that Darcy’s law is an acceptable model for water movement in mires, although the field and laboratory experiments of Waine et al. (1985), working on humified peat samples from Dun Moss, have shown non-linear effects at hydraulic gradients larger than those normally found in nature. Hemond and Goldman (1985) also argued that Darcy’s law remains an appropriate tool for modelling in wetlands, but it should be noted that their work was on salt marsh peats. However, Baird et al. (1997) pointed out that the hydraulic conductivity of a given volume of peat is unlikely to be uniform in all directions, which will affect the direction and quantity of flow, and that entrapped gas bubbles may retard flow in peat pores even below the water table (Baird et al. 2004).

### 3.5.5 Runoff generation in blanket bogs

In streams on blanket peat the discharge often responds quickly to precipitation events, typically peaking within one hour of maximum precipitation and subsiding to baseflow within 7 to 12 hours of the cessation of rainfall (Crisp and Robson, 1979, Robinson and Newson, 1986, Labadz et al. 1991). The runoff regime of blanket peat catchments can therefore best be described as “flashy”. Given the widespread production of surface runoff, it is hardly surprising that the amount of rainfall returned as stormflow is large. Labadz et al. (1991) described runoff in a small stream on Wessenden Head Moor, Yorkshire, being characterised by long periods with little or no flow, punctuated by short events with very high runoff when much of the precipitation input is returned almost immediately to the channel. They recorded an average of 35% of incident rainfall appearing as storm runoff on a small but heavily eroded blanket peat headwater catchment. There was little evidence of any delayed flow, indicating that throughflow of water in deep peat is likely to be unimportant. Whether the rapid storm response is generated by surface or near-surface mechanisms is immaterial: in both cases, large discharge volumes are produced quickly with little detention by the peat.
### 3.6 Peat Accumulation

The ecology, hydrology and functioning of a blanket bog mire is strongly dependent on the amount and nature of the accumulated peat soils, which generally form in the moist, cooler climates of England and Wales (Wheeler and Proctor 2000, Charman 2002). The depth of the peat soils varies across the UK, depending largely on these climatic and additional topographic conditions (Lindsay 1995) with depths estimated to range from 0.4 - 6m, although the average peat depth is approximately 2 - 3m (Holden et al 2006a).

Key factors in the deposition rate of peat are temperature, moisture, oxygen supply, plant composition and type of peat organisms. The annual biomass production of mires greatly exceeds the annual production of peat and therefore peat formation involves considerable losses of organic matter. Most of this takes place in the biologically active upper layer of peat, the acrotelm, which is usually <40cm deep (Ingram 1983).

The key processes involved in peat accumulation are humification and mineralisation. **Mineralisation** involves all the processes which convert organic matter into simple inorganic compounds and results in the microbial utilisation of the organic matter and release of carbon dioxide, water and nutrients originally taken up by the plants (Heathwaite and Gottlich 1993).

**Humification** is the process by which organic matter loses its original cellular and tissue structures and is converted into humic substances that are light or dark brown to black in colour and contain various quantities of nitrogen (Heathwaite and Gottlich 1993). It normally occurs simultaneously with mineralisation. Humification of peat involves the breakdown of plant debris and the synthesis of breakdown products into more stable, but complex high molecular weight compounds, generally called humic material (Jolly and Chapman 1987, Scott et al 2001). These products are found in the upper layers of the soil (acrotelm). Humification is generally restricted when peat soils are water logged and anaerobic conditions prevail, but the process increases in peat catchments during the summer when changes such as lowering of the water table and subsequent moisture deficit allow humification to proceed (Tipping et al 1989). These processes will be discussed more fully in sections 5.3.3, 5.4.4 and 6.3 which consider the effects of drought, artificial drainage and the restoration of hydrological function of blanket bog.

The residence time and rate of decomposition in the upper layer of the peat will determine the growth rate of the mire. In ombrotrophic bogs this will depend on the amount of biomass produced on the surface and the amount of peat decayed and compacted in the entire mire. However, measurement of decay rates is difficult and only average values are usually estimated (Moore and Bellamy 1974, Clymo 1997, Coulson et al 1990). For example, the average annual production rate in the UK was estimated to be rarely more than 0.5mm, with exceptionally favourable conditions rendering 1mm/year (Moore and Bellamy 1974). Tallis (1998) estimated long-term accumulation rates to be 40-100mm/century on deeper peats, rising to 70-120mm/century when shallower peats are included. At this rate, peat production (the weight of peat material deposited annually) ranges between 80 and 2100 kg/ha (average 100-700 kg/ha) compared with an average annual biomass production of mire plant stands between 2 and 10 tonnes of dry matter/ha (Eggesmann et al 1993).
3.7 The Age and Origin of Blanket Bog in the British Isles

The age and origin of the blanket peats in the British Isles are open to controversy, with often conflicting evidence of the role of climate and human impact in mire formation. This exemplifies the problems of interpretation of evidence. Many authors (Moore and Bellamy 1974, Moore 1975, Moore 1993, Tallis 1998) have reviewed the findings in detail. This report will therefore only refer to the main concepts in order to place current ideas on the management and restoration of blanket bog in the context of its origin.

Estimates of blanket peat initiation vary regionally across the British Isles within a total time span of formation from 9400-800 BP (un-calibrated radiocarbon years before present). However, the period of maximum widespread peat formation in the UK is estimated to have occurred relatively recently, during the late Devensian period between 5100-3100 BP, and has been linked to a decline in *Ulmus sp* (elm) as indicated by a reduction in the elm pollen horizon on both deep and shallow blanket peat profiles (Tallis and Switsur 1973, Tallis 1998). Moore (1993) linked the origin of blanket peats with prehistoric human activity and has argued that climatic change may not have been sufficient in destabilising the established forest (elm) cover, except in the most extreme situations, and that elsewhere peat formation may have only ensued when the forest cover was physically removed by fire, grazing animals or felling (Tallis 1998, Simmons 1990).

Such theories have been supported by archaeological data which indicate that prehistoric human populations (early Neolithic, Mesolithic and Bronze Age settlers) were capable of forest clearance in order to graze wild and domesticated livestock (Chambers 1983, Simmons 1990). It is therefore believed that the early anthropogenic activities and the synchronisation of peat growth indicate that humans had a key role in the inception and development of blanket peat.

Paludification and the initiation of peat formation may have then commenced as a consequence of the reduction in canopy cover and rainfall interception coupled with a reduction in water losses from the soil by evapotranspiration, together with an increase in runoff downslope. Such factors would have instigated soil changes, such as loss of nutrients and subsequent reduction in fertility through leaching, structural deterioration following acidification and impedance of drainage by podsolisation or gleying (Tallis 1998).

Scientific evidence based on charcoal, macrofossil and pollen analysis also seems to indicate that blanket peat growth in the British Isles resulted from human activities (e.g. Tallis and Switsur 1973, Barber 1993). Studies at individual sites, often on the marginal areas of blanket bog development such as the south Pennines and Berwyn Mountains, have been said to indicate that the peat initiation and development of a blanket bog ecosystem occurred in response to forest clearance, climatic change and soil deterioration. These factors varied in their balance and timing on a local, regional and national scale and may account for the range of peat depths and bog types across the British Isles (Tallis 1991).
3.8 UK Distribution of Blanket Bog

Montanarella et al (2006) used the Map of Organic Carbon Topsoils of Europe to conclude that the UK has a best estimate of 44,411 km$^2$ under peat and peat-topped soils with $>$25% organic carbon content. The extent of blanket bog in the UK has been estimated at 1.5 million ha (ie 15000 km$^2$), of which England has approximately 215 000 ha (Jackson and McLeod, 2000). This is based on the national cover of blanket peat soil rather than the extent of blanket bog vegetation, for which there is no agreed figure. However, the authors noted that there were discrepancies in the actual depth of peat soil used to estimate the area of blanket bog in England, Wales and Scotland. The estimated area of blanket bog in England was based on the area of peat soils greater than 1 m depth (based on British Geological Survey maps). However, in Wales the area was based on peat soils greater than 0.3m deep over bedrock or 0.4m on mineral soil (based on the Soil Survey of England and Wales 1:250,000 scale map) whilst the Scottish Blanket Bog Inventory used classified satellite imagery (JNCC 2006a). The calculations include degraded or poor quality examples of this habitat type, but afforested bog is excluded from the figures (Lindsay and Immirzi 1996, Yeo 1997). In addition, the estimates do not include the extensive areas where thinner peat occurs at depths of 0.25-0.3m, such as on steep slopes. In such areas it may be difficult to separate peatland from non-peatland based on soil characteristics alone, without the use of extensive and costly peat depth surveys. Therefore national estimates of the extent of blanket bog may be subject to error at a local scale (Chapman 2002). Figure 3.2 shows the distribution of blanket bog in England and Wales as collated by Natural England and the Countryside Commission for Wales.

Figure 3.2: Distribution of Blanket Bog Habitat Type in England and Wales © Crown Copyright. All rights reserved (2006)

These distribution estimates are included in the UK Biodiversity Action Plan (BAP), for which targets have been set on a national basis. However, many Local BAPs are defined on a county basis, usually by the local authorities and multiple partner organisations, a large percentage of which are not aware of the areal extent of blanket bog within their region (e.g. Calderdale LBAP 2003). Many BAP partnerships have combined several habitats together to develop a combined “Upland” or “Moorland” Habitat Action Plan to encompass blanket bog, wet and dry heath, and
moorland habitats (e.g. Durham LBAP 2002, Lancashire LBAP 2001) to overcome this problem of precise distribution. They have, however, still defined measurable targets to restore blanket bog habitat within a set timeframe and in order for this to become achievable on a local and national basis, the development of a fully digitised and accurate mapped database of blanket bog is essential to determining the gain or loss of this valued land type.

The lack of continuity across the UK caused by the use of a range of definitions for blanket bog is clearly confusing and in need of some clarification in order to map areas more accurately and consistently in the future. Natural England is currently updating and digitising the data for blanket bog distribution in England based on land cover map holdings and known data sets based on the JNCC definition of blanket bog at 0.5m depth. The data are available online (Natural England 2006).

3.9 UK Status – Protection and Designation

The protection and designation of blanket bog is primarily due to its conservation and wildlife value (see section 4). Blanket bogs have been recognised for their importance in terms of their biodiversity, geological and landscape value over the last fifty years and subsequently have been designated as National Parks, National Nature Reserves (NNRs), Sites of Special Scientific Interest (SSSIs) and Areas of Outstanding Natural Beauty (AONBs), Special Protection Areas (SPAs), Special Areas of Conservation (SACs). Many of the areas have been adopted into a network of protected wildlife areas known as Natura 2000 in recognition that some or all of the wildlife and habitats are particularly valued in a European context.

Blanket bogs in England and Wales have to date received limited protection under a range of regulations which include:

- The National Parks and Access to The Countryside Act, 1949
- The Wildlife and Countryside Act, 1981
- The Wildlife and Countryside Amendment Act, 1985
- The Countryside and Rights of Way Act, 2000
- EU Directive 79/409/EEC (Conservation of birds)

Some argue that it is the intrinsic value of blanket bog that is important in itself, as Britain is one of the main locations for blanket mire in the world with more than 1.5 million ha of a total global blanket mire resource of approximately 10-12 million ha (Tallis 1995, Charman 2002). In recognition of this, “active” blanket bog is considered a priority habitat under the EU Habitats and Species Directive (92/43/EEC). It comprises NVC communities M1, M15, M17, M18, M19 and M20 (Rodwell 1991, JNCC 2006a). Table 3.4 details the categories and designations that apply to blanket bog habitat.

**Table 3.4: Blanket Bog Category Type and NVC type (based on Shaw et al 1996)**

<table>
<thead>
<tr>
<th>UK BAP Broad Habitat Type/Habitats Directive Annex I</th>
<th>Bogs/Blanket Bog (active only)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annex I Code</td>
<td>7130</td>
</tr>
<tr>
<td>EU Priority Habitat</td>
<td>Yes</td>
</tr>
<tr>
<td>UK Special Responsibility</td>
<td>Yes</td>
</tr>
<tr>
<td>UK BAP Priority Habitat</td>
<td>Blanket bog</td>
</tr>
<tr>
<td>NVC Types</td>
<td>M1, M2, M3, M15, M17, M18, M19, M20, M25</td>
</tr>
</tbody>
</table>
3.10 Common Standards Monitoring and Condition Assessment

The classification of land types and condition of Sites of Special Scientific Interest (SSSIs) has recently been reviewed and resulted in a change in the Common Standards Monitoring procedure to standardise the assessment of such sites across the UK. Prior to this, different assessment methods were used in England by English Nature (Jerram and Drewitt 1997) and Scottish National Heritage (MacDonald et al 1998).

3.10.1 Common Standards Monitoring

The guidance procedures are still being developed (JNCC 2006b), but the October 2006 Common Standards Monitoring report identified “blanket bog and valley bog (upland)” and a set of generic attributes and targets associated with this habitat type. The attributes on which the condition of the habitat type is assessed are:

- Feature extent
- Vegetation composition
- Vegetation structure
- Physical structure of peat (i.e. the extent of eroding peat in relation to the extent of deposited peat and to new peat formation within the feature)
- Indicators of disturbance from drainage or herbivores and sphagnum damage

There are now seven condition categories to be used when assessing features (Williams 2006). The three major categories are:

- **Favourable** – the objectives for that feature are being met
- **Unfavourable condition** – the state of the feature is currently unsatisfactory
- **Destroyed** – either partially or completely – the feature is no longer present and there is no prospect of being able to restore it.

Where the feature is **favourable**, it is further assessed to see if it is:

- **Maintained** – it has remained favourable since the previous assessment
- **Recovered** – it has changed from unfavourable since the last assessment

Where the feature is **unfavourable**, a further assessment is made:

- **Recovering** – moving towards the desired state
- **Declining** – moving away from the desired state
- **No-change** – neither improving or declining

The report also identifies the following areas as “very sensitive to disturbance” (JNCC 2006b):

- Slopes greater than 1 in 3 (18°) and all sides of gullies
- Ground with abundant or almost continuous cover of Sphagnum, other mosses, liverworts and/or lichens
- Areas with noticeably uneven structure, at a spatial scale of around 1 m² or less. The unevenness should be the result of Sphagnum hummocks, lawns and hollows, or mixtures of well-developed cotton-grass tussocks and spreading bushes of dwarf-shrubs. The surface of the vegetation canopy, including moss dominated areas will not be uniform and some parts should be at least 20 cm higher than other parts.
- Pools, wet hollows, haggs and erosion gullies, and within 5 – 10 m of the edge of watercourses.
3.10.2 Condition Assessment

Many areas of blanket bog in the UK have now been designated as Sites of Special Scientific Interest (SSSIs) in recognition of their wildlife and/or their geological value. Natural England (previously English Nature) has been given statutory responsibility for identifying and protecting the SSSIs in England under the Wildlife and Countryside Act 1981 (as amended by the Countryside and Rights of Way Act 2000). In 2006 the JNCC completed their first six year cycle of monitoring (1999-2005) of the designated sites using the Common Standards Monitoring procedure and set out the number of sites considered to be in unfavourable condition and the activities responsible for the assessed condition (Williams 2006). Figure 3.3 shows the main causes of unfavourable condition. The main activities are over-grazing, burning (prescribed) and water management (drainage). The impacts of these activities and others listed will be discussed in section 5.

Figure 3.3: The activities practised on blanket bog deemed responsible for causing the feature to be in unfavourable condition. (Chart and data from JNCC 2006b)
4 Management and Values of Blanket Bog

4.1 Introduction

“Peatlands are systems that change over time, both in their vegetation composition with its associated fauna, as well as in their wetness and the types of pools that exist on the surface of the peatland. We need to understand the concepts of sustainability in relation to this dynamic resource before we exploit it all” (Usher 1995, p2).

Bogs can be viewed as a natural wonder (Rackham 1986) or an economic asset. An extreme viewpoint is that “peatland is a midge-infested wasteland, a wet desert” (Lindsay 1995) where “the best thing that can happen is to turn it into something else” (Faulkener et al 1992), whereas others deem blanket bog as possessing a desolate beauty and wilderness. Such extreme views can be found amongst a diverse range of stakeholders which include landowners and managers, conservationists, researchers, archaeologists, and policy makers, each with their own agenda to maximise blanket bog to its full potential. This section will consider some of the values placed on this habitat and how stakeholders perceive these values in order to rationalise the need for management and exploitation or, more recently, conservation or restoration of blanket bog. The perceived values or functions of blanket bog have determined how blanket bog is managed currently and in the past, and helps to explain the extent of its degradation. Changes in the perception of blanket bog over the last twenty years have focused attention on this once largely ignored and despised environment, with the recognition not only of its societal and conservation functions, but the much wider and more profound role it may play in carbon storage and climate change.

4.2 The Value of Peatlands

Hughes and Heathwaite (1995) divided the values of peatlands into four main functions. Values are usually seen to relate to human use and appreciation of a habitat whereas functions depend upon the physical, chemical and biological processes that characterise a wetland ecosystem. Such processes are essential to the functioning of a bog and some of them operate irrespective of whether there is any human benefit (Immirizi 1997). Table 4.1 attempts to categorise values by function, giving references to more detailed literature.

<table>
<thead>
<tr>
<th>Function</th>
<th>Value</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biological and biochemical</td>
<td>Provision of a wildlife habitat and functions as a source and sink for carbon, nutrients etc</td>
<td>Rowell (1990), Coulson et al (1990)</td>
</tr>
<tr>
<td>Societal</td>
<td>Aesthetic and landscape values, education, cultural e.g. archaeological</td>
<td>Ingram (1997), O'Connell (1997)</td>
</tr>
<tr>
<td>Physical and hydrological</td>
<td>Role in hydrological cycle, affect on runoff, recharge of aquifers, storage of flood flows</td>
<td>Holden (2003b)</td>
</tr>
</tbody>
</table>

Immirizi (1997) recognised that the dynamic biochemical, ecological and hydrological functions will all yield a number of services, products and attributes which, although not necessarily of economic value, will have a value placed on them by society. He argued that when conserved and sustained, the sum of natural functions of peatlands could be more valuable than many of the proposed commercial developments and so help to shape stronger and enforceable legislation, wetland evaluation and/or more
enlightened and innovative policies (Immirzi 1997). Table 4.2 outlines the functions, services, products and values of peat.

Table 4.2: Functions, services, products uses and values of peatlands (adapted from Immirzi 1997)

<table>
<thead>
<tr>
<th>Conservative</th>
<th>Consumptive</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flood regulation (flood reduction)*</td>
<td>Commercial forestry **</td>
</tr>
<tr>
<td>Water supply (quantity, quality, baseflows)**</td>
<td>Grazing &amp; extensive agriculture**</td>
</tr>
<tr>
<td>Ion and biomass retention/export*</td>
<td>Intensive agriculture**</td>
</tr>
<tr>
<td>Biochemical cycling*</td>
<td>Domestic peat extraction**</td>
</tr>
<tr>
<td>Food chain support*</td>
<td>Industrial scale peat extraction**</td>
</tr>
<tr>
<td>Global biochemical cycles e.g. CO2 sink &amp; CH4 source*</td>
<td></td>
</tr>
<tr>
<td>Wildlife habitat*</td>
<td></td>
</tr>
<tr>
<td>Wildlife**</td>
<td></td>
</tr>
<tr>
<td>Paleoenvironmental archive***</td>
<td></td>
</tr>
<tr>
<td>Archaeological resource***</td>
<td></td>
</tr>
<tr>
<td>Forage**</td>
<td></td>
</tr>
<tr>
<td>Genetic resources**</td>
<td></td>
</tr>
<tr>
<td>Biological diversity**</td>
<td></td>
</tr>
<tr>
<td>Cultural –wildscape/wilderness***</td>
<td></td>
</tr>
<tr>
<td>Science***</td>
<td></td>
</tr>
<tr>
<td>Erosion prevention*</td>
<td></td>
</tr>
</tbody>
</table>

KEY: * services, ** products and uses, *** attributes

4.3 Ecosystem Services of Blanket Bog

More recently, the approach exemplified by Immirzi (1997) has been extended to recognising that ecosystems and the biological diversity contained within them provide many goods, services and other benefits to humans. These goods and services have been referred to collectively as “Ecosystem Services” (Defra 2006). An assessment of the links between ecosystems and human well-being was launched in 2001 with the Millennium Ecosystem Assessment (MA) which aimed to provide a global view of the status of biodiversity by examining how changes in ecosystems are likely to affect humans in the future. A review by eftec (2005) grouped ecosystem services into six broad categories (see Table 4.3) and many of the values and functions recognised by Hughes and Heathwaite (1995) and Immirzi (1997) are applicable to ecosystem services provided by peatlands. The following sections attempt to outline and evaluate the ecosystem services provided by blanket bog in particular.

Table 4.3: Ecosystem Service Categories (eftec 2005)

<table>
<thead>
<tr>
<th>Category</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regeneration and Production</td>
<td>production of biomass providing raw materials and food, pollination and seed dispersal</td>
</tr>
<tr>
<td>Regulation and Stabilisation</td>
<td>pest and disease control, climate regulation, mitigation of storms and floods, erosion control, regulation of rainfall and water supply</td>
</tr>
<tr>
<td>Habitat Provision</td>
<td>refuge for animals and plants, storehouse for genetic material</td>
</tr>
<tr>
<td>Cycling Processes</td>
<td>nutrient cycling, nitrogen fixation, carbon sequestration, soil formation</td>
</tr>
<tr>
<td>Information/Life-fulfilling</td>
<td>aesthetic, recreational, cultural and spiritual role, education and research</td>
</tr>
<tr>
<td>Purification and Detoxification</td>
<td>filtration, purification and detoxification of air, water and soils</td>
</tr>
</tbody>
</table>
4.3.1 Regeneration and Production Services of Blanket Bog

4.3.1.1 Production: Harvesting of Peat for Fuel

The use of peat as an alternative fuel source to firewood has been recorded since AD 23-79 by Pliny the Elder (Gottlich et al 1993). A rise in population and decline in woodland cover led to an exploitation of mires for fuel during the first century, originating in The Netherlands and then spread across mainland Europe. By the seventeenth century many ‘bog men’ eked their living from the soil and it became necessary for peat extraction to be regulated by law (Gottlich et al 1993). In Britain the rights of ‘turbary’ (i.e. the right to cut peat) were established on common land dominated by peat (Rackham 1986), and the right to cut peat for domestic use, although greatly declined during the twentieth century, still continues in remote parts of northern Britain and Ireland (Charman 2002). It may therefore be difficult to find a bog in Britain that has not in some way been modified by anthropogenic means.

The use of peat as an energy fuel in Britain has never been highly developed. However, some countries use peat as a fuel for electricity production, particularly those with a significant peatland resource. In Europe large development programmes were commenced in the 1950s, for example in countries such as the member states of the former Soviet Union, Ireland, Sweden, Germany, Denmark and Finland. Following the availability of cheap oil and coal in the 1960s, the competitiveness of peat as a fuel and the role of energy peat declined in most European countries with the exception of Ireland and the Soviet Union (IPCC 2006).

During the 1970s peatlands continued to be exploited not only for energy, but also for afforestation, horticulture and agriculture with the loss of more than 50% of pristine bogs in Western Europe. The additional environmental concerns regarding the use of energy peat, the loss of peat resources and the sustainability of their use created conflict between the conservation bodies and commercial users of peat.

More recently the issues of increasing Greenhouse Gases (GHG) and the environmental impacts of energy production have amplified the concern as peat has been classified as a fossil fuel and CO₂ emissions released during combustion are included in the calculations of the International Panel for Climate Change (IPCC). This classification and calculation model has been strongly criticised by the peat industry, particularly in Finland and Sweden (who invested heavily in the peat energy programme during the 1970s-80s), as it does not consider the annual growth of peat and the possibility of producing biomass on cut-over peatlands. A report produced by the Finnish Ministry of Trade and Industry ("The Role of Peat in Finnish Greenhouse Gas Balances") stated that peat should be classified as a biomass fuel, as distinguished from a biofuel (e.g. wood) or a fossil fuel (e.g. coal) and should therefore be regarded as a slowly renewable natural resource.

The EU Directive on the promotion of electricity from renewable energy sources (2000) set the indicative targets for the contribution from renewable energy sources to gross electricity consumption by 2010 (Vries et al 2003). The aims of the directive were to liberalise the EC electricity market whilst also contributing to the EC’s climate change obligations. The UK’s Renewable Energy policy objectives and targets are closely linked to the Climate Change Programme targets of 2000 and aimed at achieving the UK’s Kyoto targets for reducing GHG emissions. One of the means of doing so was to encourage the production of electricity from renewable energy sources with a total of 10.4% contribution being required under the Renewables Obligations regulations by 2011. The legislation was particularly relevant in deciding whether peat should be recognised as a “renewable energy source” in light of the Finnish report, or support the precautionary principle put forward by the IPCC in minimising the level of carbon omissions which they believed could not be off-set by growth of biomass.
“Renewable” energy sources were defined in the EU directive as “renewable non-fossil energy sources (wind, solar, geothermal, wave, tidal, hydropower, biomass, landfill gas, sewage treatment plant gas and biogases)”. Biomass was defined as “the biodegradable fraction of products, waste and residues from agriculture (including vegetal and animal substances), forestry and related industries, as well as the biodegradable fraction of industrial and municipal waste” (European Union 2003).

The UK implemented the Directive through Statutory Instrument No. 912 Electricity England and Wales, and the Renewable Obligations Order 2002. These regulations significantly excluded peat from being a renewable source exempt from the levy [the Climate Change levy is set on the sales of electricity, coal, natural gas and liquefied petroleum gas to the business and public sectors. Exemptions to the levy are given to electricity and other forms of energy provided by renewable sources]. During the third draft of the Order, the chair, Mr Eric Illsley had stated, “I am sorry to say that peat is not included. It cannot be regarded as a renewable resource—it has many other qualities, and beyond the way in which it is used now, we should not encourage its use as a fuel on any massive scale” (Illsley 2002).

Table 4.4 shows the estimated area of peat cover, and the production and consumption of energy peat in the United Kingdom and Ireland. Data on peat production relate to energy use only. Annual production of peat is weather dependent and varies according to rainfall and evaporation rates (high rainfall or low sunshine/wind will decrease output). The use of peat, produced commercially as briquettes, has remained a major source of fuel for electricity power stations in the Republic of Ireland with an estimated 95% of peat being burnt for that purpose (CIWEM 2001).

Table 4.4: Peat cover and production of energy peat (World Energy Council 2001)

<table>
<thead>
<tr>
<th>Country</th>
<th>Peat Area (thousand ha)</th>
<th>Peat Production 1999 (thousand tonnes of air-dried peat)</th>
</tr>
</thead>
<tbody>
<tr>
<td>United Kingdom</td>
<td>1926</td>
<td>20</td>
</tr>
<tr>
<td>Republic of Ireland</td>
<td>1180</td>
<td>2927</td>
</tr>
</tbody>
</table>

4.3.1.2 Production: Forestry

In 1919 the UK government formed the Forestry Commission, a state organisation then seen as the most effective way of co-ordinating a re-afforestation plan to meet timber needs for the foreseeable future. The specific aim of the Commission was to rebuild and maintain a strategic timber reserve which had been in steady decline since the Middle Ages, struggling to meet demands of the Industrial Revolution and severely depleted during the First World War following the demands for timber for trench warfare (Forestry Commission 2006).

In the UK, forestry is an important land use on peatland and peat is an important soil type for forestry, with any peat deposit more than 0.45m deep being classified by foresters as ‘deep peat’ (Anderson 1997). Much afforestation has occurred on blanket bog as it was considered relatively unproductive in agricultural terms and therefore was cheap to purchase (Thompson et al 1988). Most of the upland afforestation on organic soils occurred between the 1940s-80s, although the Forestry Commission research branch had devised a method of classification of peatland types based on vegetation as early as 1920. Zehetmayr (1954) summarised the planting prescriptions and research on peatland types, ground penetration methods, fertiliser needs, species choice and composition and latitudinal limits. During the 1950s extraction techniques and aerial spraying were practised in several upland areas which allowed better access for commercial planting of mainly non-native conifers species such as sitka spruce and lodgepole pine. Table 4.5 shows the areas of forest on deep peat in 1993 and this indicates the importance of forestry as a land use on
peatlands and the extensive planting that took place. Thompson et al (1988) reported that extensive areas were afforested in Wales, the Cheviots and the Southern Uplands of Scotland with even the remote Scottish Isles unable to escape substantial tracts of blanket bog being afforested on the islands of Islay, Mull and Skye. Although England appears to have relatively little afforestation on deep peat, the most significant area of blanket bog planted is Kielder Forest where 50 000 hectares were planted from 1926 – 1970, mostly as even stands of single species. The management practices necessary for afforestation on such a scale on nutrient poor, acidic soils have altered the structure and physical properties of the organic soils associated with blanket bog. The causes of degradation and the conservation and restoration policy now adopted by the Forestry Commission will be discussed in sections 5 and 6.

Table 4.5: UK Forestry Plantations on deep peat (Cannell, Dewar and Pyatt, 1993)

<table>
<thead>
<tr>
<th>Country</th>
<th>Area (km²)</th>
<th>% total of peat area</th>
<th>% of total forest area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scotland</td>
<td>1629</td>
<td>9</td>
<td>14</td>
</tr>
<tr>
<td>England</td>
<td>176</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>Wales</td>
<td>91</td>
<td>13</td>
<td>4</td>
</tr>
<tr>
<td>UK</td>
<td>1896</td>
<td>9</td>
<td>8</td>
</tr>
</tbody>
</table>

4.3.1.3 Production: Grazing for Livestock

Grazing of domestic livestock has been an important component of land use in the uplands of Britain. Historically, some researchers argue that the present state of blanket bog is undeniably related to the management it received in the past (mainly grazing, burning and drainage), thereby creating a semi-natural system (Moore 1993, Tallis 1998).

Traditionally, grazing of blanket mires would have been sustainable, that is, the vegetation composition and slow peat accumulation would have been maintained. Agricultural reform, particularly following the Second World War, led to an expansion and intensification of farm practices that was extended into the uplands (Defra 2002). The support system was enforced through the Hill Farming Act (1946) which provided headage payments for breeding livestock. Between 1975 and 2000 these payments were paid on sheep and suckler cows as Hill Livestock Compensatory Allowances (HLCA) and supplemented by the Sheep Annual Premium (SAP). The HLCA acted as the main means of support for farmers in areas designated under the Less Favoured Area (LFA) Directive in Britain and acted as an incentive for farmers to raise livestock numbers to unsustainable levels and to graze on land not previously thought suitable for livestock, such as blanket bog (Shaw et al 1996, Evans 1997, Defra 2003a). This latter point was overcome by the LFA paying up to 70% of costs for the drainage of moors (the highest rate payable for any form of capital expenditure on farming) to make them more suitable for the grazing of livestock (Stewart and Lance 1983).

Since 2001, support for the LFA has fallen under the Rural Development Regulation and the LFA support has been paid under the rural development programmes for each of the UK countries, changing from a headage payment system to an area based mechanism. The relevant schemes are the Hill Farm Allowance Scheme (England), Tir Mynydd (Wales), Less Favoured Areas Support Scheme (Scotland) and LFA Compensatory Allowances Scheme (Northern Ireland) (Defra 2003b). Such agri-environmental schemes should encourage de-stocking and indirectly support the recovery of habitats such as blanket bog by reducing pressure on the land type. However, Natural England has identified over-grazing as one of the largest single causes of damage to upland SSSIs despite the change in policy (JNCC 2006b, see Figure 3.3). It is therefore unclear how long the impacts of historic over-grazing will
have on blanket bog and how soon the soils will begin to recover following the reduced grazing regime. This cause of degradation and mitigation measures for restoration following over-grazing will be discussed in sections 5.4.3, 6.4 and 6.6.

4.3.1.4 Production: Grouse Shooting

In England and Wales there are approximately 160 estates where grouse shooting occurs, covering an estimated area of 2750 km² with an average estate size of 20 km² (5000 acres) (Moorland Association 2006). The total area where grouse shooting occurs covers approximately 800,000 acres where on average 200,000 grouse are shot in a shooting season (August 12th – December 10th). The Moorland Association (2006) states that shooting tenants and their game keepers apply a sustainable approach to the sport by only commencing the shoot if a count realises 200 grouse/km², to ensure a reasonable stock for subsequent years.

"There is …. no doubt that shooting provides, in many upland areas, the only income, and it is that which pays for the maintenance, heather burning and so on...." Baroness Mallalieu, Hansard; 5 October 2000

The shooting of grouse, Lagopus lagopus scoticus is one of the main forms of income for the uplands and despite a decline in grouse numbers (most recently recorded from 1975 – 1983) grouse shooting has continued to remain a popular and profitable sport in the UK (Davies 2005). The decline has been linked to several reasons which include the loss of heather moorland and subsequent closure of several shooting estates, reduction in gamekeepers managing the moor and an increase in predator species. In addition, an increase in viral infections such as loup ing-ill transferred from sheep ticks to host animals resulting in the infection of chicks and the widespread parasitic worm, Trichostrongylus tenuis, which reduces grouse survival and breeding success have affected populations of grouse (Hudson 1992, Cox 2003).

Prescribed burning of Calluna vulgaris has been used as a traditional management tool to maximise grouse densities for sporting purposes. The burning helps prevent establishment of woody species, reduce plant litter and release nutrients (Gimmingham 1975). Such management then stimulates earlier growth of vegetation and temporarily increases the accessibility, palatability, and nutrient content of forage for grouse and livestock, thus optimising the populations for maximum profit (Lawton 1990, Tucker 2003). Although most of the burning is conducted on shallow peat and podzolic soils, it also encroaches onto adjacent areas of deeper peat found on blanket bog (Yallop et al 2005, O’Brien et al 2006). The conflicting and controversial evidence of the impact of prescribed burning on blanket bog and the associated effects will be discussed in sections 5.4.1 and 6.5.

4.3.2 Regulation and Stabilisation Services of Blanket Bog

4.3.2.1 Physical and Hydrological Function

Perhaps one of the most important, yet indirect functions of blanket bog is its ability to store water and provide runoff for water companies (potable water) and many major rivers (wildlife and navigation) in England. The quantity, quality and distribution of water throughout an upland catchment are affected by basic peatland hydrology. Recent advice on the restoration of blanket bog has advocated that a thorough understanding of the hydrology of a peatland restoration site is necessary prior to the commencement of any programme of restoration (for example Wheeler et al 2002, Acreman and Miller 2005). However, peatland studies indicate that the underlying hydrology is often complex and difficult to quantify (Holden et al 2004) and within site variations of hydrological and hydrochemical regimes will effect the
vegetation composition and structure (Ingram 1997, Mountford and Chapman 1993). There are some examples where wetlands (including blanket bogs) can reduce floods, recharge groundwater or augment low flows (Maltby 1997), but recently emphasis has been placed on the integrity of these systems as providers of water resource management (Bullock and Acreman 2003). For example, Burt et al (1990) found that peatlands were generally poor aquifers which yielded a low base flow during dry conditions and provided a very rapid response to precipitation events, thereby increasing flood peaks and an immediate response of rivers to rainfall which generated higher volumes of flood flow. This function generally occurs when the headwater peatlands are saturated and transport rainfall rapidly to the main river channels through a process of overland or sub-surface flow (Burt 1995, Evans et al 1999). The hydrological processes on a disturbed blanket bog have however, been affected by the anthropogenic influences such as the digging of moorland grips (ditches) to drain blanket bog or the blocking of moorland grips to re-wet them once more. The effects of this management will be discussed further in sections 5 and 6.

4.3.2.2 Potable Water Supply and Water Quality

In an intact peatland catchment saturation-excess overland flow or near-surface throughflow can dominate the response during a rainfall event (Holden and Burt 2003a, 2003b) and generate an extremely rapid runoff from upland blanket peat which can quickly re-charge upland reservoirs used for potable water storage (Burt et al 1990, Burt 1995, Holden and Burt 2003a).

Upland catchment areas of blanket peat have therefore been seen traditionally as a plentiful and cheap source of good quality water requiring minimal and inexpensive treatment (Naden and McDonald, 1989) with one third of the water consumed in the UK being supplied from upland reservoirs (Kay et al 1989). For example, the Howden, Derwent and Ladybower reservoirs in the south Pennines have a total holding capacity of 46345 Ml of water and provide a major source of potable raw water to the Midlands (PDNPA 2006). However, rising water colour in many peatland catchments, noted since the on-set of severe droughts in the 1970s, has increased capital and recurrent costs and reduced customer satisfaction. All of these are concerns to water companies whose catchments include areas of upland blanket bog which act as gathering grounds for the raw water (McDonald et al 1987, Pattinson et al 1994, Matilainen et al 2002). Discoloured water is undesirable for domestic use on aesthetic grounds, may increase food production costs, and can act as a deterrent to consumption of water which may otherwise be considered safe (Packman 1990, HMSO 2000).

Freshwaters draining from blanket peat can exhibit brown colouration naturally through the release of dissolved organic material (DOM) as a result of the process of humification (Worrall et al 2002) and subsequent release of humic and fulvic acids (Scott et al 2001, Dawson et al 2002). The escalation of discolouration since the on-set of severe droughts in the mid 1970s (Mitchell and McDonald 1992, Evans et al 1999) may also have been exacerbated by management practices on upland blanket bog catchments, such as prescribed (controlled) burning, drainage (artificial) and intensive grazing. Such practices have been linked with blanket bog degradation by several authors e.g. Anderson et al (1997), Bragg and Tallis (2001). However, there is little science-based evidence to indicate whether there is a link between such management practices and the level of discoloured water and carbon (dissolved, particulate, inorganic) generated in these upland catchments (Glaves and Haycock 2005). Several water companies are currently funding research to investigate the relationship between water colour/carbon generation and upland management, to determine if sustainable catchment management is an effective means of supporting traditional water management at the treatment works to ameliorate water discoulouration. Water companies that have contributed to the funding of research
to investigate water discolouration, carbon loss and land management include Severn Trent Water (O’Brien et al 2005), Yorkshire Water (Holden et al 2005b, 2006b) and Northumbrian Water (Worrall, Armstrong and Adamson 2007). The findings of this research are discussed further in sections 5.4.4 and 6.3.

4.3.3 Habitat Provision Services of Blanket Bog

4.3.3.1 Wildlife Conservation Value

The UK uplands represent some of the largest areas of ‘semi-natural’ habitat in Britain and as such are regarded as a resource of high conservation value (Backshall et al 2002). Blanket bogs represent a unique mosaic of habitats and vegetation structures for many species of plants, some of which are endemic to blanket bog in general or to specific blanket bog sites, for example, the rare Labrador tea bush, Ledum groenlandicum and uncommon bryophytes such as Sphagnum imbricatum (Rodwell 1991, PDNPA 2001).

The UK uplands support an internationally important assemblage of breeding birds, many of which are of particular conservation importance and are listed as ‘red data’ species (species threatened with extinction). Hen harriers, merlins, short eared owls, golden plovers, dunlins and greenshanks breed on the hummocky vegetation. A number of other important bird species such as peregrines hunt over some blanket bog and, throughout its range, meadow pipits, skylarks and red grouse are present although at varying densities (Thompson et al 1998). The invertebrate populations are comparatively poorly studied, but they provide an important function as herbivores, decomposers and food sources, particularly for birds.

Two particular species of mammal associated with blanket bog are considered to be of special conservation importance. The mountain hare Lepus timidus, native to Scotland, is only present in the Peak District where it was introduced in the 1860s (Mallon et al 2003) and quite recently the headwaters of upland catchments have been recognised as relatively safe refuges for the endangered water vole, Arvicola terrestris (Fraser et al 2006). Small mammals such as the field vole, Microtus agrestis are widespread and abundant, providing an important food source, particularly for birds of prey.

Although amphibians and reptiles are generally not abundant in upland habitats, the common frog, Rana temporaria and the common lizard, Lacerta agilis, are particularly associated with blanket bog. The lizard is mainly found in more open, drier areas of blanket bog, more typical of upland heath and is a priority species due to its scattered distribution. It is considered locally rare, endangered or declining on some areas of blanket bog (Duke and Firman 2003).

4.3.4 Cycling Services of Blanket Bog: Carbon Sequestration

Blanket bogs are essentially unbalanced ecosystems where the rate of accumulation of plant biomass exceeds that lost by decomposition. As a result they are also recognised globally as an important component of terrestrial carbon storage, sometimes referred to as a ‘sink’ as they contain a high proportion of partially decomposed organic matter of which approximately 50% is organic carbon (Garnett et al 2001, Holden et al 2006a). Biological processes occur during the active growth of mire vegetation when the plants photosynthesise and absorb atmospheric CO₂ to produce carbohydrates within the plant. Organic carbon is then transferred from the plant to the soil by roots and litter fall as the vegetation begins to die off. Effectively, the blanket bog sequesters CO₂ from the atmosphere and preserves it in
the accumulating peat as the plant material and organisms slowly decompose (Clymo 1983).

In addition to the biological processes, the long-term sequestration of carbon in peat involves hydrological processes which operate at different spatial scales. As each year’s decaying vegetation builds up, the plants begin to lose their structure and contribute to the poorly humified, aerobic and porous peat layer known as the acrotelm (Heathwaite and Gottlich 1993, Ingram 1983). Decrease in the pore sizes of the lower layers beneath the acrotelm reduces the hydraulic conductivity of the peat, so that precipitation is dispersed primarily through the acrotelm near the bog surface, while lateral seepage through the denser and compacted underlying layer (the catotelm) is impeded (Belyea and Clymo 2001). Ingram (1978) estimates carbon sequestration in the permanently water logged anoxic catotelm is approximately a thousand times slower than in the aerobic upper acrotelm layer. Therefore carbon is sequestered over a long time-scale by the thickening of the catotelm and a rise in the water table which effectively waterlogs the upper layer and so reduces the depth of the aerobic acrotelm layer (Clymo 1984).

Although it is accepted that organic soils, and in particular peatlands, provide a major proportion of the global supply of terrestrialised carbon (Clymo 1984, Freeman et al 2001), there are still problems in accounting for the continuous long-term peat decay. The differences between the ‘apparent’ and ‘actual’ rate of carbon accumulation are estimated by taking into account the long-term decay of peat (actual takes into account long-term decay but apparent does not). Table 4.6 shows a range of estimates of global terrestrial carbon storage, which are driven largely by prevailing climatic conditions. Changes in the climatic water budget are likely to have large effects on peatland carbon sequestration in the future, most immediately through the control of decomposition of vegetation into peat in the acrotelm (Hilbert et al 2000). The negative feedback into the carbon cycle from global warming (i.e. the role reversal of the carbon store becoming a ‘source’ instead of a ‘sink’) may infer that even small changes in soil carbon stocks may contribute significantly to climate change (Cox et al 2000) and therefore accurate estimates of the C store are required to determine their importance in regulating atmospheric CO₂ concentrations (Garnett et al 2001).

Table 4.6: Estimates of Global Soil Carbon Accumulation (Adapted from Adams and Lioubintseva 1999)

<table>
<thead>
<tr>
<th>Carbon (Gt)</th>
<th>Reservoir Type</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1115</td>
<td>Soils and present potential (prehistoric)</td>
<td>Adams et al (1990)</td>
</tr>
<tr>
<td>1395</td>
<td>Peat and soils, present potential</td>
<td>Adams et al (1990)</td>
</tr>
<tr>
<td>1640</td>
<td>Soils and peat and litter</td>
<td>Macdonald (1992)</td>
</tr>
<tr>
<td>860</td>
<td>Peatlands – present day</td>
<td>Bohn (1976)</td>
</tr>
<tr>
<td>1500</td>
<td>Soils in 1989</td>
<td>IPCC (1990)</td>
</tr>
<tr>
<td>300</td>
<td>Peats</td>
<td>Sjors (1980)</td>
</tr>
<tr>
<td>180-227</td>
<td>Peats</td>
<td>Gorham (1992)</td>
</tr>
<tr>
<td>1576</td>
<td>Global soils (present-day)</td>
<td>Eswaran et al. (1993)</td>
</tr>
<tr>
<td>500</td>
<td>Global peats</td>
<td>Markov et al. (1988)</td>
</tr>
</tbody>
</table>
Therefore, one of the key questions that is being asked today is how peatlands (and in the case of this review, blanket bogs in particular) will react to global climate change. There is much speculation as to whether these important land types valued for their carbon storage will become carbon sources with a potential to lose thousands of tons of carbon a year and so contribute to global warming (Freeman et al 2001). It has been estimated that a lowering of the water table and subsequent oxidation of as little as 2mm of peat could potentially yield up to 1.6 billion tonnes of CO$_2$, which is equivalent to 8% of current fossil fuel release – although this could be counterbalanced by the reduced output of methane released from intact bog (Holden 2006a).

Many of the estimates of C accumulation have been made on an *ad-hoc* basis without any allowance for the possible ‘pre agricultural’ state of vegetation and soils built into the models. It is evident that background changes in anthropogenic disturbance need to be taken into account in estimates of carbon storage changes in the past, as well as estimating changes for the future as this may have a significant effect on global warming (Adams and Lioubimtseva 1999).

A number of authors have attempted to estimate the carbon budget for the UK and this has been further sub-divided into England and Wales, and Scotland (e.g. Milne and Brown 1987, Garnett et al 2001, Worrall et al 2003). Table 4.7 shows the estimates of soil carbon in organic soils at different depths in England and Wales only. Although these estimates are based on a number of assumptions and data are limited for the bulk density and depths of some peat soils, it is nevertheless apparent that a large amount of carbon is bound-up in these organic soils. **It may therefore be necessary to take measures which may include sustainable management and the ‘restoration’ of blanket bog in order to enhance the carbon sequestration process and so ameliorate the release of CO$_2$ and its contribution to global warming** (as proposed more generally by Marland et al 2004).

Carbon may be released from peat into water in a number of forms including dissolved organic carbon (DOC) and particulate organic carbon (POC). Comprehension of the complex hydrological processes of blanket peat and their response to different types of land use is limited, and to include the complexity of response to climate change in order to estimate current or predict future rates of carbon sequestration may be considered by some as inconceivable. **An understanding of the fluxes of carbon (dissolved, particulate and gaseous), their association with water movement in peatlands and their inter-action with other environmental factors such as atmospheric deposition of nutrients is a major requirement for the future.**

**Table 4.7: Soil Carbon in Organic Soils in England and Wales**

<table>
<thead>
<tr>
<th>Carbon (Mt)</th>
<th>Depth (cm)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>2773</td>
<td></td>
<td>Howard <em>et al</em> (1994)</td>
</tr>
<tr>
<td>2890</td>
<td></td>
<td>Milne &amp; Brown (1997)</td>
</tr>
<tr>
<td>1209</td>
<td>0-30</td>
<td>Bradley <em>et al</em> (2005)</td>
</tr>
<tr>
<td>870</td>
<td>30-100</td>
<td>Bradley <em>et al</em> (2005)</td>
</tr>
<tr>
<td>864</td>
<td>0-15</td>
<td>Bellamy <em>et al</em> (2005)</td>
</tr>
</tbody>
</table>
4.3.5 Information/Life fulfilling Services of Blanket Bog

4.3.5.1 Landscape, Culture and Education Values

Lindsay (1995) suggested that many people may value blanket bogs for their aesthetic quality and see them as the last true wilderness in Britain, attracted by the vast openness, apparent remoteness and sometimes bleakness of this landscape. This has been recognised with the designation of many upland areas which include blanket bog as Areas of Outstanding Natural Beauty (AONBs). As such they have been described as “the jewels of the landscape” and are “protected landscapes” by law to ensure conservation and enhancement of their natural beauty now and for future generations (Natural England 2006b). However, under recent government guidelines there has been a move away from these designations in order to ensure that all countryside and landscapes are managed sustainably in the future (Natural England 2006b). This is being done through the further development of Landscape Character Areas. One example is the Derbyshire Landscape Character Assessment project to support positive planning policies and encourage sustainable development.

In addition, the European Landscape Convention (ELC 2000) is a new instrument which the UK signed in February 2006, to protect, manage and plan all landscapes in Europe. The convention recognises the relationship between place and people in the landscape and states that the landscape “contributes to the formation of local cultures and ... is a basic component of the European natural and cultural heritage, contributing to human well-being and consolidation of the European identity”. The emphasis is to stress the importance of landscape as being more than just “a view” and that it is the interaction of people with the place and the experiences gained that is central, together with the legacy of historical use of the land and how this has been shaped by human activity, land use (past and present), wildlife and the natural form (geology, drainage systems, soil, and vegetation) (Countryside Agency 2006). The archaeological and palaeological records provide much of the environmental evidence of past land use of blanket bog and these are an important source from which to interpret past landscape change associated with human activities. Stone circles, human artifacts and remains have provided evidence of our long association with this land type.

Much time and resources have been invested in informing and educating the public to conserve peatlands, particularly in heavily populated areas such as the Peak District where blanket bogs are close to schools and universities and can provide an outdoor classroom in which to learn. Many of the National Parks now employ education officers to provide information, written material and accompanied visits to areas of the Parks that include areas of blanket bog. Conservation organisations such as Scottish Natural Heritage (SNH), the Irish Peatland Conservation Council (IPCC) and Friends of the Earth have produced blanket bog education packs and advice for teachers to incorporate material into the curriculum, for example the “Wild, Wet and Wonderful” education pack (SNH 2006). Such initiatives may help in raising public awareness of the values of blanket bog and may assist in safeguarding it for the future.

4.3.5.2 Visitor Access

In the last forty years the number of people visiting upland areas including blanket bog has increased significantly, largely due to ease of access by motor vehicle. The rise in disposable income, early retirement age and increased leisure time has attracted many people to a variety of recreational activities such as hill walking, fell running and orienteering, mountain biking and off-road driving in these areas
(PDNPA 2006). It appears the relatively recent sport of “bog-snorkelling” is still restricted to Wales and Ireland (BBC 2005).

The expansion in people pressure on this sensitive landscape has been linked to increases in erosion of roadside verges, footpaths and adjacent bog; atmospheric pollution from vehicles, and perhaps most disconcerting, the risk of wildfire (an unplanned or dangerous fire) and the devastating consequences to huge areas of upland (Cosgrove 2004). These effects will be discussed further in sections 5.4.2, 5.4.6 and 6.8.

### 4.3.6 Purification and Detoxification

Blanket peat in its active form has been recognised for providing an important function in the filtration and purification of water, the detoxification of polluted air (for example, by providing a sink for atmospheric carbon and heavy metals) (Moore 2002, Eftec 2005). However, it is claimed that the ability for blanket peats to purify air and water has deteriorated as modifications to enhance one ecosystem service has generally been at the cost of another (Kettunen and ten Brink 2006).
5 Blanket Bog Management and Causes of Degradation

5.1 Introduction

The degradation of peat, evident by a reduction in peat extent and/or depth, can result from a number of natural processes which can break down the relatively fragile web of internal structures and the ‘skin’ of vegetation on the surface (Chapman 2002). A peat mass is particularly susceptible due to its high water content, low hydraulic conductivity and poor cohesiveness, making it liable to damage by natural factors such as wind, frost, drought, and water (Tallis 1998, Warburton 2003).

When considering blanket bog degradation, all processes which reduce organic accumulation need to be taken into account. These include soil erosion, peat decomposition and leaching, all of which may be exacerbated by natural or anthropogenic factors. Several comprehensive reviews on the impacts of particular land management practices have already been conducted prior to the completion of this review, and it is recognised that some overlap will inevitably occur. Recent reviews have especially focused upon heather and grassland burning (Tucker 2003, Glaves et al. 2005, Stewart et al. 2004). These were intended to update the current knowledge since the publication of the English Nature Research report, “Literature review of the historical effects of burning and grazing of blanket bog and upland wet heath” (Shaw et al. 1996). The Centre of Evidence Based Conservation (University of Birmingham) has also initiated a number of systematic reviews to determine the level of scientific evidence available on management practices which may degrade blanket bog of which reference will be made (Stewart et al. 2004).

It is essential also to consider the implications of climate change on blanket bog and the significant effects it may have on future management practices and in particular on restoration. This section will therefore also consider changes in the biochemical and hydrological functions of blanket bog and how natural factors such as climate may affect the accumulation or degradation of peatland. It will discuss how these processes might be amplified by predicted changes in climate and by land management practices.

Atmospheric pollution has also been recognised by many authors as a major threat and cause of degradation to blanket bog (e.g. Tallis 1965, Phillips et al 1981, Mackay & Tallis 1996, Proctor & Maltby 1998). The impacts of sulphur and nitrogen deposition have been identified as being of particular relevance in changing the acidity of the soil with the deposition in particular of SO$_2$, NO$_3$, NH$_4$ ions originating from industrial pollutants (Proctor 1992, Yesmin et al. 1996, Monteith & Evans 2000, Neal et al. 2003). A recent review of organic soils in England and Wales by Holden et al (2006a) examined the impacts of atmospheric pollution on organic soils and includes many references to upland peat soils. Although it is recognised that the management and restoration of blanket bog may affect the storage or release of these acids, together with mobilisation of heavy metals, the management of blanket bog has not been a direct causation of the deposition and therefore it is considered beyond the scope of this section.

5.2 Measurement of Blanket Bog Degradation

In addition to assessment of blanket bog degradation through ecological methods such as the Common Standards Monitoring approach (JNCC 2006b, see also section 3.10), there is a body of research that has assessed blanket bog condition by more direct reference to the geomorphology associated with this habitat and the rates of erosion of peat from the land surface. A blanket bog in good condition should have a
high water table and should not have extensive areas of bare peat exposed. As discussed in section 3.5, water should flow mostly at or near the surface, through the poorly humified acrotelm layer. The development of dense gully systems to channel away surface water has also been widely associated with degradation of blanket bog, although some stream networks may be much older and considered “natural”. Mackay (1997) stressed the need for a detailed assessment to determine the type and extent of erosion in UK peatlands, in order to understand the level of peat loss from these land types.

A number of different methods have been developed and adopted to measure degradation of blanket bog. Most of the early work concentrated on observing the landscape features or vegetation composition and making a qualitative assessment of blanket peat. For example, Pearsall (1950) refers to “fat” and “thin” moors to denote the depth of peat soils based on whether they originated from woodland and described the erosion and dissection of large areas of moorland “until much more has been removed than is left” (Pearsall 1950 p 25). Conway (1954) and later Tallis (1965, 1973, 1997) used pollen analysis and radiocarbon dating to assess the stratigraphy of peat soils and to approximate rates of accumulation and losses of peat.

The first systematic attempt to categorise features of blanket bog erosion was completed by Bower (1960, 1961, 1962) in the south Pennines. She identified five erosion features created by two major peat erosion processes, namely flowing water and mass movement (see section 5.3.4.1 for more detail). Later workers criticised this rather descriptive method and suggested that there is a continuum of erosion forms rather than a discrete division between linear and dendritic drainage. Recommendations have been made to further quantify the types of gully erosion through the implementation of a simple classification scheme to include linear, dendritic and anastomosing gully patterns (Wishart and Warburton 2002).

Direct measurements of a number of variables have been used to determine the rate of blanket peat erosion. Techniques used to quantify the loss of peat from bare surfaces and gully walls include the use of erosion pins (e.g. Tallis 1981, Labadz 1988, Birnie 1993, Stott 2005, Yang 2005, Evans and Warburton 2005). Pins are inserted into the bank at known locations, leaving a known length exposed to provide a point from which erosion can be measured. It should be noted that Labadz (1988) found much peat eroding from around a pin at the top of the slope would often become detained by the next pin down the slope, and that significant pedestals of peat developed around some pins. The reliability of these methods and reporting of data have therefore sometimes been questioned (e.g. Coupar et al 2002) but they are still widely used as a simple and cheap way of estimating peat surface lowering.

Sediment traps have been used to measure movement of loosened peat from gully walls and to estimate the frequency and extent of erosion from steep, exposed surfaces (e.g. Tallis 1983, Warburton 2003, Evans and Warburton 2005). These traps are often in the form of troughs made from plastic piping. Limitations include the frequency of field visits needed to obtained detailed information about peat movement, and the need for accurate survey of the contributing area, but again they provide a cheap and reliable means of estimating peat erosion on gully sides of bare peat flats.

Areas of bare peat, often thought to be the areas of maximum erosion and desiccation, have been measured and monitored through dated comparative photographs (e.g. Clement 2005, Evans 2005). Analysis of changing gully networks has also been undertaken from remotely-sensed data such as aerial photographs or satellite imagery.
Blanket peat moorlands are often used as catchment areas for water supply, so long-term rates of blanket peat erosion (over a period of around 150 years) can be estimated from rates of reservoir sedimentation. These rely either on drainage and coring of a reservoir, to construct a detailed stratigraphy and dating of sediments (eg Yeloff et al 2005) or on comparison of original figures with current reservoir capacity based on topographic or bathymetric (echo-sounder) surveys (e.g. Labadz et al 1991, Butcher et al 1992).

Contemporary rates of blanket peat loss through drainage dissection (including gully/grip erosion) have been estimated by a number of workers through the measurement of fluvial suspended sediment flux in a number of upland catchments. This is achieved either by collecting frequent water samples and filtering to assess the amount of peat present in the water, or by use of a turbidity meter calibrated against such samples (e.g. Labadz et al 1991, Evans and Warburton 2001, Harvey 2001, Worrall et al 2003). Both the reservoir survey and stream sampling methods assess sediment yield at a particular point in the catchment rather than measuring all the erosion occurring on the hillslopes, so different approaches may be used in the same study to construct a sediment budget for the bog (Evans et al 2006).

Whilst estimating the erosion caused by natural processes, identification of any additional erosion caused by anthropogenic factors is fraught with difficulty. Several authors have therefore tried to identify the effects caused by a particular land use by means of either temporal comparisons (before and after a change in management) or a paired site/catchment approach.

An early example was the work of Burt and Gardiner (1983), who compared runoff processes and peat erosion from two neighbouring catchments where one had a relatively uneroded, linear gully network and the other had a much more dense dendritic network of stream channels within the blanket peat. The paired site method has also been used to determine long-term changes in water yield or sediment flux that may occur from large-scale changes in vegetation and hydrology that are a consequence of changes in land management practices (e.g. Garnett et al 2000, Bardgett et al 2001, Evans and Warburton 2001, Armstrong et al 2005, O’Brien et al 2005). Wallage et al (2006) used this approach to investigate effects of grip blocking on water tables and dissolved organic carbon.

A number of other studies have focussed on the same site/catchment both before and after changes in land management practice. This requires forward planning and a longer-term approach than that necessary for paired catchments. The first such studies (not on blanket peat) concentrated on the effects of afforestation/deforestation, eg. the Coweeta Long Term Ecological Research Project in North America providing valuable long-term information on changes in the hydrological processes (Hibbert 1969, Elliott et al 1990, Webster et al 1992, Swank et al 2001). Paired catchment experiments and research have been adopted at several in the UK, particularly on blanket bog upland catchments where blocking of grips or gullies is occurring. Changes in the hydrological processes are perhaps easier to observe as these precipitation-fed catchments rely on one principal source of water only (e.g. Mitchell 1991, Mitchell and McDonald 1995, Worrall and Burt 1999, Evans and Warburton 2001, Holden et al 2004, O’Brien et al 2005). Of particular importance to blanket bog management and restoration are the long-term studies completed at the Moor House Reserve, Upper Teesdale with its extensive blanket peatlands, and upland sites monitored by the Acid Waters Monitoring Network, providing long-term data on several upland areas of blanket bog (Evans et al 2005, Monteith and Evans 2000). It should be noted, however, that long-term studies can only identify effects of changing land management if other factors remain constant. Given current predictions of climate change, paired catchment studies have an advantage here.
5.3 Causes of Blanket Bog Degradation – Natural Factors

5.3.1 Wind Action

Wind exposure at high altitude in the uplands of the UK is severe, with high evaporation losses from the soil, and transpiration from vegetation (Tallis 1985). Isolated plants are particularly vulnerable to exposure and although some areas of surrounding bare ground may readily be colonised by bryophytes, the peat may become so unstable and erodible when exposed that vegetation cannot easily take hold (Evans, 1997).

General observations of the removal of organic soils by wind have been made during periods of prolonged drought in spring and summer (Glatzel et al. 2006) and also in winter during periods of prolonged cold, dry weather when material is loosened by frost action (Evans 1997). Defra (2005) suggest that light peaty soils less than 1mm in diameter and containing more than 20-30% of organic matter are particularly vulnerable to wind-blow due to the low density and lack of cohesion and structure once desiccated (Evans 1997) suggesting blanket bog soils may be particularly vulnerable.

Although erosion of peat has been well documented since the 1960s (e.g. Bower 1960, 1961, 1962, Tallis 1965) and the significance of wind action in upland landscapes is well recognised by the aeolian landforms on the British uplands, such as deflation surfaces and wind-patterned ground (Ballantyne and Whittington 1987). The first systematic measurement of peat erosion by wind in the UK uplands was by Warburton (2003). He measured mass of wind-blown peat and calculated that it was equivalent to an average lowering of the peat surface of 3mm in the field. Warburton (2003) concluded that wind erosion, when coupled with rain-splash erosion, could be significant in the UK uplands where winds are strong and persistent and rainfall is high, causing localised degradation. In a more recent study, Foulds and Warburton (2007) again emphasised the effects of peat erosion by a combination of rainfall and wind, stating that peak flux rates of peat under these conditions were up to 2 orders of magnitude greater than under dry conditions, even though the latter saw fine peat dust raised to greater heights (up to 1.87m compared to 0.3m in wet conditions).

5.3.2 Frost Action

Higher altitude and lower temperatures in the uplands increase the number of occurrences and prolonged periods of frost compared to other parts of the country. Frost heave during the winter months often causes bare peat to have a ‘puffed up’ appearance, loosening the surface and causing a gradual loss of structural cohesion. This makes the surface more susceptible to movement and loss through wind or water action (Tallis 1973, 1998). A high water table during the winter and penetration of frost down to 10 cm allows needle ice to form readily on saturated peat surfaces during periods of low temperatures (Evans and Warburton 2001). Typically these layers of needle ice are capped with a thin layer of peat which has been heaved up and takes on the ‘puffed’ appearance when the ice melts and the peat is left as a loose layer on the surface. Tallis (1973) recorded a total of 28 between 1971-72 at Featherbed Moss, south Pennines and noted subsequent removal of layers of peat by wind and rain action, allow only the more resistant debris to remain on the surface in the form of upstanding pinnacles. Figure 5.1 demonstrates the result of frost heave and subsequent movement of loose peat onto snow in a gully in the Peak District.
The instability of a blanket bog surface and the considerable temperature fluctuations experienced may provide an inhospitable environment for establishment of plant propagules (Tallis and Yalden 1983). Frost heave may expose the roots of plants so the soil root may be broken by physical means (wind, rain, frost, animals) and so prevent water absorption. Exposure of the mineral substratum can also exacerbate problems of re-vegetation, both physically and chemically.

### 5.3.3 Drought

During the summer, areas of bare peat previously eroded by wind and frost action may be subject to desiccation and wind-blow (Tallis and Yalden 1983). Desiccation in peat soils has been recorded as rarely penetrating to more than 15-20 cm depth, even following a prolonged drought and therefore appears limited to within the less humified and more aerobic acrotelm layer (Ingram 1987, Francis 1990, Evans et al 1999). The low albedo of bare peat raises surface soil temperatures as the radiation is readily absorbed into the dark surface, causing the temperature in the upper layers of peat to rise (Watts et al 2001). This, together with a lowering of the water table and loss of soil moisture through evaporation, can create a hard upper crust on the peat which may crack into polygonal flakes which are then removed by wind and/or rainsplash erosion (Morgan 1995, Warburton 2003). The surface crust may also reduce the infiltration capacity and thereby promote greater surface runoff and erosion (Evans et al 1999). Alternatively, rainfall may penetrate into the peat mass down the desiccation cracks causing an overall increase in the infiltration rate and a change in the runoff process by promoting lateral subsurface flow, for example through pipeflow beneath the peat surface (sub-peat tunnels or pipes at the interface between the base of the peat and the mineral substrate) (Holden and Burt 2002b, Holden 2005b). Figure 5.2 shows an example of the cracked and desiccated peat surface resulting from drought conditions.
As the upper layers of peat dry out they change their physical and chemical composition so that they become hydrophobic in nature and resistant to re-wetting (Egglesmann et al 1993), and therefore more susceptible to the effects of wind and water erosion. Such changes in organic soils may be irreversible and therefore a simple ditch blocking technique may not provide effective re-wetting of the acrotelm and may have to be carried out with other approaches (Wheeler et al 2002).

Areas particularly vulnerable to desiccation are steep-sided gullies located within deep peat with a slope greater than 5 degrees (Pattinson et al 1994), where it is difficult to re-establish vegetation due to the soil instability. Gully walls with a southerly aspect are more susceptible to fluctuations in temperature and may erode at a greater rate than north-facing slopes due to their exposure to wind, radiation and the forces of gravity (Mitchell and McDonald 1995). Figure 5.3 shows a steep gully wall with a bare peat surface. The solifluction “head” deposit represents the surface deposit consisting of rock fragments typically in a sandy and silty matrix and formed by the seasonal downslope movement of surface soil under periglacial (areas where ground was permanently frozen and permafrost developed) conditions. These topographic and geomorphic conditions have also been linked to the production of water colour, dissolved organic carbon, and increased sediment flux associated with peat desiccation on blanket bogs (Labadz et al 1991, Evans and Warburton 2001, Worrall et al 2002, Holden et al 2004, Warburton 2003).
The loss of soil moisture retention capacity and fluctuations in surface and sub-surface soil temperatures may also stunt root growth and induce root mortality, making the re-establishment of vegetation difficult and leading to an increase in areas of bare peat if unchecked (Tallis and Yalden 1983, Anderson et al 1997). Isolated stands of vegetation and individual plants are particularly vulnerable to desiccation as peat continues to be eroded from around the plants. This can result in pedestals of vegetation standing proud of the surface (Anderson et al 1997). Bryophyte species may also be prevented from establishment in desiccated areas due to water availability (Clymo 1997, Buttler et al 1998, Gorham and Rochefort 2003). This is particularly important when the specific aim of re-establishing vegetation in many restoration projects is to reconstruct the soil’s physical structure in order to sustain hydrological function and allow the bog to act as a carbon sink (Buttler et al 1998).

5.3.4 Flowing Water

In an active blanket bog, where peat is steadily accumulating, the water table should be relatively stable and should remain at or near the surface (Evans et al 1999, Keddy 2000, Holden et al 2004). Such conditions indicate that peat soils are saturated and have reached a constant or minimum infiltration capacity (Labadz et al 2002). Thus, the prevailing high water table in a peat mass limits its capacity to retain water and much of the water is discharged at the margins of the peat blanket to pass into the main drainage channels of the catchment (Tallis 1998). The discharge may be in the form of runoff across the peat surface (diffuse flow, open channel flow or directed flow in shallow water tracks) or actually within the peat mass in the form of pipe flow or lateral seepage through the acrotelm (Ingram 1983, Labadz et al 2002, Holden and Burt 2003a, 2003b). The hydrological functions of peat were discussed in section 3.5 and their contribution to the erosion of blanket bogs is discussed here.

The overriding type of runoff from a saturated catchment will be in the form of saturated excess overland-flow which occurs frequently in catchments dominated by precipitation-fed incidents such as prolonged rainfall or frequent storm events (Burt et al 1990, Holden and Burt 2003a, 2003b). Damage to the peat occurs when the surface flow forms rills or tracks across the surface capable of transporting loosened or detached peat material (Evans et al 2001). Tallis (1983) observed that rainfall intensities in excess of 3mm.hr⁻¹ were likely to generate infiltration-excess runoff on sloping ground and erosion of peat soils has been found to mainly occur during periods of heavy rain (storm events) or during snowmelt (Burt and Gardiner 1983, Burt et al 1984, Warburton 2003). In eroded or drained blanket peat areas, the water table tends to be lower and therefore the number of incidences of saturation-excess overland flow is less frequent with sub-lateral near surface flow being the more dominant runoff process (Labadz et al 1991, Evans et al 2005, Holden et al 2006b).

Many researchers have described the runoff regime of a typical upland blanket bog catchment as “flashy” meaning that the discharge in the streams responds quickly to precipitation events, typically peaking within one hour of maximum precipitation and subsiding to baseflow conditions within 7 to 12 hours of rainfall ceasing (Robinson and Newson 1986, Labadz et al 1991, Burt et al 1997, Holden and Burt 2003a). The rapid rise in discharge in response to the rainfall event on bare peat is also associated with an immediate increase in suspended sediment concentration, particularly where there is already an actively eroding gully network (Labadz et al 1991, Worrall 2002, Warburton et al 2004). Rapid surface runoff favours acquisition of large sediment loads, especially following preparation of material by frost or desiccation (as shown in Figures 5.1 and 5.2) as these provide means of mechanical
weathering to de-stabilise the peat surface (Evans and Warburton 2001, Warburton 2003, Warburton et al 2004). Tallis (1998) claims that such sources are probably finite and limited due to the reported shallow penetration of frost or drought desiccation. Certainly a decrease of sediment concentration during peak stream flow, termed “exhaustion of sediment supply”, is frequently observed even in highly eroded catchments. This is true both in the short term after two or more consecutive streamflow (storm) events (eg. Burt and Gardiner 1983, Labadz et al 1991) and also in the longer term which considers the seasonal basis (eg. Francis 1990).

5.3.4.1 Gully Erosion

The general definition of a gully has been given by Brice (1966) as a “recently extended drainage channel that transmits ephemeral flow, has steep sides, a steeply-sloping or vertical head scarp, a width greater than 0.3m and a depth greater than 0.6m”.

Gully systems that are particularly characteristic of an eroding blanket bog are produced by water erosion (Warburton 2003, Evans et al 2005) and can be observed on the interfluves of blanket bog, particularly in the south Pennines where this type of erosion is thought to be most obvious and widespread (Conway and Millar 1960, Bower 1962, Tallis 1965, Tallis 1998, Evans et al 2005). Figure 5.4 shows an example of a large gully in the headwaters of a deep peat catchment in the south Pennines, UK.

Figure 5.4: Gully formation in deep peat, south Pennines, UK (O’Brien 2003)

Gully systems are considered to be relatively permanent water courses, but are associated with landscape instability and accelerated erosion (Evans and Warburton 2001). However, there has been relatively little research on the development of gully networks in peatland systems (Evans et al 2005). It is generally agreed that most of these networks originate from 400-600 AD, although more recent gully erosion within the last 200 years are likely to relate to the continuing long-term development of these gully systems and increased human activity which may have accelerated the erosion processes (Tallis 1965, Tallis 1985, Labadz et al 1991).
An important early study was the work of Bower (1960, 1961, 1962) who considered gully erosion to be the most important process in terms of the spatial and temporal removal of peat soils and identified two types of dissection from the study of a gully system at Burnt Hill, Moor House NNR, north Pennines. These resulted from the action of water (rain, snow or ice) or from the mass movements of blanket peat. She suggested that dissected gully systems could have originated from:

- Seepage networks within the blanket peat which occur along horizontal or vertical lines of weakness;
- Runnels on the peat surface;
- Headward erosion of gullies from streams abutting on the margins of the peat mass.

Bower (1960, 1961, 1962) further classified the dissection (gully) systems into “Type 1” and “Type 2” gullying:

- Type 1 dissection (reticulate) occurs on deep peat (at least 1.5m), flat or gently-sloping areas (<5° slope) with multi-branching dense network of gullies (>10km gully length/km² bog surface), at high altitude (above 550m).
- Type 2 dissection (linear) gullying develops on steeper slopes (>5° slope) with a parallel or fan-like system of sparsely-branched gullies (typically <5 km gully length/km²).

Bower did not undertake process measurement and more recent work has shown that there is in fact a continuum of form rather than two distinct types of dissection, but her work was important for recognising the effect of flowing water upon blanket bogs.

Bower (1960) recognised that some gullies started as underground water courses (soil pipes) with their floor on the peat base and originated with the collapse of subsurface pipes. These soil pipes have initially been attributed to a number of factors such as climate, faunal activity (burrowing) and live or decaying roots (e.g. Calluna), and occur preferentially in soils of a certain chemical and pedological quality such as those found in peat, particularly those subject to some form of degradation leading to shrinkage and cracking (Jones 1981, Jones et al 1997, Holden and Burt 2002b Holden 2005c). These pipes can be up to hundreds of meters in length and vary greatly in diameter from a few centimetres to more than a meter, but typically form branching subsurface networks which undulate throughout the peat profile (Jones 1981, Holden and Burt 2002b). Such a dense network of underground drainage coupled with surface drainage will obviously contribute to the volume of sediment and peat loss being discharged from a catchment in terms of overland and subsurface runoff.

Topography is also an important factor in influencing erosion patterns (Tallis 1985, Warburton 2003, Evans et al 2005). For example, Wishart and Warburton (2001) studied peat erosion in the Cheviot Hills and found anastomosing dissection was restricted to areas of flat or gentle sloping ground (equivalent to Bower’s Type 1 dissection) and linear erosion dominated areas of steeper uniform sloping ground (Bower’s Type 2 dissection). They found that the linear pattern changed markedly to a dendritic pattern where the topography concentrated drainage towards a central stream (phase between Type 1 and Type 2 dissection).

5.3.5 Climate Change

This report has been commissioned to review the management and restoration of blanket bog and does not explicitly consider the effects of climate change, but it is obviously a major concern because of the potential effects it may have on blanket
bog. The vegetation in these areas is sensitive to changes in climate and palaeoecological data from peat cores has indeed been used to reconstruct past changes in climate. A rise in summer temperatures and prevalence of prolonged droughts, followed by intense rain, may be expected to bring about changes in biomass, peat accumulation and nutrient cycling associated with a lowering of the water table and increased desiccation, humification and erosion in summer (Heathwaite 1993, Tallis 1998). Warmer, wetter winters with more frequent storms may also arise and may cause chemical and physical changes to soil structure which could in turn affect erosional processes, increasing the loss of biomass, vegetation and species (Tallis, 1995, 1997, Milne and Hartley 2001).

The changes in vegetation (habitat and associated species) may particularly affect those species on the edge of their range such as the south Pennines areas of blanket bog. Bog bursts and the transport of carbon flux (DOC and POC in water, CO₂ in water and air) may in turn contribute to greenhouse gases and escalate climate change (Evans et al 2002, Worrall et al 2004, Belyea and Malmer 2004). In addition, climate change may increase the number of wildfires by creating dry conditions more vulnerable to intense, high temperature and deep burns (Tucker 2003, Cosgrove 2004). Such fires may cause a serious loss of habitat which may only be restored through costly and lengthy restoration.

Climate change is therefore seen as being a fundamental influence upon changes in blanket bog both historically and in the future, and it may have a significant effect on the success of attempts at restoration of hydrological function and re-vegetation of bog plant species associated with this habitat. Escalating rates of erosional processes and consequent degradation of blanket bog are widely cited, along with the possible contribution to climate change (as bogs change from sinks to sources of carbon). Furthermore, climate change is considered by many to be the over-riding threat to the continued existence of blanket bog within the UK and there are additional concerns that some restoration projects might be in vain if the forecast changes in climate do occur (see sections 7.10.3 and 8.3.4).

5.4 Causes of Blanket Bog Degradation Associated with Land Use and Management

Although the natural processes of erosion discussed in section 5.3 (wind action, frost action, drought and water) have obviously shaped the landscape observed today, the anthropogenic pressures on blanket bog have undoubtedly increased over the last 200 years (Tallis 1998). This section will therefore consider those factors associated with land use and management which may have accelerated the rate of erosion and degradation of blanket bog within a relatively short time frame.

Section 4 identified the values that have been placed on blanket bog since its initiation, ranging from agricultural use, fuel for domestic and commercial use, afforestation and water supply to conservation and cultural heritage. The complex usage of this environment with such diverse functions has produced conflicts between different user groups. For example, what some conservationists and researchers consider to be practices that will degrade blanket bog, others, such as land managers and farmers may see as practices for improvement where some economic benefit may be gained (O'Brien 2000).

The recent JNCC Common Standards Monitoring (CSM) report of the first six year cycle of monitoring (1999-2005) of the SSSIs in England identifies grazing, burning, and drainage as the main causes of blanket bog degradation on SSSIs (Williams 2006). Figure 5.5 shows the percentage of the unit area not meeting the PSA target and shows that moor burning is the factor accounting for the highest percentage area not meeting favourable condition, followed very closely by overgrazing, and
then to a lesser extent drainage. Figure 5.6 shows the number of interest features where an activity has been reported as being implicated in the "unfavourable" condition of a feature. The contribution of these activities to the degradation and potential restoration of blanket bog will be discussed in the following sub-sections. Table 5.1 examines the various causes of degradation and whether they continue to be a threat or cause for concern. Amelioration of some of the effects that are considered to affect blanket bog will be discussed in section 6, in terms of changes in policy and recent restoration programmes initiated to reduce some of the adverse effects that have caused blanket bogs to be classified as degraded, inactive or in unfavourable condition across the UK.

**Figure 5.5: Reasons for Adverse Conditions and Percentage of Unit Area of SSSIs not meeting Favourable Condition (Adapted from English Nature 2006b)**

<table>
<thead>
<tr>
<th>Reason</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moor burning</td>
<td>32.45%</td>
</tr>
<tr>
<td>Overgrazing</td>
<td>31.24%</td>
</tr>
<tr>
<td>Drainage</td>
<td>12.21%</td>
</tr>
<tr>
<td>Air pollution</td>
<td>7.07%</td>
</tr>
<tr>
<td>Water pollution - agriculture/run off</td>
<td>7.03%</td>
</tr>
<tr>
<td>Inappropriate scrub control</td>
<td>6.05%</td>
</tr>
<tr>
<td>Undergrazing</td>
<td>5.98%</td>
</tr>
<tr>
<td>Forestry and woodland management</td>
<td>5.78%</td>
</tr>
<tr>
<td>Inappropriate ditch management</td>
<td>5.41%</td>
</tr>
<tr>
<td>Inappropriate water levels</td>
<td>2.12%</td>
</tr>
<tr>
<td>Agriculture - other</td>
<td>1.82%</td>
</tr>
<tr>
<td>Public access/disturbance</td>
<td>1.78%</td>
</tr>
<tr>
<td>Fire - other</td>
<td>1.26%</td>
</tr>
</tbody>
</table>
Figure 5.6: The activities practised on blanket bog deemed responsible for causing the feature to be in unfavourable condition. (JNCC 2006) (NB this is the number of features and not percentage)
Table 5.1: Impacts on Blanket Bogs associated with Land Use and Management

<table>
<thead>
<tr>
<th>Threat</th>
<th>Impact on Blanket Bog</th>
<th>Impact on Wider Environment</th>
<th>On-going or Ameliorated</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Controlled burning</td>
<td></td>
<td>As above with greater severity</td>
<td></td>
<td>Anderson (1986, Backshall et al 2001), Tucker (2003). Section 5.4.2</td>
</tr>
<tr>
<td>Accidental or Wildfire</td>
<td>Changes in soil structure, increased erosion, desiccation and humification caused by peat ignition. Long-term loss of peat soils with poor re-colonisation of species and recovery of blanket bog.</td>
<td></td>
<td></td>
<td>Shaw et al (1995), Section 5.4.3</td>
</tr>
<tr>
<td>Grazing</td>
<td>Changes in soil structure, increased compaction &amp; runoff, increased erosion. Raise nutrient level in concentrated areas. Frequent &amp; concentrated removal of vegetation</td>
<td>Flood risk, deterioration of water quality, health risks</td>
<td>Possible amelioration due to change in govt subsidies to area payments. More prescriptive farm plans for stocking densities. Legacy of over-grazing is severe degradation in some areas and long-term recovery.</td>
<td></td>
</tr>
<tr>
<td>Drainage</td>
<td>Soil erosion, reduction in water table, desiccation and change in vegetation composition to “dry heath” or grass species.</td>
<td>Increased runoff &amp; flooding; loss of carbon – see above. Increased siltation of lotic (flowing water) systems and decrease in reservoir storage capacity through deposition.</td>
<td>Very few drains (grips) cut, but active erosion increasing gully-network, some grips still active. Programme of grip/gully blocking initiated.</td>
<td>Holden &amp; Burt (2003a), Holden 2006), Evans &amp; Warburton (2001) Section 5.4.4</td>
</tr>
<tr>
<td>Recreation</td>
<td>Soil erosion, increased compaction &amp; runoff in concentrated areas, increased air pollution from vehicle emissions. increase risk of wildfires &amp; loss of bogs.</td>
<td>Carbon loss, loss of aesthetic value, increased runoff &amp; localised flooding.</td>
<td>Increasing – more recreation &amp; open access on blanket bog.</td>
<td></td>
</tr>
</tbody>
</table>
5.4.1 Controlled Burning

The definitions accepted by the Science Panel in the comprehensive Defra review “Science Panel Assessment of the Effects of Burning on Biodiversity, Soils and Hydrology” (Glaves et al 2005) distinguish several types of burning:

- **Controlled fires** sometimes called ‘prescribed’ or ‘management’, burns, are planned and carried out for land management purposes as they are controlled by the current Heather and Grassland Regulations and Code (though they do not always necessarily follow their requirements).
- **Accidental fires** resulting from controlled burning but where the burn gets out of control either through changes in weather conditions or due to insufficient planning/organisation.
- **Vandalism/neglect**, often, with natural fires are referred to as ‘wildfires’, where fires are started deliberately (arson) or by neglect (e.g. throwing away cigarettes, matches or broken glass, or picnic fires).
- **Natural** occurrences started by lightning, though there is little evidence to indicate that this is a major cause in England at present.

The ENNR 172, “Literature review of the historical effects of burning and grazing of blanket bog and upland wet heath” (Shaw et al 1996) and ENR 550 “Review of the impacts of heather and grassland burning in the uplands on soils, hydrology and biodiversity” (Tucker 2003) have reviewed and described the impacts of burning in the uplands and can be referred to for detail. Shaw et al (1996) recognised that the physical and biological effects of fire will depend on the vegetation composition, intensity and frequency of the fire, time of fire and antecedent weather conditions (i.e. previously wet or dry period) and wetness of the soils.

The majority of literature of direct relevance to the specific impacts of controlled (prescribed) burning on blanket bogs is quite scarce, since most is focused on the more generic “upland” or “moorland” which may incorporate wet heath and dry heath as well as blanket bog habitat. The main approach has often been concerned with the effects on agriculture from soil loss rather than specifically on conservation or restoration of blanket bog (Stewart et al 2004). However, in terms of food production from agriculture (mainly grazing) and sport (mainly grouse), the principal aims of burning are to prevent establishment of woody species, to reduce litter and release nutrients. The effect is to stimulate earlier growth and so temporarily increase the accessibility, palatability and nutrient content of forage for grouse and livestock (Tucker 2003).

Burning has been used as a management tool since the end of the Iron Age (750 BC – AD 40) in England as a means of maintaining open vegetation and improving grazing conditions by removing built-up grass litter and encouraging new, nutritious growth of palatable grasses, maintaining productive Calluna and so creating the large open upland moors that exist today (Milne and Hartley 2001, Rackham 1986). From around 1800AD moor-burning became regular practice, with the rise of sheep and grouse management and associated advent of tree-less rotationally burnt grouse moors (Gimmingham 1975).

5.4.1.1 Methods of Controlled Burning

Agricultural burning for grazing is largely uncontrolled and has often been extensive, covering tens to thousands of hectares and with very short rotations in order to improve grazing access to new growth early in the season by removing the previous years biomass. The practice of burning acid grassland has resulted in mono-culture swards dominated by the tuussocky purple moor grass, Molinia caerulea (MacDonald
et al 1995, Ross et al 2003, Hartley and Mitchell 2005). In other areas, dominated by dwarf shrub species fire is also used to reverse the phasal growth of Calluna to encourage succulent new growth and reduce the overall vegetation height. This is often executed through a number of large, but infrequent burns (Yallop et al 2006) and is claimed to be necessary to ensure that sufficient young forage is provided to avoid concentrations of livestock and overgrazing of regenerating growth, which may be exacerbated by a reduction in the shepherding of hefted flocks.

Burning on grouse moors is generally through prescribed burning of strips approximately 30m wide and 0.5 ha in total area. The normal aim is to burn the heather when it reaches a height of 20-30 cm (late building/mature stage) which generally results in a fire return of 10-15 years, whereby a tenth to fifteenth of the land would be burnt on average each year (Tucker, 2003). The practice of rotational burning is aimed at maximising the grouse populations by creating and maintaining a mosaic of different growth stages of heather across a site (pioneer [young], building, mature and degenerate [old and collapsing]). This is intended to provide the optimum conditions required by the grouse for nesting, feeding and breeding (Lawton 1990).

The method of burning dwarf shrub vegetation has undergone a revolutionary change in the last 20 years. Traditionally fire kettles (paraffin containers with a wick) were used to light the vegetation which had to be relatively dry and was therefore burnt after a period of dry weather, or at the end of a day with the potential to create a relatively hot and intense fire and result in possible damage to soils and destruction of vegetation and seed banks (Glaves et al 2005). The ‘cool burn’ technique was introduced by Geoff Eyre (private landowner/farmer in the Peak District) which uses diesel or gas pressure burners and has now largely replaced the traditional burning methods and allows burning of damper vegetation and therefore cooler burns (G Eyre 2006, pers comm).

5.4.1.2 Guidelines for Controlled Burning on Blanket Bog

During the last 20 years a number of published guidelines have focused on the practice of controlled burning specifically on blanket bog, but have given a mixed and confusing message. Table 5.2 shows the main guidelines. The guidance has ranged from not to burn on blanket bog at all (Nature Conservancy Council, 1997), to burning on a long rotation of up to 20 years and more recently the acceptance to burn on blanket bog that is defined as degraded (Yallop et al 2006).

At present, the burning of moorlands and grasslands is regulated in England and Wales by the Heather and Grass etc (Burning) Regulations 1986 (SI 1986 No. 428) as amended by the Heather and Grass etc (Burning) Regulations 1987 (SI 1987 No. 1208) which states legal prescribed burning is allowed from 1st November to 31st March in lowland areas and from 1st October to 15th April in the uplands (MAFF 1994). The timing restrictions are in place to minimise the effects of burning on any land type (not just blanket bog) so that burning takes place while the ground and vegetation are still relatively wet and have not dried out and so ensure a “cool burn” that reduces the damage to the vegetation and underlying peat. The Burning Regulations are also supplemented by a voluntary Code (The Heather and Grass Burning Code) which has also recently been reviewed by Defra.

A review of the Burning Regulations and also the Code was conducted in 2005 by Defra in collaboration with Natural England, conservationists, farmers, gamekeepers, and moorland managers to assess whether they were fit for purpose or required some revision in the light of new evidence on burning since the review was published in 1994. The aim of the review was largely to determine the best means for ensuring that burning practices are sustainable, and to the advantage of wildlife.
conservation and biodiversity, game management and agriculture throughout a range of English landscapes and habitats (including blanket bog) (Defra 2005a). The main driver for the Defra review resulted from the publication of the interim Sites of Special Scientific Interest (SSSIs) Condition assessment and the main causes of unfavourable condition which threatened the achievement of Public Service Agreement (PSA) Target 3 (Objective 1, ii):

"Care for our natural heritage, make the countryside attractive and enjoyable for all and preserve biological diversity by: Bringing into favourable condition by 2010, 95 per cent of all nationally important wildlife sites."

In addition, a Science Panel was set up by Defra to address the new “evidence” relating to controlled burning, particularly summarised in the "Review of the Impacts of Heather and Grassland Burning in the Uplands on Soils, Hydrology and Biodiversity" (Tucker 2003) which also addressed the contribution that sustainable burning practices may make to the protection of soils, water and air (Glaves et al 2005). Recently, Defra has published the Heather and Grass Burning Code 2007 (voluntary) (Defra 2007) and updated the regulations in the Heather and Grass etc. Burning (England) Regulations 2007 (HMSO 2007).

### Table 5.2: Summary Table of Burning Recommendations for Blanket Bog

<table>
<thead>
<tr>
<th>Source</th>
<th>Guidelines</th>
</tr>
</thead>
<tbody>
<tr>
<td>PDNPA (Phillips et al 1981)</td>
<td>Limited rotational burning &amp; burning of firebreaks may be necessary close to public access points/paths</td>
</tr>
<tr>
<td>Rowell (1988)</td>
<td>Burning on BB should be avoided and should not be used on M17 and M18 NVC types or any other Sphagnum rich community, and particularly not on a bog system with pools and ridges.</td>
</tr>
<tr>
<td>Nature Conservancy Council (1989)</td>
<td>BB areas should not be burnt at all</td>
</tr>
<tr>
<td>Mowforth &amp; Sydes (1989)</td>
<td>A 20-yr burning rotation is the minimum recommended for blanket mires and a 20-30 yr rotation may be preferable.</td>
</tr>
<tr>
<td>MAFF (1992)</td>
<td>Bogs should not be burnt</td>
</tr>
<tr>
<td>Tir Cymen (CCW 1992)</td>
<td>Avoid burning BB or mires</td>
</tr>
<tr>
<td>Coulson et al (1992)</td>
<td>BB vegetation should be burnt on a long cycle (with careful control) or not at all – recommend banning on BB.</td>
</tr>
<tr>
<td>Phillips et al (1993)</td>
<td>Bogs should not be burned, or at least not &gt; 15-20 years</td>
</tr>
<tr>
<td>Usher &amp; Thompson (1993)</td>
<td>i) Burning on BB minimised ii)variable burning cycle used iii) wet flushes conserved iv) upland heath margins burnt less intensively</td>
</tr>
<tr>
<td>RSPB 1995</td>
<td>Where conservation is the main objective to enhance an active peatland ecosystem, burning should not be used at all to control the vegetation.</td>
</tr>
<tr>
<td>Brooks and Stoneman (1997)</td>
<td>Generally, when managing mires for nature conservation, do not burn</td>
</tr>
<tr>
<td>UK Biodiversity Groups (1999)</td>
<td>Peatlands no longer supporting BB vegetation may be burnt except where adjacent BB is under protection or being enhanced through restoration.</td>
</tr>
<tr>
<td>Backshall et al (2001)</td>
<td>Where BB is in favourable condition, the ideal option for nature conservation purposes is not to burn at all.</td>
</tr>
<tr>
<td>Tucker (2003)</td>
<td>Burning can cause the ignition and loss of peat, reduce peat accumulation, increase run-off &amp; erosion, reduce structural &amp; species diversity.</td>
</tr>
<tr>
<td>English Nature (2003)</td>
<td>English Nature recognises the value of sympathetic burning regimes in certain habitats, notably dry heath, but also recognises that other habitats, notably peatlands (blanket Bog and wet heath), can be severely damaged by inappropriate burning'.</td>
</tr>
<tr>
<td>Stewart, Coles &amp; Pullen (2004)</td>
<td>Burning on BB may be detrimental to soils and species composition</td>
</tr>
<tr>
<td>Glaves et al (2005)</td>
<td>Peat soils are susceptible to burning and this can limit rates of peat formation, reduce infiltration and enhance soil and stored carbon loss</td>
</tr>
<tr>
<td>Williams (2006), JNCC (2006b)</td>
<td>CSM draft states burning and draining can result in changes to hydrology and loss of peat especially at the surface, resulting in floristic changes that may be regarded as degraded.</td>
</tr>
<tr>
<td>Defra (2007)</td>
<td>Burning may only take place in the burning season, unless under licence from Natural England. Burning must be conducted safely, with care for people, property, the environment, and natural resources.</td>
</tr>
</tbody>
</table>
5.4.1.3 Extent of Controlled Burning on Blanket Bog

Until recently, the actual extent and use of prescribed burning as a management tool in the uplands was unclear. Yallop *et al* (2005, 2006) has estimated the extent of prescribed burning in the uplands and acknowledges that the areas include a combination of wet heath and bog, in addition to dry heath. Remote sensing using digitised aerial photographs has been used to identify the areas and estimate a rise from 34% burns in the 1970s to 48.6% new burns in 2000 (Yallop *et al* 2006). Although the areas of consistently managed burns indicate a rotation of between 14-25 years and is within the recommended burning rotation of 20 years on blanket bog (Shaw and Wheeler 1995), Yallop *et al* (2006) found a general trend of pronounced burning intensification which included areas designated as SSSIs. Such burning regimes may have potential adverse ecological impacts at this management level, although the Science Panel remain impartial whilst there is a lack of scientific evidence to support this (Glaves *et al* 2005).

Nevertheless, the study by Yallop *et al* (2006) was the first large-scale analysis of the current burning practices in England. It had to rely on remotely sensed data due to the lack of official records (there is no national licensing system, consenting or monitoring of burning practices in England) (Yallop *et al* 2006) and indicated an unprecedented rise in burning as a management tool in the uplands. **There is a need to extend this data set to include the extent and distribution of burning management, particularly on bogs even if they are already considered to be in a degraded state.** Such information may prove useful in determining the effects of prescribed burning on blanket bog and future condition assessments.

5.4.1.4 Impact of Controlled Burning on Blanket Bog

Burning on blanket bog, wet heath and dry heath habitats has been recognised previously by a number of organisations as having critical impacts on flora and fauna, and in relation to soil, water and air. Garnett *et al* (2000) conducted experiments at Moor House in the north Pennines, and found that controlled burning at 10- and 20-year rotation led to reduced peat accumulation on their plots. They concluded that regular burning of the blanket bog had resulted in a reduced carbon storage in the peat when compared to non-burnt areas, and that consequently the abandonment of this management practice may provide an opportunity to increase terrestrial carbon storage in similar areas.

Burning has been reviewed in a number of commissioned reports such as ENNR 172, “*Literature review of the historical effects of burning and grazing of blanket bog and upland wet heath*” (Shaw *et al* 1996) and ENRR 550 “*Review of the impacts of heather and grassland burning in the uplands on soils, hydrology and biodiversity*” (Tucker 2003). Table 5.3 shows the main advantages and disadvantages for nature conservation identified by those reviews.
<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short burning rotation favours <em>Eriophorum</em> spp (beneficial to black grouse &amp; large heath butterfly)</td>
<td>Damage to bryophytes, particularly <em>Sphagnum</em> and lichens – burning at less than 20 yrs may eradicate it</td>
<td>Campeau &amp; Rochefort (1996),</td>
</tr>
<tr>
<td>Encourage fire-sensitive species e.g. cloudberry (<em>Rubus chamaemorus</em>) and bog rosemary (<em>Andromeda polifolia</em>) which may otherwise be dominated by <em>Eriophorum</em> on short rotation burning &amp; <em>Calluna</em> on long rotations.</td>
<td>Reduced peat formation, increased risk of erosion from areas of bare peat/little vegetation.</td>
<td>Mowforth &amp; Sydes (1989)</td>
</tr>
<tr>
<td>Burning in selected areas may act as a fire break and reduce the risk of severe wildfires in high risk areas.</td>
<td>Increased rate of peat desiccation through oxidation and risk of combustion with significant losses of carbon to atmosphere and physical weathering processes.</td>
<td>Garnett et al (2000)</td>
</tr>
<tr>
<td></td>
<td>Loss of structural diversity and specialised bog species, replaced by <em>Calluna</em> and/or species with limited conservation interest e.g. <em>Nardus</em> or <em>Molinia</em></td>
<td>Rodwell et al (1991), Stewart et al (2004b)</td>
</tr>
</tbody>
</table>

The JNCC Common Standards Monitoring (CSM) guidance has stated that grazing, burning and drainage are the main causes of blanket bog degradation on SSSIs (Williams 2006, JNCC 2006b) as these practices change the species composition caused by changes in peat hydrology and soils, particularly at the surface. This guidance was discussed in section 3.10. English Nature (2006b) has found that 32% SSSIs were in unfavourable condition due to inappropriate moor burning, although this figure may be exaggerated by including entire areas of SSSIs as being in unfavourable condition, when only one part of it may be degraded due to poor burning management (Yallop et al 2006). The second highest reason for adverse condition is overgrazing (31%) and this land use is often combined with the practice of prescribed burning, although it is still unclear how the two may interact to degrade blanket bog (Anderson et al 1997, Worrall, Armstrong and Adamson 2007).

Since the publication of English Nature’s (2001) “State of Nature” report (reviewing the state of upland SSSIs) and the claim that 60% of blanket bog was in unfavourable condition, there has been a fierce debate between English Nature and the Moorland Association on the use of burning as a management tool in the uplands. The Association queried the basis on which such a large percentage of blanket bog (and 72% of upland heath) was found to be in unfavourable condition as a result of prescribed burning. The Select Committee on Environment, Food and Rural Affairs in its Fourteenth Report (EFRA Committee 2004) acknowledged that there were strong differences in opinion and urged that those parties involved should reach a common science based understanding on the impacts of burning on moorland.

The differing views of controlled burning are generally centred on burning of modified bogs, in particular those dominated by heather and grass vegetation on deep peat such as those areas of the south Pennines where the heather growth resembles that of a heather-dominated heath with little *Sphagnum* growth e.g. Featherbed Moss, Alport Moor, Derbyshire. Many land managers regard such areas, often historically burnt for grouse management, as upland heath and they have little or no sympathy with identification of such areas as blanket bog, degraded or otherwise. In contrast, the government agencies’ view is that all vegetation on deep peat (0.5m and greater) should be regarded as potentially restorable to blanket bog and that there should be a general presumption against burning because of the potential damaging impacts on soil, air and water quality (JNCC 2006b). This view is supported by
evidence that vegetation which would currently be regarded as modified is chronicled in the historic plant macrofossil record for a number of sites (Barber 1993, Pancost et al 2003), suggesting that these conditions may simply represent a phase in the development of blanket bog. Changes in water level, climate and management are represented by corresponding changes in the macrofossil records, and are illustrated by both species-poor vegetation and species-rich vegetation associated with bog development at different phases (Barber 1993, Pancost et al 2003).

As a result of the differences in opinion amongst upland land-based organisations and government agencies, Defra established a Burning Review Science Panel to review the impacts of burning with particular reference to the effects of prescribed burning on wet and dry upland heath and blanket bog (Glaves et al 2005). The Panel was also asked to address the effects of burning on soil, water and air quality as these areas had been high-lighted in the Tucker report (2003) as lacking information which was considered necessary for future policy and advice to practitioners on their management of this important land type. They reviewed the research to May 2005 and again concluded there to be a lack of science-based evidence that prescribed burning degraded blanket bog. This supported earlier reviews by Stewart et al (2004a, 2004b) who used an evidence-based approach in a conservation context to determine if controlled burning degraded blanket bog. Limiting the interpretation of changes in floristic composition to the degradation of blanket bog, they were unable to find conclusive evidence that burning did degrade blanket bog and concluded that there was insufficient evidence to provide practitioners with robust recommendations (Stewart et al 2004a, 2004b). In light of the lack of science-based evidence the Panel recommended that in general the presumption should continue to be that vegetation on blanket peat should not be burnt, at least in terms of advice on good practice (e.g. in the Code) unless as part of a restoration programme or to meet wider conservation/environmental objectives (Glaves et al 2005).

Despite the lack of irrefutable evidence, Natural England has continued to practice the “precautionary principle” to minimise the effects of prescribed burning on blanket bog by incorporating the Common Standards Monitoring (CSM) guidance into management agreements with land managers who own/manage land wholly or partly classified as designated. Sympathetic burning regimes have been agreed with the provision of areas to be left un-burnt if identified as “sensitive to disturbance” and so enable the land to be re-instated or remain in favourable condition. For example recent agreements have been reached with the Dallogill estate in Nidderdale, North Yorkshire and the Spaunton Estate, in the North York moors (English Nature 2006a).

However, much controversy remains as to how much blanket bog should remain un-burnt with the fear that the dominance of mature and degenerate heather resulting from the lack of burning rotations may make such areas vulnerable to wildfire and subsequent devastation of huge areas of upland, including blanket bog (R May, Moorland Association pers com 2006). Many gamekeepers and land managers also believe that burning up to a gully edge is necessary in order to create and maintain a fire break. They believe that if a 5-10m buffer zone is left by a water course (as recommended in the revised CSM guidance), the resulting heather may ignite more easily and the wildfire may “leap” from one side of a gully to another and so move across an entire moor (G Eyre 2006 pers comm).

(Glaves et al 2005) noted the lack of science based evidence of the effects of burning on blanket bog, but some research has recently been completed or is on-going to investigate the effects of prescribed burning on blanket bog. However, this has often not been directly related to nature conservation or restoration on blanket bog due to the lack of funding and has tended to be more business-orientated e.g. water companies interest in improving surface water quality draining from upland
catchments through sustainable land management. Several water companies with upland catchment areas located on blanket peat have recently invested in research to determine the effects of land management practices (including prescribed burning) on water quality. For example, O’Brien et al (2005) have made a spatial study of water discoloration in the south Pennines (funded by Severn Trent Water) and investigated the effects of prescribed burning on a catchment scale (results pending). A paired catchment approach has been used to identify the temporal and spatial changes in water colour and hydrological processes (discharge and water table levels) on a treated catchment (where burning has been temporarily stopped for a number of years) and a control catchment (normal burning regime is practiced). O’Brien et al (2006) also completed a study of water discoloration in the headwaters of the Derwent catchment, south Pennines (funded by Moors for the Future). They found there was no significant relationship between the percentage area of prescribed burn and true (filtered) water colour across the Derwent catchments, although there was a positive correlation between water colour, soil type (specifically Winter Hill peat, characteristic of blanket bogs) and high altitude.

White et al (2003) completed a scoping study for Yorkshire Water on the control of water quality and suggested that there was a significant relationship between the area of prescribed burn and the spatial variation of water colour within the catchments studied. This study has since been repeated by Yallop et al (2006b) and the findings support the original study, indicating that there is a clear correlation between the prescribed area burnt on deep peat and the generation of water colour.

Holden (2005c) found that the number of underground soil pipes was significantly higher under Calluna-covered peat than any other vegetation types, suggesting that the current burning regime practiced to increase the spread and vigour of Calluna plants may induce sub-surface erosion through increased macropore flow around the woody rhizomes and the development of pipes.

Some very recent evidence of the effects of burning has been presented by Worrall, Armstrong and Adamson (2007 in press). They investigated the effects of prescribed burning at Trout Beck catchment, located in the headwaters of the River Tees within the Moor House NNR. They utilized the experimental plots set up on Hard Hill in 1954, which included some plots not burnt since then and some burnt regularly on 10 and 20 year rotations. 3 piezometers were installed in each of the 12 plots (ie. 2 replicates of each treatment) and were measured over a few months at the end of a burning cycle (ie. no burning for the last 10 years). Results indicated that rotational burning (with grazing) was associated with decreased relative depth of the water table (20 year cycle by 8% and 10 year cycle by 26%). The deepest water tables were found on ungrazed and unburnt plots. It was suggested that this may be explained by a change in vegetation, with shrubby species such as Calluna dominating on the “unmanaged” plots and increasing evapotranspiration. Worrall et al (2007) also noted that the presence of burning decreased the soil water pH and electrical conductivity was also found to be lower on burnt plots. On plots not burnt the soil water compositions were pH 4.11 – 6.93, whilst on burnt plots they were reduced to pH 4.09 – 5.43. The lowest dissolved organic carbon (DOC) concentrations were observed on those grazed plots which were also burnt on a 10 year rotation. These also recorded with the lowest conductivities. Several possible explanations were proposed, including changed flow paths that reduce residence time of waters, or hydrophobicity created by frequent burning that results in water having less contact time with the soil organic matter, but the presence of burnt material (ash) was suggested as the most likely explanation. Worrall et al (2007) concluded that regular burning and grazing had certainly limited development of vegetation on the plots, and noted that short burning cycles may bring water tables nearer the surface and have some benefits for loss of DOC, but they also stated that conditions may be very different shortly after a burn and that it is important to
consider the whole cycle of burning when considering whether it is a beneficial management practice.

Professor Marrs (University of Liverpool) has also recently commenced a study of the effect of cool fires on moorland vegetation in the Derwent catchment, Derbyshire (funded by Moors for the Future). Results of that study are pending.

### 5.4.2 Accidental or Wildfires

Peat loss and degradation during drought conditions may be amplified by increased numbers of accidental fires (wildfires) during periods when water tables are low, soil and vegetation at their driest and visitor access to the moors at their highest (McMorrow et al 2006). Accidental fires may result from fires used for agricultural purposes (i.e. control of vegetation) getting out of control due to inappropriate timing of fires (e.g. during too dry or windy conditions) or insufficient or inexperienced workers employed to manage the fire (Backshall et al 1998). Alternatively, accidental fires may result from visitor carelessness (e.g. inappropriate discarding of litter or cigarettes) or deliberate acts of arson (Backshall et al 1998, Anderson 1997). Such fires can cause extensive damage, particularly in years of summer drought and in areas of thin peat, resulting in severe erosion and poor vegetation regeneration (Anderson 1986, McMorrow et al 2006). Wildfires are particularly detrimental as they are largely uncontrolled and may burn for a long time; the peat/humus layer is more likely to be ignited and may result in large areas of bare peat or mineral soil being exposed for long periods, giving subsequent problems to re-vegetation and erosion (Tucker 2003, Maltby et al 1990).

It is acknowledged that the effects of wildfires differ greatly from prescribed burning and the methods and techniques used for the restoration of blanket bog burnt by wildfire as opposed to a prolonged period of prescribed burning may differ according to the degree of degradation and soil loss. Wildfires have the capacity to cause extensive damage, particularly in years of summer drought and in areas of thin peat, resulting in severe erosion and poor vegetation regeneration (Anderson 1986). Such fires are particularly detrimental as they are largely uncontrolled and may burn for a long time. The peat/humus layer is more likely to be ignited and may result in large areas of bare peat or mineral soil for long periods following the removal of vegetation, roots and seed source, giving subsequent problems to re-vegetation and erosion which may be exacerbated by grazing (Cosgrove 2004).

The rate of re-vegetation will depend on altitude, exposure of site, rainfall, levels of atmospheric pollution and grazing pressure. For example, Maltby et al (1990) found the effect of fire was influenced by peat depth, moisture content and presence of any previous desiccation cracks which could allow localised entry of oxygen. They found that where peat was more than 800mm and moisture content more than five times the dry weight of peat, the fire may affect only the surface vegetation. Where peat was 200-400 mm deep, the effects were more severe with the peat being ignited completely where areas had dried out during the summer. Where peat was 400-800 mm and moist, or contained mineral material, the fire caused charring, surface contraction and hardening, with complete loss of litter.

Watson and Miller (1976) found the water level prevailing at the time of the wildfire will influence the effects of the fire with moist peat acting as an insulator to protect buried seed and basal buds of Calluna against the heat and therefore allow rapid recovery of vegetation following the fire. Unfortunately, however, many of the wildfires occur in summer when soil moisture levels are at their lowest and vegetation is dry, allowing a fire to take hold very rapidly.
The effects of climate change and the threat of prolonged periods of drought may increase the incidences of wildfire on blanket bog, and so promote its degradation by removing vegetation and soil, increasing erosion over vast areas and damaging hydrological function. In some cases, for example, on Bleaklow, south Pennines, the damage caused by wildfire has been immense and seemingly irrecoverable (Anderson et al 1997).

The threat from climate change and the proposed changes in prescribed burning regimes has left many upland stakeholders uneasy about the potential increased risks and frequency of wildfires. Mitigation against the outbreak, combat and restoration of wildfires will require increasing cooperation to provide an adequate fire protection plan, raise public awareness of the risks of wildfire and develop a means of rapid revegetation of such areas to minimise carbon loss (McMorrow et al 2006).

5.4.3 Livestock Grazing

5.4.3.1 Overgrazing

The recent (July 2006) JNCC Common Standards Monitoring (CSM) guidance states that overgrazing is the main cause for blanket bog degradation on SSSIs in England (43 interest features have been found to be in unfavourable conditions – see figure 5.6), with 31.24% of SSSI units being found in unfavourable condition due to overgrazing (slightly lower than that caused by moor burning at 32%) (English Nature June 2006). The term “over grazing” has been included in the statutory definition of the Good Farming Practice Guide for the England Rural Development Programme and is defined as:

"Grazing land with livestock in such numbers as adversely to affect the growth, quality or species composition of vegetation (other than vegetation normally grazed to destruction) on that land to a significant degree“ (MAFF 1998)

In the foreword "State of Nature: the Upland Challenge" (English Nature 2001) Professor David Norman stated that:

"The main pressures on upland wildlife are heavy livestock grazing. Wildlife in the uplands is intimately linked with livestock farming but is sustained only through sensitive management...To achieve sustainable land management for the uplands, there is a need to reform the sheepmeat and beef regimes (and) enforce the overgrazing rule more effectively”.

Livestock farming systems have changed dramatically over the last 40 years with a see-saw effect from early encouragement of over-stocking by offering financial incentives (headage payments) to the contrasting more recent encouragement to reduce stocking levels enforced by reforms in the Common Agricultural Policy (CAP) and new cross compliance conditions that apply to agricultural activities across the entire holding (Defra 2006). During this time typical herd and flock sizes have changed (increased and then recently decreased again), shepherding has been reduced, breeds of livestock have changed, target lambing percentages and lamb weights have increased and supplementary feeding throughout the winter months has become routine (Defra 2003). For example, English Nature reported that the number of breeding ewes in English Less Favoured Areas (LFAs) increased by around 35% between 1980 and 2000 (English Nature, 2001). This has had a major impact on upland habitats of conservation importance, as a high proportion of these fall within the LFAs. Some 15% of the total area of England, and over 40% of SSSIs,
are classified as LFAs. Figure 5.7 shows the extent of LFAs in England and Wales, predominating the uplands and including many blanket bog sites.

Despite recent reforms in the Common Agricultural Policy (CAP) and subsequent changes in the payment of subsidies from headage payments under the Hill Livestock Compensatory Allowances (HLCA), which were held responsible for the severe overstocking of the uplands in England, and consequent habitat degradation, over-grazing has continued to be a significant factor responsible for the degradation of upland areas with localised erosion, exposure of peat, copaction and/or loss of soils (Hulme and Birnie 1997, Tallis 1998, Carroll et al 2004, Evans 1977, 2005).

**Figure 5.7: Less Favoured Areas in England and Wales (MAGIC 2006)**

McHugh et al (2002) assessed the extent of soil erosion in upland England and Wales and stated that severely eroded areas of peat can be found in all blanket bog regions, although the most eroded sites are concentrated in the Pennines (Peak District, Teesdale and Weardale) with an estimated 2.5% of the total upland area actively eroding.

Following the increase in stocking densities during the 1980s, concerns were raised about the impact of livestock grazing on natural and semi-natural vegetation, particularly in the hills and uplands. ENRR 172 "Literature review of the historical effects of burning and grazing of blanket bog and upland wet heath" (Shaw et al 1996) reviewed the general effects of grazing on blanket bog and upland wet heath. The main findings of the review will be summarised here and more recent literature reviewed to identify the current issues surrounding livestock grazing on blanket bog.
Small herbivores such as voles, grouse and hares are a natural feature of blanket mire and are not considered harmful, but the large herbivores associated with blanket bog are predominantly domesticated sheep (cattle, ponies and deer also graze in some areas) and have been associated with its degradation (Hulme and Birnie 1997, Reid and Grice 2001). Grazing or herbivory are frequently thought of as having negative impacts upon the maintenance of blanket bog ecosystems and may be considered completely unnecessary as a management tool where active blanket bog conditions prevail and the climax vegetation is maintained through a functioning hydrological system. However, these conditions do not persist across most of the UK blanket bogs and it has been suggested that grazing by wild and domestic herbivores is crucial in preventing colonisation of the bog surface by trees (Thompson et al 1995, Welch 1998). In fact, the most recent advice from agencies such as Natural England (previously English Nature) is to not graze at all on wet blanket bog (English Nature 2005, Reid and Grice 2001).

There is a vast amount of literature available on the effects of grazing on various land types (e.g. Yalden 1981, Shaw et al 1996, Backshall et al 2001). However, Shaw et al (1996) pointed out that much of the literature on the impacts of grazing was focused on dry heath and that very few studies have included blanket bog. The Defra literature review of hill farming in the uplands: “An assessment of the impacts of hill farming in England on the economic, environmental and social sustainability of the uplands and more widely” (IEEP 2004) also found that there was little empirical research to indicate a causal relationship between grazing and ecological or landscape changes on blanket bog or wet heath. Indeed, the commissioned research on overgrazing in the uplands funded by Defra has primarily focused on the maintenance and enhancement of heather moorland, making it difficult to identify effective management prescriptions for achieving favourable condition on other forms of moor such as blanket bog. This may be considered an area for specific research focus in the future.

Many mire species have a marked seasonal pattern of growth with only Calluna vulgaris, Eriophorum vaginatum and Vaccinium myrtillus providing winter grazing, of relevance for areas of upland which is grazed throughout the year. Fresh plant growth normally commences in April, but only Molinia caerulea, Scirpus cespitosus and Rubus chamaemorus provide summer grazing for sheep and cattle, whilst Eriophorum angustifolium is utilised in later summer and autumn, for example Rawes and Hobbs (1979) found bare ground could be created around areas of Sphagna and large lichens which attracted grazers. Several authors have observed that if the soil surface is continually disturbed by animals during the growing season, seedling germination and invasion by plants will be inhibited (Anderson and Radford, 1994; Mackay and Tallis, 1996; Bragg and Tallis, 2001). Climatic conditions occurring in the uplands in winter, such as frost-heave, heavy rainfall and strong winds may then prepare the soil for further erosion and result in the expansion of bare areas of soil (Evans 1997). Although some of these areas may be readily colonised by bryophytes, peat in particular may become so unstable and erodible when exposed that vegetation cannot easily take hold (Evans 1997). The effects of grazing can be long-lasting and there is a lack of science-based research to suggest how long it may take before a degraded blanket bog may recover from the effects of over-grazing.

The complexity of animal and vegetation processes needs careful consideration when planning restoration as key vegetation will undoubtedly attract sheep depending on the time of year (Tallis 1998) and its growth rate. For example, studies have indicated that the availability of preferred vegetation such as pioneer heather, Sphagnum flushes and seedlings will attract sheep (Evans 2005). Therefore, the burning regime adopted to create a mosaic of heather of different ages and structure will influence the movement of sheep across an area as well as the impact on
vegetation (Phillips and Watson 1995). Many practitioners have concluded that it is imperative that sheep be excluded from restoration sites where re-vegetation of bare soils has been completed in order to prevent newly-planted vegetation being ripped out or trampled down by the sheep naturally attracted to such sites (e.g. Tallis and Yalden 1983, Anderson et al 1997, Buckler 2006 pers com). Such practices can be supported by long-term research by, for example, Rawes (1983) at the Moor House NNR, North Pennines who found plant growth, improved rooting and soil condition and reduction in erosion at sites in enclosed areas excluded from sheep. Adamson and Karl (2003) more recently examined the same enclosures following the exclusion of sheep after a period of 31 years and concluded that the vegetation and peat soils were in more favourable condition than those that had been grazed.

The grazing behaviour and preferences of herbivores have been well reviewed by Shaw et al 1996, Backshall et al (2001) and these highlight the problems of determining the level of impact of the grazing livestock on blanket bog. The response to stocking densities will not only be affected by the type of grazer (due to its feeding preferences and grazing techniques), but a range of other environmental variables that may be site specific. The main components of the grazing process are defoliation when vegetation is eaten and/or trampled by sheep and exposure of bare organic soil which is susceptible to erosion through weathering processes, particularly by wind and water in the uplands. The effects of trampling are likely to be more evident on wet ground such as blanket bog, where hoof prints can cut through the vegetation into the underlying peat (Evans 2005) or disturb the upper layers of exposed peat soils and disrupt the physical structure of peat, again making localised areas more vulnerable to soil losses through erosional weathering processes and oxidation (McDonald and Naden 1998, Warburton 2003). However, the intensity and extent of damage will vary according to the following factors (RSPB 1995, Backshall et al 2001, Stewart and Eno 1998):

- Stocking rates
- Type of grazing animal (species, breed, age, sex)
- Timing of grazing (whether year round, seasonal or occasional)
- Vegetation (type and condition)
- Geographical location of the site
- Wetness and condition of the site (geology, soil type, altitude and aspect)
- Associated management practices (prescribed burning, gripping)

This diverse range of factors that may affect the intensity and extent of damage to upland habitats has made it difficult to calculate a generic stocking rate appropriate to maintain an upland feature such as blanket bog in favourable condition or to bring vegetation back into favourable condition. As a result there is no agreed stocking density rate for blanket bog per se. The ESA agreements allowed some flexibility with the Tier 1 and Tier 2 levels of grazing, but English Nature (2005) said that even at low stocking rate of damage to vegetation can be caused on blanket bog. The declines in shepherding and in use of hefted flocks are of particular concern as these more traditional methods allow better use of the grazing across the hill, avoid local concentration which can lead to overgrazing, reduce the need for supplementary feeding and are better for animal welfare. It is felt that these changes, together with changes in the stocking densities, have had a marked effect on upland biodiversity (IEEP 2004).

Variation in husbandry techniques across England and Wales may also be of relevance for the condition of blanket bog as this will affect the grazing preferences of sheep at different times of the year and the vulnerability of peat soils to increased erosion. For example, in the Peak District the normal practice is to leave most of the hill sheep out on the upland grazing throughout the winter (set-stocking) whereas at Moor House (northern Pennines) sheep generally graze only from April to October. Issues associated with increased stocking densities and lack of shepherding have
included loss of vegetation structure; creation of short swards; heavy trampling and poaching contributing to increased run-off and flooding incidents downstream; erosion of peat soils through trampling and sheltering by sheep; and contamination of watercourses with run-off from these areas (Evans 1997, Reid and Grice 2001). These effects may be exacerbated by set-stocking and over-wintering of stock on the blanket bog when the water table is high and when wet areas are more susceptible to trampling and poaching damage (Shaw et al 1996). In addition, Evans (1997) reported that where the vegetation is weakened or disrupted at small breaks of slope, sheep can form hollows or scars in which to rest or take shade. He observed that where these scars penetrate into unstable soils, such as peats, the area of bare soil can rapidly expand and lead to expansion of other bare areas downslope where the disturbed soil buries vegetation. He also noted that sheep scars may form "knickpoints" in valley floors which may initiate up-valley gully incision (Evans 1998). McHugh et al (2002) investigated the spatial distribution of erosion in the uplands through repeated visits to National Soil Inventory sites. They identified overstocking as a significant threat to the environment and found bare areas of soil were limited to discrete features such as sheep scars or gullies in areas of degraded peat.

Although many researchers have found that livestock may cause soil compaction and increase runoff from upland catchments, few quantitative studies have been completed to determine the link between livestock densities and erosion rates. However, a study at Blelham Tarn, Cumbria by van der Post et al (1997) of two frozen sediment cores showed an exponential increase in sedimentation rates for the past 40 years which could be attributed to erosion within the catchment. The predominant sediment source was identified as surface soil and could be closely linked with the increase in sheep stocking density in the catchment during the same period. Monitoring studies in Wales found an 11% loss on organic matter in soil from permanent pasture between 1980 and 1997 with the worst effects found on peaty soils and over-grazing identified as one of the major contributors of erosion (Reynolds et al 2002). Further studies have examined the affect of stocking densities on soil structure and function, including water movement in upland soils. Carroll et al (2004) completed a study at the ADAS Pwllperian research farm, mid Wales and found the infiltration rates, that is, the rate of water movement in the soil, doubled on pastures grazed by sheep over a 15 year period. During this time, the sheep numbers were reduced from 3.7 sheep/ha to 1.9 sheep/ha and the results suggest that even at quite low stocking rates, the soil may be compacted and result in a lowering of the infiltration rate. The study concluded that the relationship between peat soils and stocking densities was complex and that further studies were required on peat soils using a number of replicate plots on differing soil textures in order to further the understanding of the relationship between stocking densities and the affects on soil.

It is also acknowledged that the breeds used for hill farming differ greatly to those used in the lowlands. Backshall et al (2001) information note provides a useful description of the breeds associated with the uplands, but it is generally accepted that only certain breeds of sheep and cattle can survive the poor grazing provided by mire vegetation, for example, Swaledale, Hebridean and Scottish Blackface. Such breeds may be more suited to the upland environment, may not require supplementary feeding and may have feeding preferences that are more compatible with nature conservation objectives rather than the faster maturing continental breeds that had been introduced into some areas of the uplands under the headage payment schemes (English Nature 2005). Although there has been little research that has been completed on the use of traditional breeds for conservation purposes in the uplands, it is a practice that is well used on lowland grassland, particularly on sites of conservation importance in the Midlands (R Hart 2006 pers comm). Newborn (2000) compared the ability of Swaledale and Hebridean sheep to control invasive Molinia in Yorkshire and found Hebridean sheep showed a preference for Molinia and
noted a change in leaf density of *Molinia* and increase in heather cover. However, he was not able to find a direct link between the type of breed and changes in vegetation. Despite the recognition that grazing plays a very important part in maintaining the vegetation structure and composition, it is accepted that this can only be achieved when the type, breed and stocking densities are appropriate for the site (English Nature 2005).

There is a lack of evidence-based research to clarify the impacts of stocking densities and timing of grazing, although there appears to be abundant and sometimes conflicting advice on when land managers should graze their livestock. For example, Thompson *et al* (1995) suggested stocking rates should be no more than 0.5 ewes per ha as above this level might result in a change from heather moorland to grassland bog. However, Evans (1997) reported that stocking densities during the 1970s - 80s were generally 0.4 - 0.8 ha per sheep when erosion became widespread and Grant *et al* (1985) confirmed that grazing intensities of 0.4 ha per sheep are sufficient to initiate heather decline. More recently Evans (2005) returned to the sites of Hey Clough and Black Tor in the south Pennines to investigate the changes in sheep scars, re-vegetation of bare areas and general erosion. He advocated summer grazing only at a stocking density of 1 sheep per 0.2 ha as a sustainable level on peat soils. **Recommendation of conflicting stocking densities sends out a confusing message and requires further research in order to clarify advice to land managers.**

The complexity of the animal processes (inter-acting with a range of soil types, past and current causes of degradation, present condition of the upland and with the underlying influence of changes in climate on vegetation growth and erosional impacts on organic soils) has made it difficult to determine a generic stocking rate for the uplands, and in particular the more susceptible blanket peat areas. A number of models have been developed to predict the impact of large herbivores on the productivity and dynamics of upland vegetation. The first series of models focused on the impacts of stocking densities on heath vegetation. For example HEATHSOL, a physiological model by Grace and Woolhouse (1974), considered heather growth whilst the empirical models of Armstrong *et al* (1997) concentrated on a single site in the North Pennines. More recently, the Macaulay Land Use Research Institute (MLURI) has developed the MLURI Hill Grazing Management Model which predicts the degree of utilisation of different vegetation types at different times of year. However, this model focuses on the utilisation of grassland species (Armstrong and Milne 1995). The MLURI has also been developing Decision Support Tools (DSTs) which take into account the spatial distribution of different land uses, as influenced by climate, topography, soils, vegetation and the impacts of animals. One such DST includes HILLPLAN to predict the impact of sheep, cattle and deer grazing on upland vegetation (Milne 1997). Further models are under development to consider stocking densities per km$^2$ and impacts on vegetation types found on bog, heath and grassland in upland Britain (Evans *et al* 2003). Recently Palmer *et al* (2005) have considered the spatial variation in spatial densities by considering the pattern in habitat use and grazing density, but have again concentrated on the impacts of heather moorland rather than blanket bog. **The development of a model to predict the impacts of grazing on blanket bog would greatly assist the management and restoration of the uplands, but the complexity of the processes and the lack of quantitative research have prevented this to date.**

5.4.3.2 Cattle

Very few studies have been completed on the use of cattle and their impact on blanket bog. Studies have tended to focus on other upland habitats such as woodland, dry heath and heather moorland. The feeding preferences and bite of cattle and other herbivores were reviewed by Shaw *et al* (1996) in the ENRR 172
report “Literature review of the historical effects of burning and grazing of blanket bog and upland wet heath”. A more recent review of hill farming in the uplands: “An assessment of the impacts of hill farming in England on the economic, environmental and social sustainability of the uplands and more widely” (IEEP 2004) also gives a comprehensive account of the feeding behaviour of cattle and will therefore not be repeated here.

In the few studies undertaken on blanket bog, it is generally agreed that large herbivores are not suitable for grazing there. For example, Grant et al (1987) recommended that cattle were not suited to wet bog where their greater hoof pressure could cause severe damage through poaching, but recognised the advantage of grazing cattle on wet areas of Molinia and Calluna where sheep and periodic burning failed to break down the sward. Grant et al (1987) advocated summer grazing only on these areas.

An English Nature report “The Importance of Livestock Grazing for Wildlife” (English Nature 2005) fully advocates the use of livestock in influencing the species composition, structure and diversity in many upland habitats. However, on wet bog, the general advice is not to use cattle and to encourage land managers to work with the Agencies and apply for appropriate agri-environmental schemes to improve the wildlife value and bring the designated land back into favourable condition (Reid and Grice 2001, English Nature 2005).

5.4.4 Drainage (Gripping)

A significant threat to the sustainability of peatlands has been the degradation associated with the installation of open-cut drainage ditches (also known as grips) (Holden et al 2004). The recent JNCC Common Standards Monitoring guidance (JNCC 2006b, Williams 2006) states that burning, grazing and drainage are the main causes of blanket bog degradation on SSSIs as these practices change the species composition caused by changes in peat hydrology and soils, particularly at the surface. Approximately 18% of SSSIs and 8% of Natura 2000 features are considered to be in unfavourable condition due to hydrological management (active drainage ditches). This section will discuss the impacts particularly associated with drainage, although it should be recognised that such practices often go hand-in-hand with prescribed burning and grazing, the impacts of which have already discussed.

Several recent comprehensive reviews of the hydrological and/or hydrochemical impacts of artificial drainage on peatland or organic soils have been completed and these have identified the key processes in relation to the degradation and restoration of blanket bog (for example Holden et al (2004) and Holden et al (2006a)). The reviews have referred to the associated effects of flooding and increased sedimentation further downstream in the catchments. Although these are recognised as being extremely important in terms of costs to the environment, business and ecology, they are beyond the remit of the review which is largely concerned with the management and restoration of the blanket bog itself.

Moor-draining has been practised in the uplands for over 100 years and involves the cutting of steep-sided, narrow open ditches (grips) approximately 0.5m wide by 0.5m deep and 15 - 35 m apart on wet moorland or blanket bog (Stewart and Lance 1983). Much of the drainage on blanket bogs has been done on interfluve areas and steep slopes (Robinson 1985). With the introduction of mechanisation, in the form of the Cuthbertson plough in the 1930s, the practicality of digging and draining large areas greatly increased (Coulson et al 1990). The ditches are normally cut along a contour or in a herring-bone shape with short lateral feeder ditches collecting into a
The extracted peat (spoil) from the ditch is deposited upside down in a ridge along one side (Stewart and Lance 1983).

The number of drainage works across the UK expanded rapidly after the Second World War in an effort to increase the amount of land in agricultural production and reduce UK dependency on the imports of food. Aerial photographs indicate that over 50% of blanket bog and upland moorland was drained between the 1930s-80s (Coulson et al 1990). Much of the expansion focussed on wetlands previously too wet for agricultural use, including blanket bog in upland areas when farmers were offered an incentive of 70% of cost under the Common Agricultural Policy (CAP) to drain the land. This was reduced to 30% in December 1984, resulting in a decline in subsequent new drainage schemes (Coulson et al 1990). At its peak in 1970 the rate of drainage was estimated at 100 000 ha/yr, resulting in a significant loss of moorland blanket bog vegetation (Robinson and Armstrong 1988, Stewart and Lance 1983).

Drainage may change the flow paths of water and alter the runoff:rainfall ratio from catchments. The aim of artificial drainage is essentially to reduce wetness by increasing runoff from the bog surface and lowering the water table within the peat. The purpose was often to encourage growth of Calluna vulgaris, the staple diet of the red grouse, Lagopus lagopus scoticus (Lawton, 1990) and thus to optimise grouse populations. In addition the Calluna would provide a food source, particularly in winter, for sheep (Grant et al 1985). However, Stewart and Lance (1983) stated that there was no science-based evidence to indicate a link between increased grouse populations and blanket bog drainage.

There has been very little long-term research conducted on the hydrology and process-based measurement of these areas, despite the extensive grants previously paid for draining the slopes. Table 5.4 summarises the main effects of upland drainage in terms of hydrological and hydrochemical processes and the subsequent effects on peat soils and vegetation.

The sheer complexity and variability of the hydrological processes that occur naturally in blanket bogs, including variations in climate and the differences that result spatially and temporally on peat catchments, makes the prediction of the effects of either draining or blocking the drains of a peat catchment very difficult (Robinson and Armstrong 1998, Archer and Newson, 2002). The lack of long term hydrological process measurements following drainage or blocking of drains within the catchments means that there is very little science-based evidence currently available to support or reject these two extremes of bog management. Many of the early studies of blanket bog drainage were made on an ad hoc or piecemeal approach, with poor data availability for many of the catchment-based studies. Early evidence from Conway and Millar (1960) and Burke (1975) was somewhat contradictory, with one study suggesting increased runoff and the other a decrease. The effectiveness of the drainage systems in affecting average water table levels has also been disputed. Conway and Millar (1960) found no evidence of the water table being reduced, whilst other studies clearly found a lowering and desiccation of peat surfaces. Burke (1967) claimed that ditches are only effective up to 2m from the ditch, and Stewart and Lance (1991) stated that the drainage activity can be reduced to as little as 0.5 m from the drain, suggesting that a dense network of closely dug ditches would be necessary to effectively drain the peatland – a proposal that would be costly in time and resources and therefore unlikely to occur.

Several researchers have used a paired catchment approach by comparing a drained and an undrained catchment to determine the effects of drainage on the hydrological processes. For example Burke (1967) studied the Glenamoy drained catchment in Ireland and found that runoff was faster on an undrained section of the bog
compared to a drained section, whereas Conway and Millar (1960) found moorland drainage increased runoff by reducing the water storage capacity on hillslopes. However, McDonald (1973) concluded that these differences were likely to be because the two study sites were not directly comparable. Soil properties such as hydraulic conductivity and peat type differed between the catchments and may explain the disparity in runoff regimes. More recently Holden (2006) studied the hillslope runoff processes and stream discharge from two drained and two undrained catchments on the Moor House National Nature Reserve (NNR), North Pennines, UK. The initial investigations by Conway and Millar (1960) had found that the ditching originally resulted in shorter lag times and flashier storm hydrographs through rapid runoff resulting from rainfall events. Holden’s study of the same sites in 2002 and 2004 found that the storm runoff in the drained sites was still rapid and the hydrographs still ‘flashy’, but that the response to rainfall was less sensitive. The runoff efficiency had significantly increased in the drains causing a distinctive spatial pattern of runoff across the slopes. The range and depths of the water table are important in terms of plant ecology (Coulson et al 1990) in peatlands and Holden (2006) observed that the drainage ditches created a spatial range of depths at Moor House NNR. The assumption of an equal drawdown of water on either side of the drainage ditch, as suggested by Boelter (1972), was not found to occur where ditches had been created on slopes at Moor House. Holden (2006) suggests that the topographic position of certain ditches may be more important in affecting the level of hillslope saturation and overland flow from the catchment and may be an important when considering which drains are most appropriate to block. This supports the findings of Lane et al (2003) and indicates that peatland topography and ditch location should be taken into account when determining the priority locations of ditch blocking (see section 6.3.2). Figure 5.8 show the main processes that occur associated with the installation of artificial drainage systems.

**Figure 5.8: Positive and Negative Effects of a Lowering of the Water Table and Hydraulic Conductivity (from Schumann and Joosten 2006)**

Many drained peatland catchments have been found to exhibit an increase in low flows and this may be associated with the ‘de-watering’ of the catchment through the slow drainage and drying out of the normally saturated catotelm (Holden and Burt 2003b, Holden 2006). Although it is accepted that the lowering of the water table may cause an increase in storage of water during storm events, making the runoff less sensitive in the short-term, this is not sustainable and, in the medium term,
water will continue to be lost from the catchment (Holden et al 2004). In the long-term, continuous dewatering potentially creates desiccation and soil instability resulting in an increase in subsidence and decomposition, a widening of surface drainage and subsequently an increase in runoff and the return of a flashy response to rainfall events and flood-risk once more (Robinson 1985, Holden et al 2004, Holden et al 2006b).

Organic soils may also shrink, crack and decompose when the ditches are exposed to weathering and drying from solar radiation during the summer and the formation of winter needle-ice in the winter (Tallis 1998). This natural weathering and desiccation of peat may be exacerbated by the lowering of the water table (Holden and Burt 2002a) and any increase in the soil water storage capacity may be negated relatively soon as water is quickly channelled into the drains and discharged from the catchments as the rapid response to rainfall events ensues once again (Holden 2006).

The loss of water from the drained catchments may also be exacerbated by increased macropore flow through the soils and drainage underground in the form of soil pipes developing in deep peat (Holden et al 2006b). Holden (2006) found that macropore flow and the number of soil pipes on the drained catchments at Moor House NNR were significantly higher than those on the intact catchments. The study indicated that not only did the density, but also the size of the pipes increase over time caused by the movement and scouring effect of water below the surface (Holden and Burt 2002b, Holden 2005b, 2006, Holden et al 2006b), creating wider and deeper ditches on the peat surface. This suggests that peat properties and bypassing flow may alter over time changing the structural properties of the peat caused by enhanced desiccation which may not always be reversible simply by a process of ditch blocking (Egglesmann et al 1993, Holden et al 2006b).

The loss of vegetation and subsequent increase in bare areas of peat and acceleration of peat desiccation along the sides of a ditch can lead to hydrophobicity which may exacerbate the erosion rate and increase the volume of sediments by producing more sheet flow (Holden and Burt 2002a, 2002b). This, together with the underground erosion of soil pipes can cause an exponential rise in the erosion rate of sediment and carbon release from drained catchments (Holden 2005a). Figure 5.9 shows the linear relationship between the age of the peat drain and the cumulative carbon loss from peat caused by piping (Holden 2006). Holden (2005a, 2006) therefore suggests that those areas subject to a greater discharge of sediments and carbon, that is, areas with an ageing system of drains on steeper slopes should be targeted for ditch blocking to reduce the losses. The lack of other quantified pipeflow studies makes it difficult to estimate the typical volume of dissolved and particulate organic carbon (DOC and POC) that may be emitted from pipes, but there is a concern that the existence of pipes and macropores may open the way for water, sediment and nutrients to be transferred from deep within and below the peat rather than just simply transferred rapidly through the aerobic acrotelm upper soil layer (Holden 2006). However, Jones (2004) pointed out that soil pipes are actually a ‘natural’ feature of the British landscape with an estimated 30% of podzolic and peat soils in the UK susceptible to pipe development. He recognised the potential negative effects of flood-flow response and hydrochemical processes, but also emphasised the positive effects of piping contributing to landscape diversity by altering the ‘stormflow contributing area’ and that this natural process should be integral in preserving and restoring a ‘natural’ landscape.
5.4.4.1 Effects of Drainage (Gripping) on Vegetation

Despite the extensive networks of drainage ditches that cross many of the blanket bogs in England, there has been little investigation of associated floristic changes that result from drainage of the land. Consequently the inter-relationships between vegetation growth and hydrological conditions in wetlands are not very well understood (Yazaki et al 2005). Stewart and Lance (1983) reviewed the studies available at that time and concluded that moor grips generally had a minimal impact on the hydrology and vegetation of peatlands. They generally accepted that the immediate effect of drainage was to lower the overall water table in the adjacent mass, and to increase the amplitude of short-term and seasonal fluctuations in the water table. However, various research has reported that this effect rarely extended beyond 0.5-2 m (Stewart and Lance 1983, Robinson 1985) and therefore had little overall impact on the blanket bog. Coulson et al (1991) concluded from their study of at Moor House NNR, North Pennines and Waskerly, County Durham, that the greatest effect of drainage and therefore desiccation would occur immediately downslope of each ditch. However, they found that there was no significant change beyond 5m in the composition of flora relative to the position of the ditch and that the effects of upland drainage were negligible. Conversely, other researchers have found that following drainage, the vegetation in a narrow strip adjacent to the ditch edge is modified as a result of the lowering of the water table and the deposition of excavated peat. Studies have generally found that the prominence of dwarf shrubs such as Calluna, Empetrum nigrum, Erica tetralix and Vaccinium myrtillus increased following the installation of drainage (Tallis 1965, Anderson et al 1995, Tallis 1998).

Perhaps of most concern is the effect drainage may have on the bog-forming moss, Sphagnum, which requires water to be supplied to its apical buds in order to survive and grow (Campeau and Rochefort 1996). As the species has no vascular system to maintain it during dry or drought conditions, Sphagna is normally limited to habitats with open surface water and may disappear from blanket bog if the water table falls by as little as 0.2m (Ivanov 1981). Sphagna is also vulnerable to being washed away as it is a rootless species and therefore may be particularly vulnerable where erosive surface runoff is dominant (Bragg and Tallis 2001). These findings are supported by Schouwenaars (1993) who found the hydrophysical properties of the upper layers of a bog (acrotelm) may be irreversibly changed following drainage, causing Sphagnum mosses to die off and be replaced by Calluna, Erica tetralix and Molinia caerulea. These plants are capable of rooting into the peat soils to tap into the water at depth and over time the moss layer, with its high water storage capacity, may be replaced by a more compact slightly decomposed peat layer covered with dry dwarf shrub or graminoid vegetation.
Table 5.4: Hydrological and Hydrochemical Effects on Peatlands from Artificial Drainage of Peatlands

<table>
<thead>
<tr>
<th>Process</th>
<th>Response</th>
<th>Effect</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon sequestration</td>
<td>Change from sink to a source</td>
<td>Drainage and lowering of water table with the resultant increase in aerobic peat layers can change bog from a carbon sink to a carbon source.</td>
<td>Laine &amp; Minkkinen (1996), Holden (2006), Holden et al (2006)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Drainage and rainfall-runoff relationship will vary between peat types due to different hydraulic conductivity properties of peat soils. Drainage density – spacing of &lt;4m required, if exceeds distance may not drain peat due to very low hydraulic conductivity</td>
<td>Burke (1967), McDonald (1973), Stewart &amp; Lance (1991)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Flood peaks increased due to increase in peak flows. Changes observed at a hillslope and catchment scale.</td>
<td>Robinson (1986, Lewis (1957), Howe et al (1967)</td>
</tr>
<tr>
<td>Dewaters peat body</td>
<td></td>
<td>Drained peatlands tend to increase low flows as the peat slowly “de-waters” and temporarily increases the storage capacity as water table is lowered.</td>
<td>Baden and Eglesmann (1970), Robinson (1980)</td>
</tr>
<tr>
<td>Lowers average water table</td>
<td></td>
<td>Although the main aim of ditching is to reduce the water table, contradictory evidence of the effectiveness of the drains in doing so. Ditches may have a localised effect on the water table and may increase the runoff of surface storm water without altering the storage capacity of the catchment.</td>
<td>Conway &amp; Millar (1960), Stewart and Lance (1991), Holden et al (2004)</td>
</tr>
<tr>
<td>Slumping, hydrophobicity and cracking</td>
<td></td>
<td>Subsidence associated with collapse of drainable macropores. A rise in capillary action results in an increase in water removal from sub-surface layers leading to an acceleration of peat shrinkage and cracking. Once the peat dries out and becomes hydrophobic, it cannot be readily re-wet to re-gain its original moisture content.</td>
<td>Holden et al (2001), Hobbs (1986)</td>
</tr>
<tr>
<td>Change in vegetation composition</td>
<td></td>
<td>Loss of diversity and restriction in the full range of bog species, elimination of water-tolerant species e.g. Sphagna and increase in graminoid species.</td>
<td>Fisher et al (1996), Coulson et al (1990)</td>
</tr>
<tr>
<td>Mineralisation</td>
<td>Increased mineralisation of peat and release of nutrients</td>
<td>Oxygenation of the peat enhances the mineralisation of nutrients, particularly Carbon-bound N and S, and organically bound P. The rate of mineralisation is effected by environmental factors such as pH, temperature, redox potential in addition to substrate factors e.g. decomposition, organic matter, nutrient content, inhibitors (chemical &amp; biological) to microbial activity.</td>
<td>Scott et al (2001), Scott et al (1998)</td>
</tr>
<tr>
<td>Change in nutrient composition</td>
<td>Increase in N and P and decrease in K of peat after drainage caused by an increase in the retention of N by microbial immobilisation as plant residues decompose and total N per volume of peat is increased and lowers C:N ratio.</td>
<td></td>
<td>Sundstrom et al (2000), Proctor (1992, 1994)</td>
</tr>
<tr>
<td>Changes in water chemistry</td>
<td></td>
<td>Large increases in ammonium concentrations from ditching and lowering of water table, but small increases in nitrification. Contradictory evidence of increases and decreases in Ca, Mg and K resulting from drainage.</td>
<td>Scott et al (2001), Crisp (1966)</td>
</tr>
</tbody>
</table>
5.4.5 Afforestation

The practice of afforestation on open blanket bog has been discussed in section 4 and became a particularly common type of land use in the uplands of the UK between 1950s – 1980s. Pyatt (1993) reported an estimated 190 000 ha of forest planted on deep blanket bog peat (> 1 m) and a further 315 000 planted on shallower peat (< 0.45 m). However, the impacts of forestry plantations on blanket bog need to be understood before the question of restoration can be addressed. The recent JNCC Common Standards Monitoring (CSM) guidance states that afforestation still accounts for 5% of SSSIs and 4% of Natura 2000 sites assessed as being in unfavourable condition, although not all such planting may be on peatlands (JNCC 2006b, Williams 2006). When discussing the impacts of management practices it must be recognised afforestation is often accompanied by a series of other management practices such as ploughing and drainage to make the land more suitable for tree growth. Table 5.5 shows the major stages and effects of afforestation on blanket bog and this review will concentrate on the changes to the hydrology, pedology and vegetation resulting from afforestation.

Trees rarely occur as a natural component of bog vegetation in the UK, although palaeoecological evidence shows that trees did occur where the conditions on bog surfaces were sufficiently dry to allow trees to grow (MacKay and Tallis 1996). However, the introduction of the Cuthbertson plough in the 1930s enabled deep peats to be drained sufficiently to allow tree planting on a large scale across the UK where they would have previously been unable to grow (Stewart and Lance 1983).

Commercial afforestation fundamentally alters the peatland system as it undergoes a series of changes:
- A major change in the physical and hydrological conditions due to the combination of ploughing and drainage
- Major structural alteration to the vegetation, introducing a tree canopy where only ground and field layer vegetation existed before
- The introduction of non-native species such as the sitka spruce, Picea sitchensis and Pinus contorta

The first stage in establishment of a forest plantation on blanket bog is the change in management of the land which in most cases may have been grazed or burnt to manage livestock and game, to one with no grazing (new plantations are often fenced to protect saplings) and no prescribed burning (Anderson 2001). In an active blanket bog with a high water table this “re-wilding” may be beneficial as Calluna may naturally regenerate through layering and dominant vascular species can be kept in check due to their water level tolerance (MacDonald et al 1995, Mountsford and Chapman 1993). However, the cessation of traditional management practices is then accompanied by ploughing which causes major disruption to the surface vegetation and hydrology. The natural blanket bog microtopography and structure is heavily modified by the creation of a trough and furrow system where the peat ploughed out to create the trough is deposited on the side to become a ridged-up surface (Anderson 2001). Such actions destroy much of the natural vegetation and expose large areas of bare peat which can be subjected to natural weathering processes of wind and water during the early stages of development (Tallis 1998). Burt et al (1983) found that the surface runoff through the newly created furrows acted as shallow drainage ditches and increased the runoff which rapidly responded to precipitation events, and greatly reduced the residence time of water in the soils.
Table 5.5 Afforestation and the Changes on Blanket Bog (adapted from Anderson et al 1995, Anderson 2001, Brooks and Stoneman 1997).

<table>
<thead>
<tr>
<th>Stage in Forestry Rotation</th>
<th>Effect on Water Table</th>
<th>Nutrient Enrichment</th>
<th>Other Effects</th>
<th>References</th>
</tr>
</thead>
</table>
| Establishment             |                       |                     | - Discontinuation of burning & grazing regimes practised prior to afforestation changes ground conditions. Allows vegetation litter and raw peat to accumulate.  
| - ploughing               | Lowers water table    | Raises nutrients     | - Destroys the acrotelm  
- Subsidence of peat surface associated with peat compression.  
- Ploughing creates a long-lasting micro-relief of drier ridges and wetter furrows. Furrows continue to provide damp, humid hollows after the natural hollows in bog surface have dried out, but are inhospitable to bog vegetation.  
- Encourages non-bog species e.g. *Deschampsia flexuosa, Molinia caerulea* | Anderson *et al* (2000) |
| - ditching                | Lowers water table    |                     | - Dries mound further, increases water table drawdown and water table fluctuations  
- Increases soil moisture deficits and lowers summer water table  
- Increases mineralisation of peat soils  
- Subsidence & slumping into drains may cause increase in erosion, scouring & sedimentation | Hillman (1987), Coulson *et al* (1990) |
| - fertilising             |                       | Significantly raises nutrients | - Plant nutrient concentrations in upper 0.5 m of peat profile increase in ombrotrophic bogs following drainage.  
- Fertiliser application to forests on ombrotrophic bogs increases the rate of nutrient cycling by raising the nutrient concentrations in needle litter. Many bog species are unable to compete in the improved conditions created for tree growth.  
| Before Canopy Closure     | Lowers water table    | Raises nutrients     | - Annual runoff increases for a period of a few years following drainage and then decreases and may be lower than pre-afforestation rates. Increases result from excess runoff from a lowering of the water table, but also from secondary compression resulting from a lowering of the water table and water being squeezed out of the saturated peat below the water table.  
- Runoff decreases again when evapotranspiration from trees increases and matches the decreasing rate of water yield from the compressed peat.  
- Hydraulic conductivity of dried layer increases while that of compressed layer i.e. below the water table, decreases.  
- Peat shrinkage & cracking occur as part of the desiccation process approx 10-15 yrs after canopy closes. The cracks form a network which act as an additional drainage system and can hamper restoration attempts.  
| After Canopy Closure      | Significantly lowers water table | Raises nutrients | - Forests in high rainfall areas would be expected to dry out following canopy closure.  
- Shade and shelter increase gradually as trees grow and cover more of the ground  
- Interception loss and transpiration by trees leads to a much greater lowering of water table than caused by drainage alone and greater surface subsidence caused by shrinkage and drying of peat surface and compression of underlying peat  
- Hydraulic conductivity of dried layer increases while that of compressed layer i.e. below the water table, decreases.  
- Peat shrinkage & cracking occur as part of the desiccation process approx 10-15 yrs after canopy closes. The cracks form a network which act as an additional drainage system and can hamper restoration attempts.  
| Harvesting                |                       |                     | - Marked reduction in shade and shelter and opening of light to ground following harvesting.  
- Water table raised, although more potential for extremes of seasonal fluctuations which may hamper rehabilitation of bog. | Verry (1981) |
| - leaving residue         | Significantly raises water table | Significantly raises nutrients |                       |            |
| - removing residue        | Significantly raises water table | Raises nutrients     |                       |            |
It should also be emphasised that the grips used on open peatland may differ from those used in afforested plantations and therefore the effects, despite both being on deep peat, may differ considerably and cannot directly be compared. For example, Brocklehurst (2005) studied the Wharfedale catchment in the North Pennines and observed that the agricultural drainage on the open moor used fewer, but large ditches around the field margins, compared to the dense forest drainage grips. The ditches reduced the water table, and additional deeper ditches rapidly channelled the water away from the ploughed area (Anderson et al 1995).

Anderson et al (1995) observed that organic soils start to aerate and oxidise as a result of the drainage for forestry, experiencing increased evapotranspiration and uptake of moisture by the tree roots. This can increase the instability and cause subsidence of the soil surface by compression and shrinkage. Burt et al (1983) found a marked increase in suspended sediment following pre-afforestation ploughing and drainage indicative of an increase in erosion of organic soils and transport of material downstream. The hydraulic conductivity of the desiccated upper layers of peat may increase, whilst that of the peat below the water table decreases (Ivanov 1981). Pyatt (1993) found that such effects are short-lived and may be reduced after canopy closure and David and Ledger (1988) concluded that the intensity of these effects could also be site-dependent with factors such as ditch density, peat type, vegetation cover and climate (David and Ledger 1988).

Shotbolt et al (1992) found that once the trees reached maturity and the canopy started to close, the water table was lowered significantly due to the increased interception and transpiration of the vegetation. Pyatt and John (1989) also observed that as the peat dried out, large-scale peat cracks associated with shrinkage first appeared in soils some 10-15 years after planting when the canopy began to close and could rapidly develop over a wide area and to a depth of over 0.2m to form a dense network and create an additional drainage mechanism for the site and more importantly hamper restoration attempts following clear-felling (Anderson 2001).

It is widely accepted that loss of bog species will result from the various stages of afforestation from initial establishment to mature plantation, including the combined effects of drainage, ploughing, fertiliser application. Planting and growth will change the vegetation structure from an open peatland habitat to a typical structured forest habitat with ground, field, under-storey and canopy layer vegetation (Chapman and Rose 1991, Wallace et al 1992, Anderson et al 1995). Typically there is a change from bog vegetation to light demanding, competitive graminoid species. Sparse Eriophorum vaginatum cover, occasional ferns, mosses, lichens and liverworts are generally found (Wallace et al 1992, Chapman and Rose 1991, Tallis 1998). However, some studies indicate that ploughing can create a long-lasting micro-relief of drier ridges and wetter furrows which continue to provide damp, humid hollows after the natural hummock and hollow system dries out and ceases to function (Anderson 2001).

More recently, studies have focused on the effects of harvesting to determine the impacts of clear-felling afforested areas planted in the 1960s (for example, Anderson et al 1995, Archer and Newson 2002, Neal et al 2004, Neal et al 2005). Felling has been associated with a deterioration in water quality on a local scale through increased oxidation, microbial activity and release of dissolved organic carbon and other compounds (Soulsby et al 2001, Neal et al 2004, Neal et al 2005). Research indicates that the impacts on a catchment scale are extremely low and this may be due to site management policies adopted by the Forestry Commission (Patterson and Anderson 2000). For example, Neal et al (2004) studied the Plynlimon catchment following clear felling and found that there was a marked change in water quality.
observed at the local scale only, with increases in nitrate, phosphate and ammonium concentrations following clear-felling, but these were short-lived and levels decreased over time.

The Llanbrymair and Coalburn studies of afforestation were carried out by the Centre of Ecology and Hydrology (previously the Institute of Hydrology) (Robinson 1986, Robinson et al. 1998) and is perhaps most significant in being used to investigate the pattern of change over a complete forest harvesting cycle. The monitoring commenced in 1967 and harvesting of the trees is expected to start in 2020. This is now the longest-running experimental catchment in the UK. The Coalburn study indicated a significant increase in storm runoff and decrease in time to peak immediately following drainage, although the area recovered to pre-drainage response after approximately 10 years when the canopy began to close and the surface drains became less efficient due to in-filling and subsidence (Robinson et al. 1998).

The Forestry Commission (FC) reviewed the values of peatlands in terms of nature conservation and the contribution of the UK blanket bog as a world resource. It has concluded that habitat and species conservation, improvement of biodiversity and continued sequestration of carbon from peat soils are reasons that:

“there should be a strong presumption against further forestry expansion on extensive areas (> 25 Ha) of active blanket bog averaging 1m or more in depth or any associated peatland where afforestation could alter the hydrology of such an area” (Patterson and Anderson 2000, p4).

The FC states that it is committed to protecting these areas of blanket bog by agreeing not to approve grant applications containing proposals for new planting or new natural regeneration in these areas and to prevent forestry developments which may damage these habitats. Should unauthorised forestry developments occur, the FC is empowered to require restoration of the blanket bog (Patterson and Anderson 2000).

Although it is commendable that practices such as afforestation of a nationally and globally valued habitat have been reduced, Patterson and Anderson (2000) reported that the FC was still committed to achieving their main aim of increasing the cover of trees in the UK through the expansion of native woodlands on shallow peat and degraded blanket bog within their natural range. There has been a move towards a greater diversity in the structure and use of forests and the greater use of native species. Although much research has already considered the impacts of afforestation of conifer plantations on these upland areas, there is still a potential risk from planting on areas of degraded bog. New research may therefore need to focus on the changes in pedology, hydrology, vegetation and water quality following a change in the species of tree crop. Deciduous deep-rooted native broadleaves are likely to have very different impacts on peat soils compared to their evergreen, shallow-rooted predecessors. These research needs are likely to be driven by the Water Framework Directive in terms of controlling diffuse pollution from forestry operations, regulating acidification and raising water storage capacity to prevent rapid runoff and potential flooding (Emmett and Ferrier 2004).

5.4.6 Liming and Fertiliser

Organic soils are naturally acidic with a pH 3.0 - 4.2 (Heal and Smith 1978) so the application of lime has been used traditionally to raise the pH of the soil and
encourage vegetation growth to increase the productivity of land for grazing or afforestation. More recently, the application of lime has been used on a number of restoration projects to stimulate growth of seedlings and maximise rapid coverage of nurse-crop vegetation during initial stages of re-vegetation (Anderson et al 1997, M Buckler 2006 pers comm).

Many researchers advocate a thorough knowledge of catchment soils and hydrology (flow pathways, residence times and the quality and quantity of runoff) are necessary as a pre-requisite of a successful strategy for whole-catchment or headwater liming (e.g. Warvringe and Sverdrup 1988, Howells and Dalziel 1992, Driscoll et al 1996). Liming of such hydrological source areas is considered an effective method of catchment liming as there is a rapid response to rainfall events (Waters et al 1991). Such methods have been used to raise the pH levels and alkalinity in upland areas particularly affected by the anthropogenic influences of acidification resulting from wet and dry deposition of sulphur and nitric oxides (Evans et al 2001). However, researchers have found that lime may adversely affect the bryophytes (including sphagnum spp), lichens and other wetland plant communities (Clymo et al 1992, Gorham and Rochefort 2003). Bragg and Clymo (1995) found approximately 90% of the Sphagnum carpet in the catchment appeared to have died following the application of lime on the Loch fleet catchment area, Scotland. The effects were still apparent some 8 years later, when it was observed that vascular plants and mosses had replaced the sphagnum. Jenkins et al (1991) assessed the liming strategies in the Llyn Brianne catchment in Wales and observed that the limed headwaters of the catchment significantly contributed to stream flow and raised pH during wet conditions. However, when dry conditions prevailed, there was a change in the contributing area and the pH did not improve.

Liming can also increase mineralisation of nitrogen and organic carbon (Shah et al 1990, Dorland et al 2004) causing nitrate to leach into surface waters and so temporarily lower the pH of soil and water (that is, counteract the very aim of the application of lime). Shah et al (1990) studied the short and long-term effects of liming on podzolic soils and found nitrogen mineralisation rose sharply for a short period. The rise was accompanied by a substantial increase in soil respiration following an increase in soil microbial activity and increase in the decomposition of organic matter (Shah et al 1990, Bellemakers et al 1996). Such microbial activity, particularly in the anaerobic upper soil layers of organic soils has been associated with a deterioration in water quality and release of discoloured water consisting of a series of natural organic compounds, primarily humic and fulvic acids (Tipping et al 1989, Worrall et al 2002 ). The increase in the rate of decomposition of the peat soils may also alter the rate of peat accumulation resulting in a change in the rate of carbon sequestration and potentially, the carbon balance from a sink to a source. Table 5.6 summarises the main advantages and disadvantages of catchment liming.

### Table 5.6: Advantages, Disadvantages, Effectiveness and Duration of Catchment Liming

<table>
<thead>
<tr>
<th>Method</th>
<th>Advantages</th>
<th>Disadvantages</th>
<th>Reference</th>
</tr>
</thead>
</table>

Although emphasis has been placed on the necessity to fully comprehend the hydrology of a catchment prior to any liming, the sheer complexity of these hydrological processes is daunting (see section 3.5). In addition, catchment hydrology is likely to be significantly altered by afforestation/deforestation and other management practices associated with the degradation of blanket bog. Peat desiccation and the subsequent shrinkage and cracking of soils may increase the volume of water routed through preferential flow paths such as soil pipes resulting in
rapid runoff (Holden and Burt 2002b, Evans et al 1999). Accelerated discharge rates and flow through underground soil pipes and cracks will decrease the contact time with the neutralising lime, reducing the amount leached into the soils and potentially increasing the levels found in water courses (Holden 2005b).

In addition, the practice of liming catchments has been recommended to restore the natural conditions of a watercourse to those levels prior to anthropogenic acidification. However, blanket bog is associated with a naturally acidic oligotrophic status and further research may be required to determine the effects of liming on adjacent water courses, not only in terms of chemical water quality (mineralisation of nitrogen, release of carbon, water discoloration etc), but also biological water quality and the potential to change the trophic status from a naturally acidic nutrient-poor system to a meso- or even eutrophic nutrient-rich system. Donnelly et al (2004) briefly reviewed liming and its ecological consequences in the context of reducing acidification in surface waters and the effects on forest plantations. Many of the studies have examined the effects of soils on forest floors, which differ greatly in structure and hydrology from blanket bog which has never been planted with trees, although MacKenzie et al (1990) conclude “no single optimum dose of lime would be compatible with the conservation of upland bog communities”. There is a clear need to improve our knowledge of the processes associated with liming on a catchment and localised level, and the short and long-term effects of such practices.

The Water Framework Directive (WFD) (2000/60/EC) has recently been adopted by the European Union with the purpose of establishing a framework for the protection of inland surface waters. The Directive defines pollution as “the direct or indirect introduction as a result of human activity of substances or heat into the air, water or land which may be harmful to human health or to the quality of aquatic ecosystems or terrestrial ecosystems” (Article 2.33). The application of liming materials could potentially be classified either as a pollutant under the WFD, or conversely as a mitigation measure. There does not appear to be any clear policy on the use of lime in catchments following a consultation on river basin management guidance (Defra 2005a) and the subsequent report on the results of the consultation published in September 2006 (Defra 2006). The use of liming in blanket bog restoration requires careful consideration, especially in large scale projects.

5.4.7 Recreation

There is a strong synergy between nature conservation and recreation in the uplands and the aesthetic value of this landscape and yet it is one of the most challenging conservation tasks to allow adequate access while maintaining the ecological quality of these popular areas (Charman and Pollard 1995). Although Charman (2002) argues that peatlands are not popular locations for regular recreational use compared to other natural or semi-natural habitats, they are still considered by many to be our last true wilderness in Britain (Lindsay 1995) and as such attract many visitors seeking the wilderness experience. In the UK, visitor pressure is particularly severe in the National Parks where tourism is an important source of income and is actively encouraged. National Parks such as the Yorkshire Dales, North York Moors and Peak District National Park all have extensive areas of moorland and blanket peat. The Peak Park is perhaps one of the most accessible, being surrounded by major cities. It is one of the most popular tourist destinations in the country and has an estimated 18–22 million day visits to the National Park each year (PDNPA 2006).

Walkers and hikers are one of the major causes of recreational disturbance in the uplands and the erosion of footpaths and adjacent land has become a widespread
problem in England, particularly on areas of peatland which are more sensitive to moderate disturbance due to the soft soil structure and low-growing vegetation. Repeated trampling of an area, such as a popular footpath regularly frequented by walkers can cause a reduction or destruction of vegetation and compaction and erosion of soil if the recreational carrying capacity is exceeded (Shimwell 1981). Carrying capacity is defined as "the level of use an area can sustain without an unacceptable degree of deterioration of the character and quality of the resource or of the recreation experience" (Countryside Commission 1970). However, the effects of a given intensity of recreational pressure are dependent on the nature of the physical and biotic environment such as the geology, soil type, slope, aspect, species composition, past management regime and weather conditions during the period of recreational use (Shimwell 1981, Grieve 2001). Anderson (1990) noted that blanket bog vegetation associated with the high plateau areas in the Peak Park was less resistant to trampling than was the low growing grass sward of the in-bye land, indicating that less modified vegetation is more vulnerable to trampling than that managed more intensively.

Studies of the effects of trampling on upland vegetation such as Calluna vulgaris and Vaccinium myrtillus have also found that the bruising of such vegetation by trampling makes it vulnerable to desiccation and winter frost browning (Watson 1984, Cole 1987). Of even more relevance to blanket bog and its restoration is the impact of recreation on lower plants, particularly Sphagnum mosses and lichens. Borcard and Matthey (1995) found that 10 minutes of experimental trampling repeated only three times a year for three years almost destroyed the cover of Sphagnum recurvum and S.fuscum.

The removal of surface vegetation and exposure of bare peat soils by trampling also heightens the risk of soil erosion through the natural weathering by wind and water. In an upland environment such as a blanket bog, the linear nature of the paths on a gradient may localise water run-off and the rapid transport of sediment, soil deposition in watercourses and change species composition (Morgan 1995, Grieve 2001). For example, the popular Pennine Way footpath originates in the Peak District and is intensively used by walkers. Its use was monitored between 1971 – 1988 when it was found that the width of bare ground increased by 300-900%, resulting in an average width of 7-8m of bare peat, but extending to 70m in places and an estimated peat loss 10mm/yr (Porter 1990). Various solutions have been sought and changes have been made to improve the amenity value of the route by paving areas with gritstone slabs across particularly vulnerable areas of blanket bog (Porter 1990, Anderson et al 1997).

In his study of soil profiles on the Cairngorm plateau, Grieve (2001) found the mean organic matter under disturbed trampled vegetation was less than half that under a complete vegetation cover and concluded that human trampling affects the organic matter storage in soils in much the same way as natural geomorphological processes. These effects are likely to continue under conditions of climate change and the prediction of warmer, wetter winters, and increased rainfall may produce soils even more vulnerable to trampling processes and release more terrestrial carbon. There is an obvious need to continue to monitor and predict the sensitivity of soil systems to changes in human activities and to identify the recreational carrying capacity for areas of blanket bog and so determine the threshold values for resistance/erosion of hill vegetation. The capacity will change according to the degree of soil wetness and the ability to react to extremes and in the light of increased leisure time, and early retirement at present, the number of visitors to such sites is likely to increase.
6 Restoration of Blanket Bog

6.1 Introduction

Peatland restoration is gaining in importance with the wider recognition by many that these ecosystems provide several important functions of which carbon retention, sequestration and the potential to counteract the threat of climate change are paramount. However, such functions may be strongly context-dependent and the actual environmental role of most sites and the implications of restoration are still to be established (Wheeler et al. 2002). In addition, the term “restoration” may be in need of clarification as landowners, practitioners, policy makers and scientists may each have their own interpretation.

At its simplest restoration has been defined as the “reinstatement, re-establishment, return or repair of”, in this case, a land type or habitat. Charman (2002) stated that ‘restoration’ is the term most commonly recognised as trying to bring a peatland back to a functioning ecosystem. However, one of the most difficult questions facing many land managers is “what to restore a blanket bog to?” and Wheeler et al. (2002) advocate that this must involve a) identification of objectives; b) identification and reinstatement of appropriate habitat conditions; c) facilitation of species recolonisation.

Wheeler (1995) suggested that ‘restoration’ may encompass a set of objectives to restore a site to its original or former state and ideally restoration should be to restore peatland to the condition it would have been in now without disturbance (Charman 2002). Clearly, both of these end-products cannot be achieved simultaneously on the blanket bogs of England which have changed temporally both through natural succession and through direct and indirect anthropogenic activities over many centuries. It should be remembered however, that the “start” conditions for restoration are not a stable state and merely reflect a single point along a trend. It may be possible to reverse the trend but not to restore the community to its original state (Bradshaw, 2002). The terms ‘rehabilitation’ and ‘renaturation’ are now also being used to imply a wider range of acceptable objectives than ‘restoration’, but have not replaced the more popular ‘restoration’ term. ‘Restoration’ implies the use of much greater resources to reverse the earlier destruction and re-creation of a habitat that has some conservation value, due to its species, ecosystem services or functions it possesses (Charman 2002).

In the last 20 years there have been several publications in the UK alone which give guidance on the practical aspects of restoration of blanket bog habitats, for example Rowell (1988), Rowell (1990), RSPB (1995), Brooks and Stoneman (1997), Backshall et al. (2001), Adamson and Gardner (2004). Many of the recommendations are generic with the main guidance focussing on the stabilisation of soils and the reinstatement of hydrological function to be achieved by a programme of re-planting, fertilisation, gully blocking and changes in land management (Gorham and Rochefort 2003). Fundamental to the restoration process is the necessity to restore the hydrological integrity of the site so that it becomes self-sustaining and no longer requires artificial water tables such as those created by the blockage of gullies. This section will consider to what state blanket bog should be restored, the considerations in deciding on the objectives for the site, and the techniques advocated in order to achieve those objectives. Research and case studies are used to illustrate the techniques and monitoring undertaken. An overview of recent research by different bodies and the case studies are located in Appendix I.
6.2 Blanket Bog Restoration

6.2.1 Objectives of Blanket Bog Restoration

The objectives of blanket bog restoration are often detailed, extremely variable and can be affected by the subjective views of individuals and the relative values placed on the ecosystem (see section 3). Wheeler (1995) advocates four factors when considering whether the objectives of restoration are achievable. Clearly these will have an influence on prioritising restoration sites as invariably the restrictions of finance, resources and time will prevent the ability to restore all blanket bog sites, designated or otherwise, in England.

Wheeler (1995) suggested consideration of:

- **Feasibility** – Restoration options may depend on the existing environmental conditions and the scope for ‘modifying’ them. The cost-effectiveness of possible restoration objectives should be carefully considered, particularly in the light of climate change and water supply.

- **Former Character** – The rationale for restoration may be provided by the character of the peatland prior to the onset of its degradation. Although palynological records may provide information on the past vegetation composition, it may still not be clear which stage of development should be aimed for.

- **Rarity** – Although rarity has been used for the purposes of blanket bog conservation (i.e. UK has 15% of the world’s blanket bog), and is often used as a measurable objective in many local BAPs, it may be difficult to prioritise rare habitats and species and may lead to a conflict of interests. For example, the restoration of heather moorland on blanket bogs to favour bird populations against the restoration of blanket bog and its associated invertebrate populations.

- **Scarcity of Opportunity** – The relative ease in which to achieve the objectives of restoration in a wide variety of locations compared to the difficulty in achieving the objectives on a few more complex sites may mean decisions to restore are made on the basis of existing condition (e.g. unfavourable – recovering), historical precedent or the subjective perceptions and aspirations of landowners or managers (Wheeler 1995).

Although these considerations may not be simple to assess, they provide the rationale for taking radical and expensive measures to achieve restoration. In the light of the estimated expenditure to restore blanket bog over the next six to seven years, these considerations may be useful when allocating grants and funding to future restoration schemes. Kettunen and ten Brink (2006) indicated that the current PSA targets formulate a nationwide plan to improve and manage approximately 300 000 ha of blanket bog by 2010 and a further 225 000 ha by 2015. The UK’s action plan to restore 75% of degraded peat mires cost approximately € 20 million/yr in 2005 and is estimated to cost approximately €65 million/yr for the subsequent 10 years. It is estimated that the total expenditure to restore 845 000 ha will be approximately €680 million (€800/ha).

6.2.2 Principles of Blanket Bog Restoration

Wheeler (1995) stated that there are two main strategies to restore habitat conditions: by repair and by rebuilding. Restoration by repair attempts to restore requisite conditions directly, tends to be small-scale and recovery and achievement of objectives can be relatively fast. Re-building however, considers restoration on a larger scale, or on badly damaged sites where there has been irreversible change.
Such restoration can be prohibitively expensive or technically challenging and may take a long time for species communities to develop.

The development of restoration strategies is often troubled by lack of knowledge. Workshops which bring practitioners, scientists and policymakers together to consider areas of further research have identified gaps in the knowledge and these will be discussed in section 8. Broadly, there is still a need to quantify the causes of damage to peatlands, the processes involved in the degradation and recovery of peatlands, and the responses of flora and fauna to such processes. Such lack of knowledge has meant the first attempts to restore peatlands have been based on assumptions and experience rather than hard data or scientific principles. For example, factual data on the environmental optima and tolerance-range of bog species and the conditions required for their successful re-establishment and persistence are still lacking. However, several studies have recently focussed on the barriers to rapid primary or secondary succession of Sphagnum and the methodologies to measure the return of different ecosystem functions of a peatland (Rochefort 2000) and will be referred to in the following sections.

Kettunen and ten Brink (2006) suggest eight factors that may affect the success of a restoration project.

- Area and depth of extraction
- Type of exploitation (block cutting, drainage etc)
- Depth and type of peat remaining
- Degree of hydrological disturbance
- Presence of remnant vegetation
- Nature of former vegetation
- Nature of surrounding vegetation
- Time of abandonment to attempted restoration

Charman (2002) suggested that the level of disturbance should also be considered when determining the aim of a blanket bog restoration project, as both past and present disturbance may be relevant in the formation and accumulation of peat and in its current management. Restoration should also consider which of the peatland properties have been disturbed and whether any of them are irreversible. Table 6.1 summarises attempts to classify peatlands according to the level of disturbance and the types of disturbance are exemplified.

Table 6.1: Peatland Classification According to the Level of Disturbance. Adapted from Warner 1996, Charman 2002 and Schumann and Joosten 2006

<table>
<thead>
<tr>
<th>Disturbance Level</th>
<th>Character</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimal Disturbance</td>
<td>Human influence restricted to hunting/gathering. Initiation and development processes proceeded naturally, no drainage, ecology little altered from natural succession.</td>
</tr>
<tr>
<td>Minor Disturbance</td>
<td>Historic or minor disturbance by humans e.g. low intensity grazing or forestry, not/slightly drained. Peatland type and form retained if not disturbed.</td>
</tr>
<tr>
<td>Modest Disturbance</td>
<td>Recently deeply drained resulting in a change in vegetation composition, no pedogenesis (soil formation).</td>
</tr>
<tr>
<td>Moderate Disturbance</td>
<td>Historic or present disturbance levels sufficient to alter type or form of peat e.g. long-term very shallow drainage. Some pedogenesis and change in vegetation composition. Functioning bog retained but structure and function are altered.</td>
</tr>
<tr>
<td>Major Disturbance</td>
<td>Human activity altered structure and form of bog through subsidence and oxidation, changing function of peat significantly e.g. long-term deeply drained or intensively grazed, strong pedogenesis. Major hydrological changes and vegetation impoverished.</td>
</tr>
<tr>
<td>Artificial/Maximum</td>
<td>Intensive drainage almost completely destroyed peat bog, strong pedogenesis or compacting of peat surface, extensive peat erosion, oxidation.</td>
</tr>
</tbody>
</table>
Charman (2002) outlined three potential methods of managing disturbed peatland sites:

- Prevent further disturbance and aim to restore the peatland to its natural state using active management where necessary.
- Maintain the disturbance as a means of preserving the status quo and retaining existing values of the site.
- Allow disturbance to continue and then restore the site once the economic value has been fully exploited.

Using the argument that where a highly disturbed blanket bog exists “any bog is better than no bog at all”, the first option may be considered the only one acceptable. For example, it may be possible to create a bog as close to natural conditions by controlling the management of burning and grazing whilst allowing the marginal growth of ‘natural’ vegetation such as downy birch *Betula pubescens* or mountain ash, *Sorbus aucuparis* which were known to grow on blanket bog in the past (Andersen 1997).

Adamson and Garner (2004) state that the objectives for a site should be reviewed prior to the commencement of a management programme which may include a restoration strategy for the site. They focus on adopting specific objectives based on the outcome of an initial condition assessment as different practices may be required depending on whether the site is favourable, unfavourable or destroyed. This is a similar approach to that advocated by Charman (2002), as the level of disturbance would ultimately affect the condition of the site (Schmann and Joosten 2006). Adamson and Gardner (2004) go on to list the main factors in need of consideration when setting restoration objectives, summarised here in Table 6.2.

**Table 6.2: Factors to Consider When Setting Conservation/Restoration Objectives (Adapted from Adamson and Gardener 2004)**

<table>
<thead>
<tr>
<th>Factor</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flora and fauna</td>
<td>Map site (NVC categorisation)</td>
</tr>
<tr>
<td></td>
<td>Assess site condition – JNCC condition assessment methodology</td>
</tr>
<tr>
<td></td>
<td>Identify and map rare and important species – local and national status</td>
</tr>
<tr>
<td></td>
<td>Check historic records – previous habitats and communities of species</td>
</tr>
<tr>
<td><strong>Is restoration of these flora &amp; fauna possible?</strong></td>
<td></td>
</tr>
<tr>
<td>Current/Past Management</td>
<td>Grazing – stocking densities, species &amp; breeds of animal, shepherding, supplementary feeding</td>
</tr>
<tr>
<td></td>
<td>Prescribed burning – frequency of burn, vegetation burnt</td>
</tr>
<tr>
<td></td>
<td>Drainage – artificial drains – frequency, active</td>
</tr>
<tr>
<td></td>
<td>Recreation and sporting activities</td>
</tr>
<tr>
<td></td>
<td>Vehicle use</td>
</tr>
<tr>
<td></td>
<td>Peat cutting</td>
</tr>
<tr>
<td><strong>How do the management practices affect habitat and species?</strong></td>
<td></td>
</tr>
<tr>
<td>Local Information</td>
<td>Specific biodiversity objectives for the region/county</td>
</tr>
<tr>
<td></td>
<td>Local nature conservation projects</td>
</tr>
<tr>
<td></td>
<td>Current research/monitoring of sites</td>
</tr>
<tr>
<td><strong>Do the site objectives support these?</strong></td>
<td></td>
</tr>
<tr>
<td>Additional Considerations</td>
<td>Legal/statutory obligations for the site/area</td>
</tr>
<tr>
<td></td>
<td>Factors that may constrain management change e.g. public access, tenancies</td>
</tr>
<tr>
<td><strong>Are there measures to counter these constraints?</strong></td>
<td></td>
</tr>
</tbody>
</table>

It must be noted that management of blanket bog can rarely be undertaken in isolation, as the landscape consists of a mosaic of wet and dry communities resulting from the complex microtopography of the pool and hummock system within the macrotopography of raised, valley and blanket mires (Reid *et al* 1994, Tallis 1994, Tallis and Livett 1994, Lindsay 1995, Belyea and Lancaster 2002). The following sections are divided into specific management strategies for different situations, but land managers and practitioners may undoubtedly select several strategies that may be appropriate to the whole landscape. For example a spatially variably burning pattern may be implemented together with fencing of protected areas, low-intensity
grazing, blocking of existing drains and re-seeding of badly damaged areas across an upland blanket bog which may encompass several catchments and multiple landowners. The success of any blanket bog restoration will ultimately be judged according to the value we perceive as being provided by the ecosystem and the services it provides.

6.3 Restoration of hydrological function

Water and hydrological functionality are central to the condition of a blanket bog. Without adequate water, a blanket bog will eventually cease to exist, firstly by the change of vegetation composition, followed by the shrinkage and decay of peat soil (Charman 2002). The management of water is therefore paramount to maintaining suitable conditions for peatland ecology. The relative position of the water table within the peat will affect the stability of the ecosystem by balancing the level of accumulation and decomposition (Holden et al 2004).

It is recognised that even slight changes in hydrology may result in significant alterations to the hydrological processes and so endanger the highly valued ecosystem services of blanket bog identified in section 4, such as carbon sequestration, species composition and water supply. It is therefore important to gain an understanding of the hydrodynamics of the peatlands in terms of comprehending the effects of different types of degradation on hydrology and also the ability to identify suitable restoration strategies (Brandt et al 2004, Bullock and Acreman 2003, Burt 1995, Evans et al 1999, Labadz et al 2002)

The UK is in the process of implementing the Water Framework Directive (2000/60/EC) and together with the Habitats Directive (92/43/EEC) it provides the legislative tools to protect and support blanket bog restoration. Acreman and Miller (2005) have emphasised the need to develop a consistent hydrological impact assessment approach to wetlands (including blanket bog) based on fundamental hydrological principles. Their assessment integrates four important concepts which can be adapted to blanket bog:

- Building a sound conceptual understanding of the hydrological processes that control water movement into and out of a wetland and can be tested by the water balance;
- Using a risk-based approach;
- Recognising a hierarchy of modelling tools from simple to complex that require different amounts of data, different user time and deliver different levels of confidence;
- Recognising the changes in water influx and its importance e.g. during periods of drought

Acreman and Miller (2005) suggest the use of an Environmental Impact Assessment (EIA) as a means of collating and assessing the likely significant environmental effects of a restoration programme. An EIA is required for any major development in EU States under EU Directive 97/11/EC, but at present this does not include wetlands. However, under the (Ramsar) International Convention on Wetlands, contracting parties are required to maintain the ecological character of wetlands and the Convention’s ‘Science and Technical Review Panel’ has developed guidance on the relationships between wetland and catchment hydrology with the publication of "The Ramsar Handbooks for the Wise Use of Wetlands". The handbooks are being published on-line as they become available and include Handbook 13 on “Impact assessment” which incorporates guidelines on biodiversity-related issues with environmental impact assessment legislation and/or processes. Particular emphasis has been given to the scoping and screening stages of assessment (Ramsar 2006).
Although it is accepted that there will always be an element of uncertainty, it is widely upheld that the more data available and research undertaken, the better the understanding of the complex processes involved. The EIA survey may therefore assist in avoiding unnecessary work, such as, blocking ditches that are already re-vegetating or gullies that are too degraded, whilst increasing the level of understanding so as to improve the decision-making process.

6.3.1 Grip/Drain blocking

6.3.1.1 Methods of Grip Blocking

Many of the peatland restoration projects to date aim for the re-establishment of high water tables along with the re-colonisation of bog-forming species such as *Sphagnum*. The purpose of grip blocking is to minimise water loss from the area. Throughout the UK this method has been used by a variety of organisations including Natural England, The National Trust, Forestry Commission, the RSPB, The Wildlife Trusts, plus numerous landowners.

Water loss can be prevented by the damming or infilling or these drains (grips). The main objectives of the ditch blocking to bring blanket bog back into favourable condition are (Backshall *et al.* 2001):

- To restore natural drainage
- To encourage revegetation of the bog surface
- To reduce erosion
- To minimise the effect of flooding and erosion in the catchment

The *Upland Management Handbook* (Backshall *et al.* 2001) also advocates that the above objectives can be achieved by:

- Allowing grips to naturally infill where possible
- Blocking eroding ditches (and those feeding into eroding areas)
- Blocking ‘active’ grips that are self-maintaining

Natural revegetation by infilling with sediment and vegetation of moorland ditches located on blanket bog can reduce the effectiveness of the drains in removing excess water from the site (Stewart and Lance 1991). This type of non-intervention management may be one of the simplest management strategies proposed, but the extent to which it occurs naturally will depend on the peat type, the angle of slope and the drainage area feeding into the drain as this will affect the volume of water and erosive processes acting on the peat (Evans and Warburton 2001). Natural infilling can occur where peat has slumped to the drain floor, slowing water flow and encouraging the build-up of sediment and eventual recolonisation of pioneer species such as *Sphagnum* and *Eriophorum angustifolium*. The extent of this natural revegetation is, however, limited and in other areas many of the original drainage networks have actively eroded vertically through the peat soils to the substrate, together with lateral erosion to enlarge the drains 10 to 15 times that of the original width (Holden *et al.* 2006). Figure 6.1 shows an eroded grip in the Ashop Catchment, south Pennines, Derbyshire.
More active methods of grip blocking are therefore often considered necessary. Various dams, together with a range of approaches for installation, have been developed to raise and maintain water levels according to the prevailing conditions on the bog. In most cases it is the size of the ditch and the resources available that dictate the techniques and materials used for damming (Brooks and Stoneman 1997). Several publications have described the methods and techniques for the choice of materials and installation of blocks. These include Rowell (1985), Backshall et al (2001), Adamson and Gardner (2004), and the very comprehensive Brooks and Stoneman (1997). Table 6.3 summarises the materials, techniques and objectives that have been used for ditch/gully blocking, giving reference to case studies in Appendix 1 where applicable.

<table>
<thead>
<tr>
<th>Dam Type</th>
<th>Peat Type</th>
<th>Grip/Gully Measurements</th>
<th>Primary Function</th>
<th>Installation &amp; Maintenance Issues</th>
<th>Relevant study</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peat dams</td>
<td>Width: &lt;1m-&gt;3m, Depth: &lt;1m-&gt;1.5m</td>
<td>• Trap sediment and encourage revegetation&lt;br&gt;• Hold water and create small pools once established</td>
<td>• Should only be used on disturbed peat&lt;br&gt;• Requires nutrient poor, impermeable peat in plentiful supply&lt;br&gt;• Prone to scour on steep slopes</td>
<td>2,4,9,10</td>
<td></td>
</tr>
<tr>
<td>Plastic piling</td>
<td>Medium to deep peat</td>
<td>• Hold water&lt;br&gt;• Create large pools</td>
<td>• Ensure blocks driven into sides of gully – if side-cutting occurs it may no longer retain water and erosion may occur around the dam blocks&lt;br&gt;• Ensure dam is lower than surrounding veg height (to minimise visual impact)&lt;br&gt;• Dams may split and no longer retain water</td>
<td>2,4,5</td>
<td></td>
</tr>
<tr>
<td>Wood</td>
<td>Medium to deep peat, mineral soil</td>
<td>• Trap sediment and encourage revegetation&lt;br&gt;• Hold water and create small, shallow to large, deep pools once established</td>
<td>• Under and side-cutting of grips may occur on mineral soil and cause a sediment loss and may no longer retain water</td>
<td>2,4,5</td>
<td></td>
</tr>
<tr>
<td>Stone</td>
<td>Very shallow peat, mineral soils</td>
<td>Any – but dependent on size of stone</td>
<td>• Trap sediment and encourage revegetation</td>
<td>• Prone to side-cutting – water may wash around sides and increase erosion of gully sides and reduce sediment accumulation&lt;br&gt;• High maintenance/repair</td>
<td>1,4</td>
</tr>
<tr>
<td>Heather bales</td>
<td>Any – but must be able to support stakes driven into bottom of channel</td>
<td>Any – but dependent on bale size</td>
<td>• Trap sediment and encourage revegetation&lt;br&gt;• Possible creation of small pools</td>
<td>• Ensure prevention of under &amp; side cutting&lt;br&gt;• Ensure material not a source of nutrients&lt;br&gt;• Bales need to extend to full width of grip/gully&lt;br&gt;• Can be washed away during storm events so no longer function as a dam for retaining water</td>
<td>1,4</td>
</tr>
<tr>
<td>Heather brash</td>
<td>Any – but must be able to support stakes driven into bottom of channel</td>
<td>Any</td>
<td>• Trap sediment and encourage revegetation&lt;br&gt;• Possible creation of small pools</td>
<td>• Ensure prevention of under &amp; side cutting&lt;br&gt;• Ensure material not a source of nutrients&lt;br&gt;• Can be washed away during storm events so no longer function as a dam for retaining water</td>
<td>1,4</td>
</tr>
<tr>
<td>Rush bales</td>
<td>Any – but must be able to support stakes driven into bottom of channel</td>
<td>Any</td>
<td>• Trap sediment and encourage revegetation&lt;br&gt;• Possible creation of small pools</td>
<td>• Ensure prevention of under &amp; side cutting&lt;br&gt;• Ensure material not a source of nutrients&lt;br&gt;• Bales need to extend to full width of grip/gully&lt;br&gt;• Can be washed away during storm events so no longer function as a dam for retaining water</td>
<td>1,4</td>
</tr>
</tbody>
</table>
Irrespective of the material selected, Brooks and Stoneman (1997) state that the dam spacing and positioning need to be planned correctly to optimise their potential to raise water levels and retain water evenly over the length of the drain. Figure 6.2 shows the principles of ditch blocking to mitigate the effects of drainage.

**Figure 6.2: Recommended Dam spacing Along a Ditch (adapted from Evans *et al* 2005)**

The most cost-effective and one of the most successful methods of ditch blocking on blanket bogs is the use of peat itself, whereby material is scooped out from ground adjacent to the ditch and immediately upslope of the proposed dam, and then firmly packed into the ditch itself (Egglesmann 1988, Brooks and Stoneman 1997, Backshall *et al* 2001). Typically, this has been done with a leveller or a front end loader on large-scale restoration projects, particularly post-harvested mined peatlands. Examples can be found in North America, where the surface topography and soil structure is already structurally altered (Quinty and Rochefort 2003). Those ditches not filled up to the peat surface or not compacted then create shallow, more humid depressions suitable for peat bog species. Table 6.3 notes some of the problems associated with this technique. The use of peat dams is only recommended on altered (i.e. no longer considered pristine) peatlands due to the large degree of disturbance. Quinty and Rochefort (2003) also recommend that the peat should not be allowed to dry (and so become hydrophobic). Use of wet peat should minimise leakage and breakage of the blockage.

The use of peat and peat plugs is considered unsuitable for ditch blocking on steep slopes as the water flowing in the ditch can scour around and undermine the compacted peat (Brooks and Stoneman 1997, Quinty and Rochefort 2003). Other techniques for refilling the drains through a strategy of small ditch blockages have therefore been developed. These include the use of heather bales, heather brash or *Juncus* (rush) bales which allow water to flow through at a slow velocity (trickle dams) and so allow sediment to accumulate. Erosion is minimised by the slow accumulation of sediment which is strained through the heather bales and allows a slow release of water (Holden *et al* 2004). This is considered particularly useful for the blockage of large grips (or gullies) where the impoundment of water may create instability and an increase risk of bog bursts (Tallis 2001). The *Calluna* also provides a seedbank for revegetation and a source of nutrients whilst avoiding scouring erosion around the dams. Box 1 gives a specific example of the restoration project
at Halton Lea Fell within the Geltsdale and Glendue Fells SSSI managed by English Nature and funded as part of their *Nature for People* Project. There heather bales and peat have been used to block the drains.

**Box 1 – Geltsdale and Glendue Fells Restoration Project (see also Case Study 1, Appendix 1)**

**Aim:**
To restore blanket bog by grip blocking and to minimise “death trap” pools for livestock and wildlife. To manage upland heath and blanket bog for hen harrier, black grouse, skylark and reed bunting.

**Methodology:**

i) Blanket bog restoration through drain (grip) blocking using peat dams heather bales and plastic dams along entire length of grip;
ii) Reduction in grazing pressures (reduction of sheep numbers);
iii) Reduction in cutting and burning of heather;
iv) Introduction of cattle

Peat dams and heather bales taken from adjacent land have been used to trial a series of techniques for grip blocking on steep slopes located on deep blanket peat within the Geltsdale and Glendue Fells SSSI, Cumbria. Peat dams were used to restrict the flow of water, supplemented with heather bales to fill the ditches and further protect the dams from erosion by physical weathering and desiccation.

**Fig 6.3: Ditch blocking with heather bales**
©English Nature

**Monitoring and Results**

Monitoring of the grips was carried out by the University of Leeds (Dr Joe Holden) between 2002 and 2004 to determine whether the grip blocking has altered the flow regime and restored hydrological function to the site (Holden 2005d).

Data indicate the grip blocking has lead to some recovery of the peat by reducing the overall discharge of the grip (reduced discharge for year 2 compared to year 1 despite there being similar precipitation totals for both winters (Holden 2005d)).

Low flows were maintained during summer 2 (but no data for summer 1). However, high flows were maintained along the monitored grip during the winter indicating that it remains an important conduit for water. The blocked grip should result in the return of a fully functioning hydrological system with overland and sub-surface flow regimes reinstalled once the peat has re-saturated.

Data from four boreholes indicated some evidence of hydrological recovery as a result of grip blocking, illustrated by a generally higher water table, but more importantly by changes in the amount of fluctuation and a tendency for the water table not to penetrate into deeper layers of peat soil.

Further monitoring was recommended to test the magnitude of change and determine whether the recovery is ongoing and the system has stabilised following the blocking.

Project Manager: Mr Simon Stainer [simon.stainer@natural-england.org.uk](mailto:simon.stainer@natural-england.org.uk)
On other sites techniques have been trialled using hard materials such as wood, stone and plastic piling. The methods and maintenance issues are again summarised in table 6.3. Many of these techniques have been used in the blocking of gullies on deep peat (normally wider and deeper than man-made grips) and they have been tested extensively by the National Trust (Trotter et al 2005). Each technique has its own advantages and disadvantages (case studies of projects in appendix I). Box 2 gives details of the Exmoor Mire Restoration Project where a combination of wooden dams, *Molinia* bales and peat are to be used to block ditches.

<table>
<thead>
<tr>
<th>Box 2 – Exmoor Mire Restoration Project</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Aim:</strong></td>
</tr>
<tr>
<td>To restore the natural hydrological state of the mires where ditches have been dug and so recreate a stable high water table required for the growth of bog plants and the active accumulation of peat.</td>
</tr>
<tr>
<td><strong>Methodology</strong></td>
</tr>
<tr>
<td>• <strong>Creation of wooden dams along the lengths of ditches.</strong> Structural barriers to hold back the infill materials used, trapping solids and preventing them from washing downstream. Wooden dams to be built from plank sections (specifications available from project manage).</td>
</tr>
<tr>
<td>• <strong>Grips upstream of the dams filled with bund of peat.</strong> Peat taken from adjacent moorland to help retain water in ditch.</td>
</tr>
<tr>
<td>• <strong>Grips filled with <em>Molinia</em> and other moorland vegetation</strong> (collected from adjacent moorland) to act as ditch packing, retain moisture and trap sediment. Provide substrate for revegetation of mire plants.</td>
</tr>
<tr>
<td>• Back filling ditches between dams with material originally excavated from the ditch (lying adjacent to ditches). These banks have become vegetated by mire species or acid grassland and will help to consolidate material in the ditch and help natural recolonisation of indigenous species. Ditches to be filled back up to the level of the surrounding land to reduce erosion on peaty ditch edges and reinstate hydrological function by allowing water to flow overland and not channelled into ditches.</td>
</tr>
<tr>
<td><strong>Specifications</strong></td>
</tr>
<tr>
<td>It is expected that three sites will be restored (Broadmead, Roostitchen and Squallacombe)</td>
</tr>
<tr>
<td><strong>Broadmead</strong></td>
</tr>
<tr>
<td>12 wooden dam blocks</td>
</tr>
<tr>
<td>180m of spoil and bale fill</td>
</tr>
<tr>
<td>600 bales</td>
</tr>
<tr>
<td><strong>Roostitchen</strong></td>
</tr>
<tr>
<td>60 dams</td>
</tr>
<tr>
<td>360m of rubble fill</td>
</tr>
<tr>
<td>405m of bale fill</td>
</tr>
<tr>
<td>259 posts</td>
</tr>
<tr>
<td>2700 bales</td>
</tr>
<tr>
<td><strong>Squallacombe</strong></td>
</tr>
<tr>
<td>44 dams</td>
</tr>
<tr>
<td>120 peat bunds</td>
</tr>
<tr>
<td>850m spoil and bale fill</td>
</tr>
<tr>
<td>3400 bales</td>
</tr>
<tr>
<td>It is expected that the works will take 6 months to complete, commencing in December 2006.</td>
</tr>
<tr>
<td>Project Officer: David Smith email: <a href="mailto:dmsmith@exmoor-nationalpark.gov.uk">dmsmith@exmoor-nationalpark.gov.uk</a></td>
</tr>
</tbody>
</table>
Metal sheet dams made from double-sided plastic-coated corrugated steel were first used for blocking ditches in the 1980s, but this blockage material has now generally been superseded by pre-formed recycled plastic piling. The plastic dams have several advantages over stone, wooden or metal dams in that the material is light (transportation is easier), is durable (life-cycle ~ 150 years), and is easy to work with (making construction much faster) (Brooks and Stoneman 1997). However, this method is only suitable where the peat is deep enough to drive the piling into the gully sides and bottom of the channel, and care is needed to ensure the plastic dams are sited correctly into the gully sides and at the correct height to trap water (Trotter et al 2005). A low point in the middle of each dam allows water to overflow the middle of the dam and prevent side cutting (see figure 6.4). In addition, the plastic piling can be constructed in a box or deep V configuration to reduce leakage and allow a greater volume of water to be impounded (Brooks and Stoneman 1997). Figure 6.5 shows an example of a box configuration construction and Box 3 gives details of the Whitendale Trial. This forms part of the SCaMP Project managed by United Utilities and provides an example of the use of plastic piling and heather bales to block ditches.

The National Trust has provided some initial information on a number of techniques used for grip/gully blocking (Trotter et al 2005). Also, Armstrong et al (2005) (currently in press as Worrall, Armstrong and Holden 2007) reported that there was no significant difference between peat turves, plastic piling and heather bales used for blocking grips at Whitendale (see Box 3). Peat turves were therefore recommended as a more economical alternative. The focus of much grant funding to date appears to be on the capital costs of restoration with little consideration being given to monitoring of these schemes both before and after the damming-up of ditches. Without such scientific assessments it is difficult to evaluate the success or to determine the effects of such management.

Figure 6.4: Plastic piling dam with lower section in centre of dam (O’Brien 2005)

Figure 6.5: Plastic piling constructed with a Box configuration or deep V configuration (Grove 2005).
Box 3: Sustainable Catchment Management Programme (SCaMP)  
(see also Case Study 4, Appendix 1)

**Aim**

To develop an integrated approach to catchment management incorporating sustainable upland farming which delivers government targets for SSSIs, biodiversity plans for priority habitats and species, improved raw water quality.

To be achieved by entering into long term agreements between landowner (United Utilities) and tenant farmers to enable farming plans to be agreed to achieve aims of project.

**Methodology**

- Re-wet blanket bog through grip blocking using plastic piling, heather bales and peat turves
- Modified vegetation management – cutting/burning/cessation of burning
- Buffer strips around water courses
- Removal/reducing of livestock from restoration areas
- Long term farm plans under tenancy agreements

---

**Fig 6.6: Grip blocking with heather bales**  **Fig 6.7: Grip blocking with plastic piling**

**Monitoring and Results**

The Whitendale Project was funded by United Utilities to form a preliminary study of the effects of grip blocking before embarking on the large-scale SCaMP Project which will include areas of the Peak District, Goyt Valley, and Forest of Bowland. The monitoring and results were completed by the University of Durham (Dr Alona Armstrong and Dr Fred Worrall) and the University of Leeds (Dr Joe Holden) (Armstrong *et al* 2005) and include data from two MSc studies of the grip blocking (Keen 2005, Grove 2005).

The study commenced in February 2005 and was concluded in October 2005. It indicated that grip-blocking reduced runoff in the grip by up to 90% with an average effect of a 70% decrease in flow, and that water tables significantly increased during that period. However, the study also indicated that grip-blocking increased water colour concentration within the grip when compared with unblocked (control) grips and this was maintained throughout the study period. The runoff from the blocked grip was also higher in water colour and there was no significant benefit on the water colour of the blocked grips within the limited period of the study (Armstrong *et al* 2005, Worrall, Armstrong and Holden 2007).

There was also found to be no significant difference in results from the different techniques for drain blocking and it was recommended that the peat turves may provide a cheap, effective alternative to the costly and more labour intensive techniques of plastic piling and heather bales.

Project Manager: Martin McGrath  
email: martin.mcrath@uuplc.co.uk
There has been some recent work completed to improve the selection and prioritisation of understanding of the suitable locations for grips/gully blocking. In the past, \textit{ad hoc} and largely pragmatic methodologies have been used to prioritise sites suitable for blocking, but these have resulted in most drains within a site being blocked, including those that may be infilling naturally through a process of temporary surface stability that promotes revegetation and stabilisation of the grip/gully system (Warburton \textit{et al} 2004, Evans \textit{et al} 2005). Topographic attributes such as slope gradient and drainage area have been linked to the density of the drainage network of a catchment and therefore the probability of gully/grip channel development and these could be used to identify potential areas for blocking (Poesen \textit{et al} 2003, Evans \textit{et al} 2005, Holden 2006). Poesen \textit{et al} (2003) describes the threshold concept used to predict locations of gully heads whereby a given slope gradient ($S$) and a critical drainage areas ($A$) are necessary under a landscape with a given climate and land use, to produce sufficient runoff and initiate gully incision. As the slope steepens, this critical drainage area decreases and vice versa so that a lowering of the slope gradient with increased drainage area may cause a decrease in the transporting capacity and therefore a decrease in the gully channel depth (Poesen \textit{et al} 2003). Using these principles, it is possible to develop simple topographic models to predict which land drains are more important in reducing flooding and saturation downslope and so determine which land drains should be targeted for blocking (Evans \textit{et al} 2005, Lane \textit{et al} 2003). This supports the findings of Holden (unpublished data in Holden \textit{et al} 2006a) who found naturally infilling drains occurred on gentle slopes under $4^\circ$, whilst those over $4^\circ$ rarely infilled. Drains on slopes less than $2^\circ$ rarely eroded and erosion became more rapid on slopes above $4^\circ$. Simple topographic models (e.g. based on TOPMODEL) can be developed by mapping the drainage area and slope characteristics to enable individual land drains to be targeted for blocking (Evans \textit{et al} 2005, Lane \textit{et al} 2003, Haycock \textit{et al} 2004). The impacts of land use and climate change on grip/gully erosion also need to be considered and more research is required to identify the different spatial and temporal scales of erosion under a range of environmental conditions. Remote sensing techniques are being developed to support a range of upland management appraisals, particularly in relation to restoration of soils and associated hydrology (Haycock \textit{et al} 2004). These developments are discussed further in section 7.

\subsection*{6.3.1.2 Results of Grip Blocking}

Historically ditch blocking has taken place on peat (both raised and blanket bog) that has been severely degraded by peat harvesting and extraction, resulting in a change in soil structure, loss of hydrological function and change in vegetation. Although the effects of restoration through ditch blocking have been monitored at sites in North America, Northern Europe and the UK, the results may not be directly comparable or perhaps even relevant to the effects that may occur from ditch blocking on a degraded blanket bog. Conditions and therefore responses may vary greatly. Research on the different techniques of grip blocking in the UK has been limited due to a dearth of prioritisation of funding for monitoring by land managers and agencies and therefore a lack of science-based evidence exists. Despite this, a programme of restoration by grip (and gully) blocking seems to be going ahead unabated, reflecting perceived urgency of the situation as a result of the recognition of these sites as important stores of carbon, water and wildlife which need to be protected from further degradation. However, the lack of funding for sustained scientific monitoring means there are a number of unresolved issues regarding the short- and longer-term effects of such management practices. These research needs will be discussed further in section 7.

The rationale used for many ditch/gully blocking restoration projects is to “raise the water table level” (see case studies, Appendix I) in an attempt to increase the
wetness of the peat and so facilitate conditions for mire plant vegetation and the continued sequestration of carbon. Where monitoring has taken place, there is a general indication that water table recovery following ditch blocking is quite rapid (Grosvenier et al 1997, Price 1997, Veli-matti et al 1999, Holden 2005a). However, Wheeler (2002) considered that it was still unclear whether full hydrological and hydrochemical recovery is possible, together with the recovery of an accepted vegetation composition desired to enhance peatland biodiversity (Bragg and Tallis 2001).

Nevertheless, some recent research has indicated positive changes associated with ditch blocking. A limited amount of research has been completed as to the effectiveness of ditch blocking in terms of hydrology, sediment production, and carbon release (raw water colour and DOC) and this has largely been supported by water companies such as Yorkshire Water, United Utilities and Northumbrian Water who have a vested interest in the upland catchments which provide an important source of potable water. A study of the hydrologic status of an intact, drained and blocked area of the Geltdale and Glendue SSSI by Holden (2005d) found that there was evidence of hydrological recovery on the blocked site. There was less tendency for the water table to penetrate the deep peat (catotelm) and less fluctuation in response to climatic conditions. Overall discharge of the monitored grip showed a reduction in the discharge in year 2 compared with year 1 (under similar climatic conditions) and low flows were maintained in the blocked grip during the second summer (see Box 1).

The Whitendale Trial (Armstrong et al 2005, currently in press as Worrall, Armstrong and Holden 2007) showed that grip-blocking reduced runoff in the grip by up to 90% with an average effect of a 70% decrease in flow, and water tables increased significantly during that period. However, the study also indicated that grip-blocking increased water colour concentration within the grip when compared with unblocked (control) grips and this was maintained throughout the study period. The runoff from the blocked grip was higher in water colour and there was no significant benefit on the water colour of the blocked grips within the limited period of the study (Armstrong et al 2005) (see Box 3). Grove (2005) also studied the Whitendale site and observed that erosion occurred around the edge of some of the plastic piling blocks where the peat had been exposed at the surface, causing desiccation and shrinkage of the peat soil resulting in a crack being created between the pile and the peat. Such cracks are susceptible to further erosion, particularly by water (see section 5.3.4) and at such points the water may find a preferential path around the grip, scouring out the peat and so reducing the effectiveness of the grip block (Grove 2005). Figure 6.8 shows a crack formed at the grip blockage at the Whitendale site.

Figure 6.8: Soil Shrinkage by Grip Block (Plastic Piling) (Grove 2005)
Another concern for the hydrology of blanket bog is that there is a potential for drainage to cause major and irreversible damage to peat soils. Holden (2005a) suggested that many of the restoration programmes which place small dams into ditch (grip) networks in order to block them up and re-wet the peat soils should also consider the changes in peat structure and hydrological routing that may have taken place since the drains were installed. This rerouting of water through a dense network of soil pipes may need careful consideration when planning future restoration work in order for such projects to achieve their aims of re-wetting the blanket bog and reducing the volume of sediment and particulate carbon from the catchment via a dense pipe work mechanism.

Holden et al (2006b) found blocked ditches produced approximately the same sediment load as undrained peat and that partially blocked drains (for example, naturally infilled drains partially blocked by slumping peat) had a mean flow velocity of two orders of magnitude lower than that in clear drains and three orders of magnitude less sediment than clear drains.

Wallage et al (2006a, 2006b) examined the effect of drain blocking for reducing dissolved organic carbon (DOC) and water discoloration from Oughtershaw Beck, a headwater tributary of the River Wharfe, northern England. The ditches in this area were blocked using peat blocks in 1999 under the Upper Wharfedale Best Practice Project (see case study no.6). They found that the artificially drained areas of peat produced higher levels of water colour and DOC compared to intact areas of peat and the blocked drains produced lower rates of water colour and DOC (average 62% and 69%) when compared with the drained site. However, they also found that the colour and DOC were significantly lower at the blocked sites than on the intact peat, which suggests a store exhaustion process and alteration of hydrochemical processes. The Carbon:Colour ratio showed that for every carbon unit, the DOC at the blocked treatment contained significantly more colour than per unit of carbon at the intact or drained sites. This suggests that the DOC at the blocked site was obtained from a more humified source than at the intact site. This implies some form of disturbance to the DOC production and/or transportation process (drainage installation creating water table fluctuations and increased oxygenation and enhanced microbial activity). They concluded that most of the additional colour and DOC came from peat deeper than 0.1m, but shallower than 0.4m, with an almost 40% increase at 0.2m depth. They recommended ditch blocking as a suitable technique to ameliorate the enhanced water colour and DOC associated with peatland drainage.

Monitoring of ditch blockages on peatland catchments thus appears to indicate that there is a beneficial effect in terms of hydrological function by re-wetting the peatland and reducing the discharge from the catchments, and there is at least one study showing evidence of decreased water colour on blocked sites, but early indications show that the ditch drainage and subsequent blocking can cause an increase in the release of water colour and DOC. There is a need for further research and the collation of spatial and temporal data to determine if initial changes observed are a result of variability in catchment conditions or are a result of changes in land use and the re-blocking of grips. The research on effects of grip blocking has generally been completed within the last five years and there is a lack of long term data available to assess the impacts of ditch blocking on the soil processes, stability and vegetation which are likely to change over a period of time. It is recommended that baseline data of prevailing hydrological conditions such as water tables, stream flow, drain flow, overland and surface flow should be collected for as long as possible prior to the commencement of any restoration project. Without such data for a ‘control period’ it is difficult to provide the scientific evidence of the full effects of grip blocking. These issues will be discussed further in section 7.
6.3.2 “Natural” Gully blocking

The occurrence of dense networks of deep, wide gullies on blanket peat is thought to be a natural phenomenon which has been stated to have commenced around AD 1250 to 1450 (Tallis 1994, 1997), although estimates vary depending on location. The rate of gully network development on blanket peat in the last 150 years is, however, of concern, having been estimated at around 6mm.year⁻¹ (Tallis 1998). Labadz et al (1991) found evidence that much of a gully network in the Peak District would have eroded within 200 years at current rates, with sediment yield estimated at around 50 t.km⁻².year⁻¹. Evans et al (2006) compared a gully system in the north Pennines (Rough Sike) with one in the southern Pennines (Upper North Grain). They obtained organic sediment yields of only 31 t.km⁻².year⁻¹ in the former, where revegetation seems to be occurring naturally, but as much as 195 t.km⁻².year⁻¹ in the latter where active erosion represents a significant loss of particulate carbon. As was discussed in section 5.4.4, gully erosion and its contribution to peat desiccation and accelerated decomposition has also been associated with the release of carbon into water courses (POC, DIC, DOC and water discouloration), CO₂ into the atmosphere (Evans and Warburton 2001).

The main aims of gully blocking stated by Moors for the Future (Evans et al 2005) are to:
- Control further gully erosion
- Reduce sediment loss from peatlands
- Promote revegetation
- Reduce water discoloration in streams
- Raise local water table levels to saturate peat

The rationale for gully blocking on blanket bog is thus similar to that already discussed in section 6.3.1 on grip blocking. However, gully blocking in deep peat is still a very recent approach to moorland restoration and erosion control. It has been pioneered by the National Trust in a number of areas in the Peak District, and by Natural England (eg. Saddleworth Moor) (Trotter et al 2005). Although the National Trust has used gully blocking as a restoration technique since 1992, this has generally been on a small-scale where specific gullies have been targeted for blocking (e.g. Kinder Scout, Bleaklow, North Grain on the High Peak Estate, south Pennines). There is currently only one example of large-scale restoration using gully-blocking on a catchment-scale and this has been implemented by the High Peak Partnership Project on the Within Clough catchment, south Pennines. The project is a partnership between The National Trust, Natural England, Severn Trent Water and Nottingham Trent University. Natural England funded the National Trust to install the gully blocks and Severn Trent Water funded Nottingham Trent University to investigate the effect of gully blocking on water discoloration and associated hydrological processes (see Box 5 and case study no.5). This site was also used by the University of Manchester to determine the extent of revegetation of blocked gullies with those that had revegetated through natural blockage in the gully system.

The lack of experience of techniques and of empirical science-based evidence to support on-going gully blocking strategies resulted in the Moors for the Future (MFTF) commissioning of the Universities of Manchester and Leeds to identify strategic locations for gully blocking in deep peat and review methods and techniques for gully blocking (Evans et al 2005, Trotter et al 2005). The research objectives were to assess and predict the hydrological and geomorphological impacts of existing and planned blocks within the Dark Peak; to determine feasible locations for gully blocking in deep peat and to develop a decision making process for prioritising sites and materials that could lead to the successful revegetation and control of moorland erosion (Evans et al 2005). This resulted in the publication of a comprehensive
report: “Understanding Gully Blocking in Deep Peat” (Evans et al 2005), necessary due to the planned extensive and potentially costly use of gully blocking in the Bleaklow Restoration Project (see Box 5 and case study no.6).

Box 5: High Peak Estate Partnership Project

Aim:
To restore the water table and hydrological regime to that which resembles an active bog in order to ameliorate surface water quality and manage water colour through sustainable land management; reduce the loss of carbon by reducing discharge and minimising levels of erosion and sediment production, encourage indigenous blanket mire species and enhance biodiversity and conservation of the blanket bog habitat.

Methodology
- Preliminary field studies of peat depth, width and slope of gullies were conducted and remote sensed data (LiDAR and CAST-2) processed to produce a high-resolution terrain model (DTM) to assess the surface morphological features and prioritise appropriate gullies to block (Haycock et al 2004).
- Dams (820) constructed from plastic piling were installed in the headwaters of a deep peat catchment. They were installed at intervals of between 3-8m so that the top of the lower dam was level with the bottom of the upstream dam to allow for a continuous level water surface between the dams. (Water flowing over the top of the dam will then flow onto water held by the downstream dam rather than onto bare peat or mineral). This technique should minimise erosion (scouring of peat) and sediment loss.
- Gullies were installed using a ‘top to toe’ approach with the installation commencing at the head of the gully, dams installed down the entire length (see figure 6.6 and fig 6.7) to the main tributary into which it drains.

Monitoring and Results

Monitoring by Nottingham Trent University commenced in 2002 using a paired catchment approach to enable comparison of the treated (blocked) catchment with a control (unblocked) catchment. Baseline data were collected (water colour, discharge, water table, rainfall, vegetation) for a period of 12 months prior to the installation of blockages on the catchment in autumn/winter 2003/04 (O’Brien et al 2003, 2005). Post installation monitoring has continued to October 2006.

Results indicate that the water table rapidly rose following the installation of the blockages and water was maintained in the blocked gully throughout the monitoring period. Fluctuations in water table levels were reduced following installation and the water table increased and has remained at or near the surface during the winter period following autumn recharge.

Daily mean discharge from the blocked catchment has been reduced since the installation of the blockages indicating a less ‘flashy’ response to precipitation events and a more controlled flow regime with less frequent high discharge rates. Lower flows are also recorded over a longer period indicating the slow release of water and reduction in water table levels during drier periods as the top layer of the peat slowly becomes aerobic. Water colour levels have continued to rise since the installation of the gully blocks and are above the levels of water colour predicted if no blocking had taken place.

Vegetation Ellenberg indicator species (Hill et al 1999) indicate an increase in soil wetness conditions. Species such as Vaccinium oxyccocus and Rubus chamaemorus have increased since the installation of the blockages.

Project manager: Mr Mike Innerdale. email: michael.innerdale@nationaltrust.org.uk
See also Case Study 5, Appendix1
The University of Manchester surveyed a range of naturally revegetated gully sites within the Bleaklow/Kinderscout plateaux, south Pennines which represented the range of conditions under which natural revegetation might occur and which could therefore be considered as natural analogues of gully blocking and so assist in the identification of potentially successful locations for intervention (Evans et al 2005). The survey confirmed that natural revegetation was widespread with the pioneer species, *Eriophorum angustifolium* the first to colonise on areas of re-deposited peat surfaces (peat flats), behind natural gully blockages where mass failure had occurred and resulted in the collapse of gully banks, and bare peat (dominated by *Eriophorum vaginatum*) or mineral floored gullies with reduced stream power (dominated by drier species such *Vaccinium myrtillus, Empetrum nigrum* and *Deschampsia flexuosa*) (Evans et al 2005). This supported the earlier findings of Wishart and Warburton (2001) who found that large gullies naturally revegetated where stream flow decelerated, thereby reducing the erosion and scouring effects of water.

The characteristics of revegetated assemblages were positively correlated with the type and morphology of the gullies, particularly gully slope floor and gully width which is linked to the stability of peat on the gully floors, the accumulation of eroded peat upstream and the subsequent recolonisation and revegetation of eroding gullies. Evans et al (2005) therefore concluded that natural gully blocks provided important analogues for artificial blocking, particularly the relationship between blocking and successful revegetation of *E angustifolium*. The study was limited in its analysis of the effectiveness of gully blocking due to the short time that elapsed between the blocking and surveying (12-16 months), although natural revegetation of sites has been further confirmed by ongoing PhD studies at the University of Manchester (Crowle, unpublished) and Nottingham Trent University (O’Brien 2006). Additional results indicated that the artificial gully blocks were effective in accumulating sediment behind the blocks and this was considered a precursor to revegetation (as seen by the natural gully blocks). Figure 6.11 shows the recolonisation of *E angustifolium* in a previously bare peat gully at Within Clough.

**Figure 6.11: Recolonisation of *E angustifolium* at Within Clough Gully Blocked Site (Summer 2006) (O’Brien 2006)**

Wood and stone blocks were found to be the most efficient in trapping sediment, with plastic piling trapping approximately 50% less sediment, but retaining more water behind the dam (Evans et al 2005). Hessian sacks filled with sand were found to be the least effective with the lowest mean sediment accumulation. This may have been caused by inappropriate placing of the dams lower downstream making the blockage susceptible to higher flow velocities and increased erosion from water and subsequent scouring. Several have failed within the Within Clough catchment since their installation (O’Brien 2006). Table 6.4 summarises the feasible blocking sites on deep blanket peat.
Table 6.4: Recommended Gully Blocking Sites on Deep Peat (adapted from Evans et al 2005)

<table>
<thead>
<tr>
<th>Factor</th>
<th>Recommendation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Critical gully slope</td>
<td>&lt;6°</td>
</tr>
<tr>
<td>Block spacing</td>
<td>≤4m</td>
</tr>
<tr>
<td>Gully width</td>
<td>≤4m</td>
</tr>
<tr>
<td>Target gully block height</td>
<td>0.45m (min 0.25m)</td>
</tr>
<tr>
<td>Headwaters</td>
<td>&lt;130m from gully head</td>
</tr>
<tr>
<td>Bare peat areas</td>
<td>Greatest source of sediment supply</td>
</tr>
</tbody>
</table>

These recommendations are appropriate for blocking relatively minor gullies (max 4mx4m) in the headwaters of deep peat catchments. Given that some of the natural gullies have now eroded to over 20m width (see figure 6.1 and Evans et al 2005), new techniques may need to be developed for these larger and deeper gully systems, particularly when considering the impoundment of large volumes of water and sediment and the potential for mass failure.

In addition to the monitoring of gully blocking on sediment accumulation and revegetation, the University of Leeds assessed the peat hydrology of Bleaklow and Kinder Scout, south Pennines in order to develop a tool to predict the impacts of gully blocking, for example, detrimental effects such as the development of further gullies and/or underground soil pipes, and allow strategic planning for suitable gully blocking locations (Holden et al 2005e).

Work on the location of gully blocks has also been undertaken by Holden et al (2005e). High resolution topographic data (LiDAR) was coupled to a GIS hydrological modelling tool able to predict hillslope saturation (desaturated/dry peats are more susceptible to erosion, generate higher levels of water colour and DOC and release CO₂) and used to identify potential areas that could favour an increase in peat saturation on hill slopes and therefore identify sites suitable for gully blocking (Holden et al 2005e). The team produced flow accumulation maps of the High Peak Estate (133km²) to show the distribution of active and passive gullies (eroding and revegetating). Their aim was to simulate the complete or partial blocking of gullies and so provide information on which gullies should be targeted for restoration. Although developed for the High Peak Estate, it is stated that such a technique is transferable to other blanket bog catchments to identify suitable sites for gully blocking based on a scientific approach rather than the ad hoc or pragmatic approaches used in the past. However, it should be remembered that unlike grips, gully systems have developed naturally over many years resulting from the action of natural components of the environment and there may be some support for representative examples of the full range of erosion types to be conserved (Lindsay 1993, Tallis 1998, Holden et al 2004).
6.4 Re-vegetation of bare ground

Techniques to re-establish vegetation on bare blanket bog have been used in the UK since the early 1980s (Phillips et al. 1981, Tallis et al. 1983, Anderson et al. 1997, Stoneman and Brooks 1997). Contrasting techniques have been developed to restore the former bog vegetation on many historically cut-over European bogs, for example in the Netherlands, Germany and Finland (Schowenaars 1993, Ferland and Rochefort 1997, Gorham and Rochefort 2003). In these Northern European countries emphasis has been placed on water management and many land managers consider the most important factor in achieving a fully hydrologically functioning bog is to raise and control the water level. This is usually achieved by increasing the water level near to the peat surface and limiting water table fluctuations (Schowenaars 1993). By stabilising the water level, the bog vegetation is put under less stress and the chances of vegetation re-establishing are then greatly increased (Quinty and Rochefort 2003). Initial studies in northwest Germany advocated the refilling of open drains using strongly humified peat (Egglesmann 1998, Blankenburg and Kuntze 1987) and, despite criticisms of adopting such practices without a detailed survey of the ecological, pedological and hydrological characteristics of the site prior to ‘renaturation’, managers in the UK appear recently to have adopted a similar programme of restoration for re-wetting peatlands.

However, it is important to note that the early methodologies adopted in Europe and some areas of the UK were largely concerned with the restoration of raised bogs which differ greatly from blanket bog in their formation and hydrology. Many of the raised bogs have also been damaged by peat extraction and the removal of the top layer of peat (acrotelm) and part of the underlying soil (catotelm). Such extraction not only damages the soil structure, but also the basic hydrology of the site (see section 4) and priority has therefore been placed on hydrological restoration at these sites.

On most blanket bog sites in England the acrotelm and catotelm are still present, albeit in a degraded state. Many conservationists advocate that the first stages of peatland restoration of badly degraded sites such as the blanket bog found in the south Pennines, is the stabilisation of the peat surface to protect the soils (and land type) from further degradation, prior to any attempt at reinstatement of the water levels on a catchment (Buckler pers comm. 2006). The Peak District Moorland Restoration Project (Phillips et al. 1981, Tallis et al. 1983, Anderson et al. 1997) has provided much of the evidence and advice on the current revegetation strategies. These stem from evidence gathered from experimental plots set up and monitored during the 1980s and 1990s (Anderson et al. 1997). Similar work has been carried on in the North York Moors National Park to re-vegetate areas of heather moorland following the episodes of wildfire (Charles et al. 2001). The early trials focussed on two specific areas of re-vegetation:

- the re-vegetation of areas of deep peat on blanket bog
- the re-establishment of Calluna on Molinia-dominated moorland;

The Peak District Moorland Management ‘Restoring Moorland’ Phase III report (Anderson et al. 1997) described the techniques used at 12 specific monitoring sites in the south Pennines to reduce the area of bare peat and re-establish vegetation. Several other restoration publications provide additional advice on generic techniques to optimise vegetation cover (Tallis et al. 1983, Anderson et al. 1997, Stoneman and Brooks 1997, Backshall et al. (2001, Adamson and Gardner 2004, Schumann and Joosten 2006). All involve a sequence of treatments, the complexity of which depends on the site characteristics are summarised in table 6.5.
Table 6.5: Methodologies for Re-Vegetating Peat Surfaces

<table>
<thead>
<tr>
<th>Method</th>
<th>Rationale</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fencing</td>
<td>Exclusion of grazing animals may be necessary between 5 – 20 years, and permanently on some sites. Active shepherding to reduce overall stocking rate may also be considered (see section 6.5)</td>
<td>Backshall et al (2001)</td>
</tr>
<tr>
<td>Natural recolonisation</td>
<td>Possible if a viable seed bank is stored within the upper layers or peat or potential for windborne spores/seeds from adjacent refugia. Success will depend on hydrological and hydrochemical characteristics of peat.</td>
<td>Brooks &amp; Stoneman (1997)</td>
</tr>
<tr>
<td>Transplanting</td>
<td>If natural seed bank has been lost, additional supplementary seed sources of indigenous bog/moorland plants, whole plants, groups moved as turves, cut fragments e.g. <em>Sphagnum</em> may be planted onto the bare peat areas. Where the surface peat or soil layers have compacted and hardened from desiccation it may be necessary to rotovate the surface and break up the top layers of soil prior to transplanting species.</td>
<td>Brooks &amp; Stoneman (1997), Tallis (1998), Adamson &amp; Gardner (2004)</td>
</tr>
<tr>
<td>Nurse Crop</td>
<td>Where soil is more mobile, a nurse crop of fast-growing hardy species e.g. <em>Deschampsia flexuosa</em>, <em>Agrostis capillaries</em>, <em>Festuca ovina</em>, <em>Lolium perenne</em> may be used to stabilise the peat and provide a micro-climate for mire seedlings to grow. recommended sowing rate for these nurse crop species is 2gm²</td>
<td>Anderson et al (1997), Adamson &amp; Gardner (2004)</td>
</tr>
<tr>
<td>Geojute/other geotextiles</td>
<td>On severely degraded sites, treatments may need to be supplemented by a form of surface stabilisation such as a biodegradable Hessian jute-fibre netting with a high water absorption capacity (geojute) or coir mats. The netting can be laid out and pegged down to hold the peat in place and supplemented with a nurse crop (plants grow through mesh and help stabilise peat).</td>
<td>Anderson et al (1997), Adamson &amp; Gardner (2004)</td>
</tr>
<tr>
<td>Liming &amp; Fertiliser</td>
<td>On severely degraded sites where geotextiles and nurse crops are required, it may be necessary to add lime and NPK fertilizer for the initial growth of the nurse grasses to increase the pH and nutrient levels to encourage plant growth.</td>
<td>Anderson et al (1997), Mackay (1997)</td>
</tr>
<tr>
<td>Heather brash</td>
<td>Locally sourced heather brushings can be spread over the peat surface to stabilise soils, introduce additional seeds and spores, including <em>Calluna</em> and create a micro climate to encourage plant growth.</td>
<td>Anderson et al (1997), Mackay (1997)</td>
</tr>
<tr>
<td>Introduction of vascular plants</td>
<td>In addition to <em>Calluna</em> being introduced where appropriate on seed, litter or cut brash, additional dwarf shrub species may be introduced to enhance the biodiversity e.g. <em>Empetrum nigrum</em>, <em>Vaccinium myrtillus</em>, <em>Erica cinerea</em>, <em>Vaccinium vitis-idaea</em>. Studies have found which species successfully propagate from cuttings, seeds etc.</td>
<td>Adamson &amp; Gardner (2004), Brooks &amp; Stoneman (1997)</td>
</tr>
<tr>
<td>Introduction of <em>Sphagnum</em></td>
<td>Rates of colonisation are variable, but if conditions are amenable to <em>Sphagnum</em> growth, colonisation may be rapid. This may depend on the distance from refugia, nutrient status, fluctuating water tables. Changes in air pollution levels (e.g. reduction in sulphur deposition) may encourage <em>Sphagnum</em> recolonisation. Reintroduction through fragments and diaspores</td>
<td>Adamson &amp; Gardner (2004), Gorham &amp; Rochefort (2003)</td>
</tr>
<tr>
<td>Blocking of gullies/ditches</td>
<td>If the site is affected by drainage ditches or peat gullies, then a series of dams can be inserted along the channels at regular intervals (dependent on the slope) to impede water flow and reduce erosion and peat loss from the site. See section 6.3.1 and 6.3.2</td>
<td>Brooks &amp; Stoneman (1997).</td>
</tr>
</tbody>
</table>
The Peak District Moorland Management Project (Phillips et al 1981, Tallis et al 1983, Anderson et al 1997) has provided a long term study of several large and small scale projects within the Peak District National Park and so provided a sound database on which to formulate future restoration projects. Anderson et al (1997) again emphasised the need for site characteristics to be assessed and evaluated prior to the revegetation of peatlands. From the trials they concluded that areas of deep peat, particularly at high altitude (>550 m) on steeply sloping ground (soil covered hillsides or gully sides), and areas of extensive downwash of sediments and unstable peat soils, were particularly difficult to restore. Many of the trials met with limited success under these conditions. Nevertheless, Anderson et al (1997) identified severely overgrazed areas, extensive expanses of bare ground resulting from fire damage, and badly trampled stretches across deep peat, such as sections of the Pennine Way (see section 5.4.6) as prime targets for peatland restoration and so presented a challenge for future restoration projects in the south Pennines.

One such project is currently being managed by The Moors for the Future (MfTF) initiative, a partnership project set up in 2003 "to restore and conserve moorland sites most damaged by access, pollution and erosion". This is currently the largest upland conservation project in Britain. Box 6 describes the methodologies used in this large-scale restoration project, the mere logistics of which make this a formidable project to achieve success.

**Box 6: Moors For The Future – Bleaklow Restoration Project**

**Aim:**

The project aims to restore 3 km² of the worst degraded areas of the Dark Peak, south Pennines, Derbyshire which have been caused by accidental fire and which are now extensive areas of bare peat landscapes at risk of severe erosion.

**Problems:** Natural re-vegetation of the sites is prevented by the instability and mobility of peat which prevents the establishment of indigenous seedlings.

**Methodology:**

- Removal of livestock (sheep) from entire restoration area.
- Establish a nurse crop of grasses and heather seed (Agrostis, Festuca, Lolium, Deschampsia and Calluna species) to stabilise the peat over a 3-5 year period and support natural vegetation establishment.
- Nurse crop seed was prilled with a mix of clay and waste materials in increase the weight and so allow it to be spread more accurately by helicopter.
- Lime (300kg/ha) and NPK fertiliser (a water soluble phased released fertilizer at a rate of 5:26:13) applied to the site to raise the pH (soil recorded acidity levels of pH 2.7-3.4 prior to treatment – Matt Buckler pers comm. 2006) and supply nutrient for plant growth.
- Helicopter transported seed, lime and fertiliser and spread it evenly on the restoration plots.
- Heather brash applied to flat areas to protect soil and seed from physical erosion (wind and water erosion) and to act as a seed-source for Calluna and fungal spores required for Calluna to survive.
- Geojute textiles used on steeper slopes to keep peat held in position and minimize loss of peat soils through erosion and runoff. Geojute secured with pegs onto the mobile peat surface.
- Blocking of gullies on Bleaklow sites to raise water table levels, re-wet peatland and encourage bog species e.g. sphagnum on site.

**Logistics**

- 500 hectare site
- 1200 tonnes of lime and fertiliser applied
- 55 tonnes of grass seed
- 19 hectares of geojute
- 1000 tonnes of heather brash

**Project manager:** Mr Matt Buckler email: matt.buckler@peakdistrict.gov.uk

See also Case Study 6, Appendix 1
The restoration techniques have been monitored and, although no baseline data were available of conditions prior to the commencement of the project, initial findings have been supplied by the Moors for the Future (MfTF) partnership. Full details will be available in forthcoming report to be published by MfTF in 2007 (Buckler et al. 2007). Results of the revegetation post-restoration for the first three years (2003-2006) indicate that vegetation cover of nurse crop and other plant species is much higher at the treated sites (lime, fertiliser applied) and supports earlier findings of Anderson et al. (1997), Richards et al. (1995) Dorland et al (2004) (see figure 6.12). Figure 6.13 shows that the species used in the nurse crop had a variable rate of successful establishment. In the first three months, Lolium sp and Agrostis sp performed well, but Festuca sp did not establish itself fully until the second and third year, when it has continued to do well and dominate over the other species (Lolium disappeared in the second year and Agrostis declined sharply by the third year). Figure 6.14 shows the Bleaklow restoration sites treated with heather brash had a higher vegetation cover after the first three years and figure 6.15 also shows that those sites that were treated with geojute had a higher cover of vegetation after three years.

**Figure 6.12: Vegetation cover of Treated and Untreated Plots at Bleaklow Restoration Sites (Buckler et al. 2007)**

![Vegetation cover on sites restored on Bleaklow three years after restoration in 2003.](image)

**Figure 6.13: Nurse crop establishment on Sykes Moor – treatment 2004 (Buckler et al 2007)**

![Nurse crop establishment on Sykes Moor. Treated in 2004.](image)

103
Evans et al (2006) in their study of two contrasting gully systems noted that revegetation of gully floors is especially important for controlling sediment flux and thus for reducing losses of particulate carbon from the system. They noted the limited extent of empirical data on the use of the various restoration techniques and stated that optimum implementation will therefore rely on understanding the physical process dynamics relating revegetation and sediment flux. They therefore suggested that techniques such as gully blocking, followed by revegetation within the channel, may be a preferable restoration technique rather than attempting to revegetate all bare areas in gullied peatlands.

6.4.1 Lime and Fertiliser Applications

Air pollution and the \(\text{SO}_4\) and \(\text{NO}_3\) resulting from acid rain has the potential to increase plant growth rates, particularly where N is the limiting nutrient (Charman 2002). However, it is unclear by how much the natural acidity of ombrotrophic blanket bogs may have increased as a result of acid rain (Clymo 1984). This is despite it being identified as one of the main factors causing the degradation of blanket bogs in the south Pennines due to the proximity of the industrial cities of
Manchester and Sheffield (Phillips et al. 1981). The reduction of pH in peatland waters due to acid rain has been estimated at 0.7-0.8 pH units (Charman 2002) and acidity levels in peat soils have been recorded as low as pH 2.2 in the south Pennines (Anderson et al. 1997).

The liming of soils has been seen as necessary in order to raise such abnormally low pH levels to encourage nurse crop establishment (Gore and Godfrey 1981, Anderson et al. 1997, Tallis 1998). However, it is still unclear for how long the lime will remain in the soils and how the soil processes will be affected, such as the increase in microbial activity, oxidation of peat soils, and release of humic and fulvic acids which may cause pH levels to decrease (and so counteract the effects of liming) whilst increasing water colour and DOC (Bellemakers et al. 1995, Evans et al. 2001, Worrall et al. 2003). The introduction of a labile carbon source and the increase in the decomposition rate of organic matter, loss of carbon (as DOC, POC and DIC), reduction in carbon sequestration and the potential for areas of blanket bog to become carbon sources instead of carbon sinks may counteract the argument for use of lime as a restoration tool for this land type. In addition, it is unclear whether the liming and fertilising of a naturally acidic habitat will effect the re-establishment of bog species such as sphagnum in the long term. It is evident that the use of lime raises many questions and the need for further research. These issues will be discussed further in section 7.

In the light of these questions, MTF have commissioned Manchester Metropolitan University (Dr Simon Caporn) to investigate the effects of the application of lime and fertiliser on grass growth, soil pH and soil CO₂. The study is on-going and has been set up at Black Hill, south Pennines, Derbyshire (Caporn et al. 2006). The study site comprises 4 replicate blocks each containing 10 plots of size 3 x 3 m². Three levels of lime and three levels of fertiliser (zero, half and full) were applied giving 9 treatment combinations. The ‘full’ treatments are the standard rates of application i.e. Lime 1000 kg/ha and fertiliser 365 kg/ha. These all had nurse grass seed added. An extra plot had no seed and no treatments. Figure 6.16 shows the rate of grass growth and indicates both lime and fertiliser had significant interaction, reflecting the nil effect of fertiliser when lime was absent and the reverse when lime was applied (Caporn et al. 2006).

Figure 6.16: Grass Growth with the Application of Lime and Fertiliser at Black Hill, Derbyshire (Caporn et al. 2006)

The soil pH at Holme Moss was approximately 3.4 and increased to pH 4.3 on one of the lime treatments, but no significant statistical effect was recorded between the treatments to date (Caporn et al. 2006). Prior to the treatments, baseline assays
detected a small, significant plot effect of soil CO$_2$, reflecting natural variation across the site. Post-treatment, the soil CO$_2$ release rates stayed very low (except for October) and were not affected by treatment. In October the release rates were clearly higher than the other months, and there was a trend of a higher rate in the higher lime plots, but the statistical analysis revealed no significant differences (lime effect $P = 0.094$) (Caporn et al 2006). Figure 6.17 shows the soil respiration of CO$_2$ on the control and treated sites at Black Hill. Further assessments are to be made on the grass and lime/fertiliser treatments in December 2006.

Figure 6.17: Soil Respiration of Treated and Untreated at Holme Moss, October 2006 (Caporn et al 2006)

6.4.2 Sphagnum revegetation

*Sphagnum* species are recognised as being globally important owing to their peat-forming ability and may be considered as the most important peat-forming genus with more carbon stored in *Sphagnum* than any other plant genus (Clymo 1997). The species contributes to carbon fixation since their ground-cover in an active blanket bog may comprise 80-100% (Gunnarsson 2005) with an estimated cover of 1.5 Mkm$^2$ ground cover and carbon storage of 300 Gt dry mass or 150 Gt of carbon, assuming that 50% of the northern peatland areas are covered and built by *sphagnum* (Rydin and Jeglum 2006). The species are particularly useful in having adapted to acid, cool, water-logged and extremely nutrient-poor conditions that dominate active blanket bog habitats. Caporn et al (2005) worked at Holme Moss, south Pennines, and indicated that there has been a significant increase in *Sphagnum* on ombrotrophic moors and ‘natural’ colonisation is evident from the large bryophyte flora. Rydin and Jeglum (2006) detail the autecology of these species.

Much of the work on the re-establishment of *Sphagnum* and the restoration of peatlands has focussed on the severely degraded peat-harvested sites in northern Europe and North America (Rochefort 2000). In this instance, peatland restoration has been seen as re-establishing a plant cover dominated by *Sphagna* and other mosses, and reinstatement of the diplotelmic hydrological layers (acrotelm and catotelm) that characterise active peatlands (Rochefort 2000).

Despite the extensive study of the ecology of *Sphagnum*, there is still comparatively little knowledge of the life history strategies of *Sphagnum*, particularly concerning the dispersal and establishment potential of these species which is seen by many as being paramount to the success of peatland restoration in the context of creating an
‘active’ bog. Studies in North America have, however, resulted in a number of recommendations which can improve the establishment and coverage of Sphagnum mosses (eg. Campeau and Rochefort 1996, Rochefort 2000, Gorham and Rochefort 2003). These can be summarized as follows:

- **The restoration process must be preceded by an accurate spatial evaluation** of current hydrology, including a study of peat structure, hydraulic conductivity and vertical seepage (Gorham and Rochefort 2003).
- **The active introduction of moss diaspores** is essential as virtually no recolonisation of *Sphagnum* will occur on sites abandoned after industrial-scale peat extraction (although little is known about natural recolonisation on severely degraded blanket, resulting from, for example, controlled burning or overgrazing) (Rochefort 2000). Studies indicate colonisation by fragments of shredded *Sphagnum* on permanently wet bare peat or in strongly shaded depression have achieved a high level of success in re-establishing vegetation cover (eg. Rochefort 2000, Rydin and Jeglum 2006). These should be from local remnants or adjacent refugia.
- **The presence of a protected straw mulch** is recommended (1 500kg/ha) to stabilise the peat surface. Price (1997) found the straw mulch cover also increased surface soil moisture by 15%, decreased the amplitude of diurnal temperature changes, decreased evaporation of the underlying soil and hydraulic conductivity, increased relative humidity and sustained a water table close to the peat surface. There was a negligible effect on the leaching of nutrients from the straw mulch, and a reduction in light intensity from the mulch did not adversely affect *Sphagnum* regeneration.
- **Re-wetting a site by blocking ditches/gullies** is seen as essential action to optimise re-establishment of *Sphagnum* by increasing the humidity, raising the water table level and reducing fluctuations of water table level (Rochefort 2000, Wheeler and Shaw 1995, Wheeler 2001). The re-wetting should be to the point of water surplus and by creating a large water storage capacity at the peat surface (Heathwaite and Gottlich 1997, Grosvernier et al 1997).
- **Choice of Sphagnum species** is important as some species of *Sphagnum* have a greater ability to colonise bare surfaces than other species and how the species interact and compete may affect their ability to revegetate areas (Campeau and Rochefort 1996, Sundberg and Rydin 2002).
- **Quantity and size of diaspores introduced** will have a direct effect on the success of *Sphagnum* establishment. There is a positive linear relationship between spore introduction and cover of bare ground (Rochefort 2000). The large diaspores have an increased chance of survival and establishment. These can be collected from between 0.05-0.1 m depth of an active blanket bog and scattered over the restoration site (Ferland and Rochefort 1997) and spread at a ratio of between 1:50 and 1:100 on the surface of degraded sites.
- **Use of nurse plants** with the introduction of *Sphagnum* may assist in stabilising the peat surface and reduce effects of physical weathering e.g. frost heave and runoff (Ferland and Rochefort 1997)
- **Fertilisation** with phosphorus has been shown to have a positive effect on *Sphagnum* establishment (Ferland and Rochefort 1997), although studies have only been completed on cut-over harvested peatlands where the nutrient and acidity levels may differ from blanket bog.
- **The peat type and structure** may affect *Sphagnum* establishment. Poorly humified peats (von Post H1 and H2) are more favourable for *Sphagnum* regeneration – generally found in the upper layers of intact blanket bog in the acrotelm layer, although further research is required in this area (Rochefort 2000, Gorham and Rochefort 2003).
- **Annual climatic variation** (temperature, rainfall) will effect the growing season. Studies indicate that *Sphagnum* growth is maximised in the spring and autumn during wet, humid conditions (Rydin and Jeglum 2006), but little is known about the effects of climate change on *Sphagnum* establishment and colony stability.
On severely degraded bogs Buckland et al (2000) stated that it may be impossible to return a bog to its original state as the Sphagnum species that were predominant peat formers may be rare or disappeared from the site. In addition, the climatic conditions under which the bog originally developed will no longer prevail so that the species will react differently under the current climate. For example, in the Peak District, Moss (1913) listed 18 Sphagnum species present with only 2 rare, whilst Tallis (1964) recorded only five species of sphagnum with only S. recurvum occurring in large amounts. He found that the disappearance of the species was correlated with the appearance of soot deposits, a legacy of the industrial past.

6.5 Prescribed burning

The effects of prescribed burning and the current debate on burning on blanket bog have been discussed in section 5.4.1. Although many of the guides on blanket bog or upland management give advice on burning, such advice can be conflicting and confusing (see Table 5.2). It is therefore difficult to give definitive advice on whether to burn or not, as there are many factors which will affect the use of prescribed burning as a management tool on blanket bog (Adamson and Gardner 2004).

The revised Heather and Grassland Burning Regulations and Code, having been reviewed in 2005/06 (Defra 2005c), are likely to be published in 2007. Consideration was given to a number of issues during the consultation process which may have a bearing on the new regulations and burning practices to be adopted on blanket bog. Of the three options under consideration during the consultation process, those proposals for updating the Regulations and Code with direct relevance to blanket bog are in Option 2, as follows:

Heather and Grassland Burning Regulations and Code Option 2 (Defra 2005c)

Regulations:
- To include a requirement for approved burning plans (on SSSIs/other designated sites, with level of detail in plans appropriate to each) to be agreed with and approved by English Nature (and copied to the Fire Service)
- To include a requirement for burn managers to give the Fire Service notice of burning, referring to the plan and confirming the location and the extent of the burn,
- To prohibit burning on blanket bog and shallow soils
- Otherwise to be as they are currently framed.

The Code:
- To be restructured to address specific issues and measures in relation to burning for different habitats, regions and management purposes
- To be drafted in precise language, incorporating basic principles, but not too much detail (as it might otherwise be difficult to use)
- To include additional information in appendices/supplement (like the Muirburn Code in Scotland)
- To cover uplands and lowlands and give clear advice on best practice (e.g. where to burn and when; whether to burn, or not to burn; and how to burn)
- To include definitions of no-burn areas, such as “blanket bog”, “shallow soils”, “watercourse” and “maritime heath” etc
- To include advice on heather cutting
- To encourage the use of burning plans by burning operators on all sites, and to recommend that for plans relating to SSSIs and other designated sites, approval should be sought from English Nature
- To encourage burners to seek training and include advice on how to get it
- To encourage burners to cease burning earlier than legal burning dates if circumstances warrant it
• To encourage burners to search for certain species of early nesting birds and not to burn where they are discovered
• To encourage burners to inform Fire Brigade prior to burning

The consultation process included taking views from the general public, land managers, agents, academics, NGOs and government agencies, together with the recommendations made by the Science Panel (Glaves et al 2005). The intention was to provide a suite of measures, through the revised Heather and Grassland Burning Regulations and Code, which can address heather and burning practice. It is hoped that these will provide the best practice guidance for the management and restoration of blanket bog with regard to prescribed burning, and the issue will therefore not be reviewed further within this report.

6.6 Grazing

The general advice during the restoration of highly degraded peat soils is the immediate removal of livestock because of the severe erosion and degradation of peat soils likely to be caused by intensive grazing of domestic livestock (see section 5.4.3). Certainly, land managers advocate the exclusion of sheep in particular from revegetating sites where animals are likely to be attracted to vegetation treated with lime and fertiliser. Such applications give the vegetation a 'sweeter bite', make them more palatable and therefore more attractive to the livestock (Matt Buckler 2006 pers comm).

Sheep have generally been successfully excluded from degraded areas of moor by livestock fencing (post and wire) which can protect vulnerable areas susceptible to soil disruption e.g. sheep scars, peat hags and bare areas of peat on steep slopes from further erosion and allow seedlings to establish (Evans 2005). Such exclusion should protect damage to vegetation from being eaten whole, uprooted or trampled on (Tallis and Yalden 1983). Where peat has been exposed and is eroding, Adamson and Gardner (2004) suggest that sheep should be excluded from restoration sites for between two and twenty years, depending on the rate of seedling establishment.

Several studies have shown that vegetation does recover on blanket bog sites following a reduction in grazing. For example, Welch (1998) studied the impacts of winter, summer and year-round grazing on sites in the Ashop Valley, Derbyshire and found that stands of Vaccinium myrtillus and Calluna increased in height, Deschampsia flexuosa flowered freely, Empetrum nigrum increased and Nardus stricta was reduced.

Anderson and Radford (1994) studied the effectiveness of shepherding as a means of securing revegetation of eroding ground without the expense of fencing, or supplementary treatment with seed or fertilisers and found a significant increase in dwarf shrub cover with increases in Calluna, Vaccinium and Deschampsia flexuosa. They did however note that other plant species were slow to expand or colonise, particularly on steep slopes which was largely attributed to the instability of the substrate which could be readily dislodged by trampling and grazing (in addition to climatic conditions such as frost-heave and runoff). Anderson and Radford (1994) and Anderson et al (1997) reported that the colonisation of vegetation was slow, taking eight years for the average plant cover to increase from 49 to 92 %.

Evans (1977, 2005) completed a long-term study of Hey Clough, Derbyshire and examined the effects of reduced grazing on blanket peat. The study commenced in 1966 and noted that, following a reduction in sheep grazing pressure, recolonisation of bare soil began to occur on the lower slopes but not on the higher exposed slopes where deeper peat was present. Following a further reduction of grazing pressure in
the 1980s, many former eroding sheep scars recolonised slowly leaving several scars which stayed active by the remaining sheep. Evans (2005) noted that it took two decades for areas of bare soil to revegetate on the higher slopes and this did not occur until all the peat and underlying leached (Ea) soil horizon was totally stripped.

Rawes (1983) undertook a study of sheep exclusion and vegetation composition at Moor House NNR, north Pennines. He found that the botanical composition of blanket bog could be rapidly reversed following the exclusion of sheep. He found that Calluna, Narthecium ossifragum and Rubus chamaemorus responded quickly to a no-grazing regime, whilst Empetrum nigrum which is not normally grazed by sheep, also expanded due to the lack of trampling and creation of micro-habitats of taller and denser vegetation which offered shelter and protection. Rawes (1983) concluded that protecting an area from sheep grazing resulted in a change in the size, position and frequency of indigenous species rather than the invasion of new species. The cover of Sphagnum species such as Sphagnum capillifolium and S papillosum was also found to be closely related to the canopy development of Calluna and the change in soil moisture regime resulting from an increase in plant cover, growth and transpiration. However, Rawes (1983) also noted that areas of bare peat were slow to colonise despite the removal of sheep, and attributed this to the rapid runoff of surface water across the bare soils and the steepness of the narrow gullies and their inability to colonise vegetation due to the instability of the soil surface.

Grant et al (1985) examined bog flora species and their sensitivity to grazing management at the Hill Farming Research Organisation’s Lephinmore field station in the Cowal district of Argyll. They found that stocking rates of above one sheep.ha⁻¹ needed vigilance, as the tolerance level of blanket bog vegetation to grazing was particularly low. However, they concluded that floristically rich areas were better able to tolerate grazing and this may indicate that following the re-establishment of a floristically-rich sward, some areas of blanket bog may be able to tolerate higher stocking levels. **There is a need for long-term studies to assess the response of indigenous vegetation, particularly bog forming mosses, to grazing levels.**

The effects of herbivore grazing on vegetation is a highly complex process which is likely to be modified by site-based factors such as altitude, aspect and soil conditions (Hartley and Mitchell 2005) in addition to the type and age of the herbivore and the vegetation composition present. Hartley and Mitchell (2005) investigated the effects of grazing, the exclusion of grazing (fenced) and nutrient deposition on vegetation composition on two upland moors in the Grampian mountains in north-east Scotland (Glen Clunie and Glen Shee). They found that protection from grazing caused a rapid and dramatic increase in Calluna cover, whilst grazing, particularly when combined with nitrogen addition, caused a decline in Calluna. However, when grazing was totally excluded, nitrogen addition did not lead to a significant increase in Calluna, although ungrazed plots were found to have a greater cover of dwarf shrub species. They also found that bryophyte cover was generally higher on plots that had not been treated with additional nitrogen. Fencing increased the cover of grazing-intolerant, low nutrient demanding, competitive species and the additions of nitrogen and phosphorus caused a significant rise in the cover of ruderal species that required high fertility and could tolerate higher levels of grazing. They concluded that plant composition may be changed by the competitiveness and grazing tolerance of species.

A number of options to achieve sustainable grazing in the uplands are recommended in the Upland Management Handbook (Backshall et al 2001) in order to maintain or achieve favourable condition. These are summarised in Table 6.6
### Table 6.6: Grazing Recommendations for Blanket Bog in England

<table>
<thead>
<tr>
<th>Aim</th>
<th>Prescriptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maintain vegetation in favourable condition</td>
<td>Maintain current grazing practices provided the grazing regime has not recently been altered as this may take several years to manifest itself as the cause of degradation.</td>
</tr>
<tr>
<td></td>
<td><strong>Introduce or maintain shepherding</strong> to ensure the area is grazed evenly or in areas desired.</td>
</tr>
<tr>
<td></td>
<td><strong>Do not use supplementary feed</strong> on habitats of nature conservation importance</td>
</tr>
<tr>
<td>Bring vegetation into favourable condition</td>
<td>Off-winter livestock to reduce vegetation damage when most susceptible, particularly in spring and autumn and consider extending the period from Sept to May-June.</td>
</tr>
<tr>
<td></td>
<td><strong>Reduce stocking densities</strong> to maximum of 0.1 sheep/ha (0.015 LUs/ha) or 0.5 sheep/ha or 0.075 LUs/ha where recovery into favourable is required.</td>
</tr>
<tr>
<td>Bring severely degraded blanket bog into favourable condition</td>
<td>Remove grazing temporarily to enable areas of eroding peat to be stabilised and seedlings to become established.</td>
</tr>
<tr>
<td></td>
<td><strong>Consider large grazing exclosures</strong> to allow a return to a more natural state to increase habitat and species diversity.</td>
</tr>
<tr>
<td></td>
<td>Only return livestock to excluded areas when the vegetation has recovered and introduce a low-stocking regime as above when appropriate.</td>
</tr>
<tr>
<td></td>
<td><strong>Remove grazing permanently</strong> if appropriate to continue recovery and enhance biodiversity through creation of more diverse vegetation structure.</td>
</tr>
</tbody>
</table>

### 6.7 Mitigation of Forestry Practices and Restoration of Afforested Sites

Section 5.4.5 described the main effects of forestry operations and acknowledged that the soil disturbance accompanying forest ploughing, drainage, road work and harvesting operations can potentially cause large quantities of sediment to enter water courses and create an increase in turbidity and siltation. Detailed guidance on these aspects and other issues has been incorporated into ‘Forests and Water Guidelines’ (Forestry Commission 2003). The guide was first published in 1988 and is regularly updated for forestry managers and practitioners giving “best practice” techniques based on current research. Nisbet (2001) reviewed the role of forest management in controlling diffuse pollution in UK forestry and examined the guidelines and their level of achievement. He concluded that the guidelines effectively tackle the main water issues of concern in the UK and recognised the need for meticulous planning and supervision of all operations including the use of a wide range of pro-active measures to control diffuse pollution are necessary. Research has indicated that forest clearance could exacerbate erosion and sediment loss by potentially altering the deep, narrow grips into shallow, wide streams and so may trigger greater sedimentation loss and increase the risk of flooding downstream (Holden and Burt 2003a). Table 6.7 summarises principles that have been put forward by the Forestry Commission and several other review guides for the conservation and restoration of blanket bogs, to minimise the potential destructive operations of forestry on blanket bog (Forestry Commission 2003, Patterson and Anderson 2000, Anderson 2001, Backshall et al 2001 and Adamson and Gardner 2004).

- The FC, as a competent authority, under the Habitats and Species Directive and Birds Directive 1991 must pay particular attention to the implications of proposals for blanket bog and for designated species which use those sites.
- An Environmental Impact Assessment (EIA) may be required, subject to FC approval, on areas of blanket bog which exceed the normal open ground provision.
- The FC will agree a management plan for the bog restoration project setting out how, who and when it will be achieved. The FC will work with partner organisations to develop suitable management plans.
- On areas of deep peat (average depth 1m or more) which are judged to have a high probability of successful restoration to active blanket bog, the FC is likely to give felling approval without a replanting condition and may not pay grants for restocking through planting or natural regeneration.

Restoration Options
- Grant aided bog restoration options such as drain blocking or the removal or unwanted natural regeneration in areas forming open-ground of woodlands.
- Conservation of 10-20% open ground within the total area of woodland on peatland habitats.
- Restore areas of former bog habitats where possible within larger openings in extensive plantations.
- Create transition zones at planted forest edges adjacent to blanket bog. A buffer zone should be used to protect areas of active blanket bog over 1m deep from any peatland planting sites which are hydrologically linked to it. Generally, potential peat desiccation or nutrient enrichment effects should be minimised within the same hydrological unit as the proposed planting site. A minimum buffer distance of 100 m between the planting site and areas of bog is proposed as a standard, but may vary according to circumstances at individual sites.

The FC has embarked on several large-scale restoration projects throughout the UK to restore blanket bog in areas that have previously been subject to afforestation. Recent projects include restoration in Forest of Alyth Mires in Perthshire, Stell Knowe in Newcastlefen Forest in the Scottish Borders, the Border Mires in Northumberland’s Kielder Forest and a blanket bog in Clocaenog Forest, Conwy, Wales. The Border Mires project commenced in 1998 and has restored 240 hectares of bog, but is to expand the restoration programme to clear-fell areas following the allocation of £600 000 of Defra funding. Details of the project can be referred to in case study No. 2 in appendix I. The objectives of the Border Mires project include restoring the hydrological function of the deforested area by blocking the drains (using plastic piling and peat plugs) in order to raise the water table close to the surface and so enable it to support bog vegetation and encourage peat accumulation and carbon sequestration. It is suggested that the water table should lie within 0.1 m of the surface during winter to enable restoration as drier conditions would not favour restoration of a bog habitat, but there is little scientific based evidence to support this as the deforestation/restoration programme commenced in the 1990s and no long-term studies are available on the recovery of vegetation on previously forested sites. The only comparisons can be made with sites which have been actively drained and those that have not been disturbed. For example, Stewart and Lance (1991) compared water table depths at a range of distances from moor-drains with the depths of a similar undrained bog. They found that plant species dependent on high water table levels had a lower cover-abundance near to active drains, and species with a drier heathland affinity, had a higher cover. They also noted that the decline in cover of Sphagnum was highly localised and took nearly 20 years to reach.
statistical significance which could infer that the blocking of drains may increase the cover of species dependent on high water table levels and encourage the spread of *Sphagnum* provided it is already present or is re-introduced (see also Gorham and Rochefort 2003, Quinty and Rochefort 2003).

### 6.8 Recreation

Section 5.4.7 discussed the potential negative impacts associated with increased public access and recreation in the uplands and it is acknowledged that an increase both in the numbers of visitors and range of activities may potentially degrade blanket bog through the increase of footpath erosion, the incidence of wildfires and disturbance of sensitive habitats.

Areas particularly vulnerable to recreational impacts are areas of steep gradients, wet areas and areas of bare soil or sensitive vegetation such as *sphagnum* where excessive trampling can lead to a loss of vegetation, erosion and discernible scars (Backshall *et al* 2001).

The “Upland Management Handbook” (Backshall *et al* 2001) published by English Nature advocates several options to minimise or mitigate against the potential harming effects of public access and these are summarised in table 6.8.

**Table 6.8: Summary of Recreational Management (adapted from Backshall *et al* 2001)**

<table>
<thead>
<tr>
<th>Option</th>
<th>Rationale</th>
</tr>
</thead>
</table>
| Car Parking  | • Car parking is of primary consideration to many visitors and ease of access to a site is an influential factor. The size of the car park will therefore dictate the approximate number of visitors and potentially reduce visitor pressure.  
• ‘Lay-by’ parking may reduce visitor pressure, but may encourage ‘off-road’ parking and damage to the edges of sensitive soils and spread of erosion e.g. unauthorised turning circles.  
• The significance of the car park as an initial visitor access point may provide an opportunity for guidance of specific routes, education and raising awareness of sensitive habitats and associated species. |
| Zoning       | • The encouragement/discouragement of visitors to use certain areas of a site through well maintained public access routes and publication of leaflets to encourage visitors, or the deliberate non-improvement of paths and lack of publicity to sensitive areas where the public are not encouraged.  
• Access on a site can be restricted by the low maintenance of areas e.g. non-removal of scrub/bracken, leaving paths to deteriorate). |
| Interpretation| • Interpretive material at discrete sites or before a site visit may influence visitor movements and activities. The material should help direct people to particular areas, prevent or minimise access to sensitive areas, raise awareness of the sensitivity of the site, enhance enjoyment of the site.  
• Interpretive material may be in the form of information boards (showing a map and route of the site); leaflets (detailing general and specific information)  
• Codes of Conduct may be employed to raise awareness, responsibility and means of access management. They may be targeted at certain users or recreational activities.  
• Nature trails can be used to concentrate interest and direct visitor movement. |
| Footpaths    | • In upland areas the majority of visitors will follow recognisable routes e.g. a flagged area over wet peat and may encourage visitors not to stray onto more sensitive areas.  
• The purpose of footpaths in the upland should be to protect or re-colonise vegetation and not encourage more visitor access. Construction of footpaths over deep peat and water logged conditions is difficult and wherever possible new footpaths should not be constructed over peat. Floated aggregate paths, flagged paths and soil reorganisation paths may be constructed (see Backshall *et al* 2001 for details) |
| Prevent Erosion| • Pro-active measures to prevent/minimise erosion by reducing grazing pressure, restimg a route by temporarily changing the alignment, creating desire lines, re-seeding areas. |

Many of the restoration programmes appear to be currently aimed at restoring the hydrological function of a blanket bog and an extensive grip and gully-blocking programme is taking place across the UK. Those areas open to public access under the Countryside and Rights of Way Act (2000) may be particularly sensitive to trampling and limitations to public access or a raising of public awareness may be required to minimise the damaging effects of human trampling on such sites.
6.9 Agri-Environment Schemes and Policy

Only a brief outline is given here of the context for policies and agri-environment schemes within which blanket bog may be managed. Agricultural policy in England underwent radical changes recently, with the implementation of reforms of the Common Agricultural Policy (CAP) in 2005 and the adoption of Environmental Stewardship (ES), a new agri-environment scheme to replace the existing Environmentally Sensitive Area (ESA) and Countryside Stewardship Schemes (CSS) also in 2005. Although seen as partially responsible for the degradation of upland environments, including blanket bog (by offering financial support and encouragement of potentially damaging management such as moorland gripping, extensive controlled burning and high stocking densities) both CAP reform and the new Environmental Stewardship Scheme have been implemented to re-dress some of these problems and could be fundamental in restoring some areas of blanket bog.

CAP reforms introduced the Single Payment Scheme (SPS), which effectively decoupled the previous farm subsidy payments paid on commodity e.g. payments per headage livestock, and introduced payment by land area, irrespective of the land use. Applicants have to adhere to certain statutory environmental, public and animal health and welfare standards, plus a set of new standards for Good Agricultural and Environmental Conditions. These are designed to help protect soils, permanent pasture, habitat and upland features (including blanket bog). The SPS allows all agricultural land to be entered into the scheme regardless of its environmental value and a flat fee payment is given for income forgone provided that the management meets the requirements set under the Good Agricultural and Environmental Conditions, thereby rewarding environmentally friendly farming practices.

Although a reduction in livestock is likely to occur in the uplands as a result of SPS, this is not the main aim of the scheme’s implementation. Defra has, however, been encouraging a reduction in sheep numbers on blanket bog and moor for a number of years under schemes such as the ESA, Moorland Scheme and CSS (S Gardner 2006 pers comm). A reduction in sheep numbers is seen as a positive step towards restoration of blanket bog, by reducing the effects of intensive grazing on sensitive sites. However, there are significant concerns that SPS may also lead to a loss of cattle from the hills, and although unlikely to be used on wet, active blanket bog, the use of cattle on Molinia-dominated sites (often on degraded blanket bog) is seen as valuable in controlling rank grasses (English Nature, 2004).

The Environmental Stewardship Scheme is divided into two tiers, the Entry/Organic Level (ELS/OELS) and the Higher Level (HLS). It provides funding to farmers and other land managers in England who deliver effective environmental management on their land. The ES replaced the ESA and CS schemes and it is intended to build on the success of the previous schemes. The main aim of the scheme is to maintain environmental features that are in “good” condition or to restore or recreate them. The environmental objectives targeted are biodiversity, landscape, historic features, public access, resource protection, flood management and conservation of genetic resources.

The ELS of Environmental Stewardship is open to everyone, but entry to HLS is targeted and competitive, concentrating on the more complex types of management where land managers need advice and support. This is normally only suitable to land of significant environmental interest (although not necessarily designated), and would therefore include blanket bog. The scheme may be considered beneficial to blanket bog by supporting and funding practices such as grip blocking, livestock exclusion, and shepherding. In addition, the scheme provides a Farm Environmental Plan (FEP) detailing prescriptive conditions on appropriate land management tailored to the site to maintain or create land in “good” condition (Defra 2005b).
7 Qualitative Analysis and Evaluation of Interviews

7.1 Introduction

Requests for interview were made to 35 specialists in blanket bog management and restoration. In total 22 individuals agreed to be interviewed (listed in Table 2.2). In addition, a number of other experts were consulted and their comments have been integrated into the report (see acknowledgements). The organisations represented have been grouped into broad categories and Figure 7.1 illustrates the distribution of individuals these groups. The response to the interview request was considered to be good, with 63% of those approached agreeing to be interviewed. Of those who declined, most indicated that this was because of their work load, others because they no longer considered themselves to be specialists in blanket bog, and a small number (11%) made no response following several attempts at contact.

Figure 7.1: Distribution of Specialists

The interviews were conducted using a formal set of questions (see appendix II), but interviewees were encouraged to provide further information through additional questioning during interview to help clarify points raised. The interviews were used to evaluate the perceptions, opinions and priorities of individuals and organisations involved in the management, conservation and/or restoration of blanket bog.

Most specialists provided information freely during interviews (face-to-face or occasionally by telephone) and many sent further information by email/post. Where this was not possible, it was largely due to client confidentiality issues and this review can therefore provide only limited detail on some of these areas of work. Attempts have been made to fill such gaps by internet searches for other information sources and for grey literature.

The following sections give an overview of the issues discussed during the interviews. These focus upon blanket bog, its management and its restoration, with particular regard to the prioritisation of future research. The issues discussed were considered to be important to the interview respondents and include the definition of blanket bog; the perceived values and threats to blanket bog; agricultural policy and future research needs. Quotes have been used where appropriate to highlight the
concerns of individuals or to represent the general opinions of the respondents. The attribution of comments remains confidential in order to preserve the anonymity of individuals.

7.2 The Definition of Blanket Bog and its Condition

The specialists interviewed were asked for their opinion of what they considered to be the main features of blanket bog, in order to determine what was generally recognised as a blanket bog and whether these differed from “official” definitions such as described in the UK HAP. Further questions were asked to clarify the various categories of blanket bog such as “active”, “degraded” and “modified”.

Several participants proffered the UK HAP definition of blanket bog having in excess of 0.5m of peat, with the actual condition of the bog being considered irrelevant. Others were less exact and stated that blanket bog was generally recognised as being an area of “deep” peat, whilst some acknowledged that blanket bog could also include areas of peat that were less than 0.5 m deep, particularly when considering the stage of peat deposition and accumulation. For example, one respondent stated:

“I am not sure whether I would stick to the 50 – 60 cm depth ... I think you have to think well, when peat actually began to form, it has to start from somewhere, it starts from zero you know and it is still active bog in a way even if you just have 10cm of it, the potential is there for it to increase.”

All respondents recognised that blanket bog should ideally be wet or remain generally damp with a high water table for a major part of the year with drier conditions only occurring during two-thirds of the months during the summer. Most participants also associated blanket bog with a mixed assemblage of typical “bog” species associated with wet/damp conditions, such as bryophytes, with particular reference to sphagnum; cotton grasses, and dwarf shrub species, together with areas of open water and pools. However, several respondents acknowledged that sphagnum was not a necessity, for example:

“Well, a lot of people talk about having to have a sphagnum cover. I actually don’t agree with that. I think you can have active blanket bog which affects sphagnum so the habitat will be obviously one dominated by a very wet environment, typically dominated by grasses, mosses, but in many cases small shrub species as well.”

Most participants recognised the key features of a blanket bog they described potentially pertained to an “active” blanket bog, that is, actively sequestering and accumulating peat and likely to be intact and in good or favourable condition.

However, all respondents recognised that blanket bog was poorly defined and were frustrated at the lack of guidance and clear definition, particularly on areas of poor, degraded or modified blanket bog which had “dried out”, had a low water table and vegetation more representative of a dry heath with a predominance of dwarf shrub species. Some respondents stated that they would not recognise such a habitat as blanket bog irrespective of the peat depth and considered that such areas should be managed as a dry heath rather than “a blanket bog trying to achieve favourable status” if this was no longer considered feasible. One respondent stated:

“Blanket bog has a lot of variation and I think that is one of the problems. English Nature says that it is one habitat and defines blanket bog as having more than half a meter of peat and we try and go along with that because we have to use other peoples definitions to a certain extent, but that definition is a
bad definition because it does not allow for changes in topography and the fact that peat developed not now, but thousands of years ago under different climatic conditions. So you have got blanket bog in the Peak District which is actually heather dominated with some cotton grass, on peat which is much more than half a meter deep, on slopes, fairly well drained and we don’t know what our blanket bog should be like and whether we should still be managing it as such.”

In addition, several respondents stated that the definition of blanket bog and the categories of condition were also unclear and required clarification. For example one respondent summarised this point by saying,

“There is a problem with the definition of blanket bog and different definitions are used by different people for different reasons.”

For example, the existing agri-environmental schemes and Higher Level Stewardship Scheme use the UK BAP Priority Habitat as a framework for collecting information on habitats and attempting to report against the targets. This defines blanket bog by particular mire and bog pool communities, so excludes the severely modified bog types which are unlikely to have the same species assemblage as an active blanket bog and yet includes the definition of peat depth in excess of 0.5m which would include degraded blanket bog. Therefore the ecological use of these definitions may not be suitable for agri-environment scheme purposes.

It was generally considered that a consistent, national guideline to define blanket bog was required with the potential to tailor it to specific site conditions dependent on local variations of topography, climate and peat type. The definition was considered by some respondents to be of particular concern with regard to the practice of prescribed burning where the current Heather and Grassland Burning Regulations and Code prescribes not to burn on blanket bog, whilst consents are currently issued by Natural England which permit controlled burning on areas of degraded blanket bog under certain conditions.

Some respondents also considered there was a need for further clarification of the Condition Assessment and the factors determining the status of a SSSI unit into categories of "Favourable – Declining/Favourable – Recovering” etc. Some respondents again felt that local variations in location, climate and soil types should be accounted for, together with the anomalies of the Higher Level Stewardship prescription to restore to “good” condition, habitats that are considered to be in “poor” condition with fewer attributes and targets prescribed for individuals entering the agreement.

### 7.3 The Value of Blanket Bog

The persons interviewed were firstly asked what they (or their organisation) considered to be the values of blanket bog and secondly, what they considered other people, such as landowners, businesses and the general public saw as the value of blanket bog. The questions were asked in order to determine what the respondents perceived to be the main ecosystem services and values of blanket bog in society.

Many of the respondents (82% of respondents) recognised the value of blanket bog as being multi-fold with the primary value being its ability to store carbon and potentially sequester carbon and therefore act as a carbon sink. This was recognised as a value in terms of counter-acting the threat of climate change and global warming, and to assist in achieving international targets set by, for example, the Kyoto Protocol.
The secondary value recognised by many respondents was its intrinsic value in being an international priority habitat under the UK BAP with important designated site features; the rarity of such a land type being sufficient for it to be a national obligation to safeguard the habitat.

All respondents recognised the biodiversity value of blanket bog with particular regard to its conservation value and associated assemblage of species. Particular mention was made of rare upland wader birds such as the golden plover, curlew, snipe and dunlin associated with the habitat. Although *sphagnum* and other floristic assemblages were sometimes mentioned, together with insect and invertebrate assemblages, these were less frequently considered. It was felt by many of the respondents that the conservation/biodiversity value was appreciated by others, such as landowners, practitioners and the general public, in addition to the conservation organisations responsible for upland wildlife and habitat.

Some respondents recognised that others might regard blanket bog as being relatively unproductive, although the agricultural production value of blanket bog was considered as primary by some respondents, particularly in terms of cattle/sheep production from grazing on the blanket bog and the economic value of grouse shooting. However, it was recognised by the majority of respondents that this value was particularly in decline, exemplified by the reduction in livestock numbers, and that the grouse shooting could be considered of high or low value depending on the state of the grouse moor and numbers.

Forestry production, although recognised as an economic value by a few respondents, was largely seen as an industry in decline in upland areas, with relatively small areas of blanket bog in England still under conifer plantation.

Some participants recognised the value of blanket bog as an important water source and supply of potable water, with the potential to discharge high quality water and store it in the upland reservoirs. For example one respondent commented, using the south Pennines as an example:

"The monetary value of moorlands for water companies should be considered, as most of the water in the surrounding urban areas comes from the Peak District moorlands and water quality and water yield are very important."

"Wilderness" was a term used frequently by the respondents to describe their own and others perceived value of the landscape of blanket bog. Although recognised as being completely "man-made" and intensively managed, the respondents still considered blanket bog to be a relatively undisturbed and unique landscape which provided an element of escapism. Examples of comments made during the interviews are:

"I think in the past it has been regarded as a barren wasteland and now it has changed a lot – most people value this."

"There is a landscape value and a large number of our National Parks are or the majority of them are peat blanket bog type environment upland types, so there is a landscape and a tourism value."

"I think the vast majority of the general public would see the value of the moors as a landscape rather than being of significance for nature conservation or wildlife."
Recreation and amenity value were also mentioned by many respondents, largely for economic reasons and of importance for raising incomes of residents, particularly in less favoured or severely disadvantaged areas.

The cultural heritage, archaeological and palaeological importance of blanket bog was discussed by only a few respondents, who recognised the value of blanket bog as providing a function for environmental history and an archive of past anthropogenic use of this environment.

However, several respondents were quite sceptical of others’ perceived value of blanket bog:

"Amongst the public I think that if you compare it to some other environments: it is less visual on a grand scale. I don’t think the public value it anywhere near as much as they should. What do you do with bog? You can’t run across it, you don’t play football on it. I guess amongst land managers, be that regulatory land managers such as Natural England or land managers and land owners, they do value it and they understand its relative uniqueness and relative importance and economic value. I think beyond that it dies off rapidly in appreciation”.

7.4 Threats to Blanket Bog

The participants were asked what they considered to be the main threats to blanket bog in order to determine if the threats were long-term, external threats or short-term internal threats that could be ameliorated by, for example, changes in legislation, management, or the instigation of suitable restoration techniques.

Climate change was seen as the primary concern by 77% of the participants interviewed, with blanket bog being recognised as one of the most likely habitats to be first affected because of its reliance on high rainfall, maintained throughout the year, and on relatively low temperatures. The respondents were aware of the potential altitudinal shifts of habitat and species loss, particularly those considered already on the edge of their range, for example, in the south Pennines. Examples of the respondents’ comments are:

"I think the dominant one is the context of climate change. A peat bog is a phenomenon of a cold, wet climate. As we get into a warmer, drier one then the peat bog becomes naturally unsustainable. This is not a human pressure, but I think it is still the dominant context in which we are working.”

"Climate change is a threat, certainly to marginal blanket bogs which is obviously going to be spatially controlled and effect the more marginal bogs which are going to be eastern and southern, but it is important not only in terms of changes in precipitation totals and temperature increases, but seasonality increases too. You can see it by changes in frost frequency which is actually quite important for habitats, controlling things like the micro-organisms which live within the peat.”

Respondents were also concerned with the potential effect on carbon sequestration in future with the loss of peat formation, accumulation and important carbon sink storage, and with the forecast escalation of climate change and associated accelerated losses of CO₂ into the atmosphere from increased peat desiccation.

Linked to climate change was the increasing threat of wildfire (accidental or deliberate) which was considered by the majority of respondents to be a major
threat to blanket bog because of the severity of the burn and potential to cover and "destroy" vast areas of blanket bog. The high temperatures, deep burn and structural alteration of the top layers of peat soils, increased erosion and peat loss, and removal of vegetation, root stock and seed source were all considered highly detrimental to blanket bog. All of these could worsen with climate change and the predominance of dry conditions for longer periods. Several respondents commented on the effects:

"All peat damage that I have seen is essentially summer fire. The key to damaging the peat is to destroy the vegetation and its roots then you expose the peat, then you have got bare peat for centuries."

"Wildfires can leave an area exposed to environmental conditions for years and years and it can completely transform it if all the peat is burnt away."

"Wildfire is mostly hot fire that burns deep into the peat and takes off all the vegetation layer and so for long-term, it can limit any re-vegetation and therefore cause decomposition of the peat and erosion of particulate fluxes, particulate carbon as well as dissolved organic carbon in great quantities of up to several tens of centimetres a year in heavy storm events in some areas."

However, one respondent commented that,

"Wildfire is an issue, but it shouldn't be such a big issue as it is being made out to be. It is more of an issue for drier heath than blanket bog I think and certainly on very active blanket bog you are never going to get very woody, shrubby heather growth anyway that you would reach a stage where people would want to burn in the first place."

Poor land management in the form of over-grazing or over-burning (prescribed/controlled) was identified by all respondents as a cause of degradation and a threat to blanket bog. However, it was accepted by most respondents that the practices of both grazing and prescribed burning had changed over the last five years, largely as a result of changes in agri-environment payments, no longer providing a financial incentive to manage large stocks or frequently burn on moorland.

The combination of these types of management was seen by some respondents as a cause of continued blanket bog degradation, for example:

"I suppose it is the combination of burning and grazing isn't it? That the burning results in a shift in the vegetation type which perhaps makes it more palatable to grazing and so the Dartmoor bogs that are Molinia dominated or grassy are attracted to stock, particularly in late summer-autumn when stock congregate on areas that have been burnt."

"We don't really know historically which effect triggered what, so it is very difficult to pull them apart and say which one is the most important."

The threat of over-grazing on blanket bog was seen by many respondents as being no longer a serious threat in terms of livestock causing erosion and increasing areas of bare ground. One respondent commented:

"With cross-compliance it [grazing] should do no more damage so any blanket bog that is in poor condition as long as it doesn't get any worse, cross-compliance doesn't bite so to speak. For recovery and restoration, grazing levels need to be low on blanket bog."
However, several respondents acknowledged that previous stocking rates may have caused significant damage to blanket bog, and that such intensive management had left “scars” on the landscape with some areas particularly susceptible to erosion, for example:

“It is undoubtedly true that what could be called blanket bog has been heavily grazed particularly by sheep, but also by cattle as well ... there was 60% grazing pressure on Dartmoor by cattle in terms of livestock units and that included out-wintering cattle and feeding so that was quite damaging particularly to peat soils and potentially wet soils.”

"Although grazing numbers have been reduced, we are still suffering from the effects of that increased grazing from some time ago.”

However, several respondents were concerned with the lack of management and “re-wilding” of the landscape caused by low levels of management intervention. Some participants believed this could potentially increase the risk of wildfire by increasing the amount of biomass available and so potentially raise the heat intensity and prolong the burn. For example, several respondents considered that lack of grazing/burning could result in scrub or tree encroachment on blanket bog.

“Sheep are a management tool that you need to stop it [blanket bog] going back to scrub, otherwise you just have the whole hill covered in trees.”

However, it was also conceded that,

“If all the upland bogs now were active and lots of Sphagnum and very wet, then we wouldn’t need animals on them.”

One respondent referred to the spatial variation of the “digestibility of the moor” and its ability to provide sufficient food source for livestock and in so doing, determine the effective stocking rates across an area.

Prescribed/controlled burning was considered by 73% of the respondents to be a threat to blanket bog. Several respondents commented on the practice of prescribed burning used for the purposes of grouse management being based on anecdotal and previous practice rather than science-based evidence. The lack of science-based evidence was seen as problem in concluding whether the practice should be allowed to continue or be restricted in some way on blanket bog. For example:

“Mainly cool burns are done now and they are more sustainable in managing the moor, but there is a lack of science based evidence on the effects of managed burns and a disagreement between parties on whether it is beneficial or detrimental, for example, the loss of biodiversity and increase in monoculture, or the increase in water discolouration and carbon loss if done too close to the gully edges.”

“Certainly heather burning seems to have increased in the past 15 years and it is a problem. On a lot of moorlands that are burnt it is not active blanket bog anymore and if you don’t burn it I think there is a bigger risk of wildfire causing catastrophic damage than the rotational burning for grouse.”

“I am uncomfortable with routinely burning vegetation on a peat soil on the grounds that if you don’t, there might be a wildfire. You can be doing the same amount of damage, but over a much longer period and if you get a really bad wildfire it doesn’t matter if you have burnt it already as it will just jump straight
through it…More research is needed to provide information that burning is damaging to blanket bog and therefore in the meantime we should be trying to minimise the damage until we are in a position to know whether it is OK.”

Other respondents commented in favour of the continuance of burning as a management tool on blanket bog, for example:

“I don’t think there is any evidence that controlled burning damages blanket bog if it is done appropriately and properly done.”

“We must burn during the winter to create and secure a safety measure. We are going to have to burn more in the future than we have in the past, quite simply because with sheep being taken off the moor, the biomass of heather and grass is going to increase, particularly grass, and grass gets very dry so if there are fewer sheep there is going to have to be more burning.”

Historic artificial drainage (grips) and the intensity and scale on which the moorlands were drained was recognised as a cause of degradation by 68% of the respondents. The grips were considered potentially to encourage increased discharge from the blanket bog catchments, a lowering of the water table and increased aeration, and subsequent erosion of soils and peat loss.

“Clearly it [drainage] is an important factor and there is a lot of pressure to address it in terms of restoration sites, but gripping has been done on such a large scale that it is quite a difficult issue to tackle and potentially very expensive.”

Several respondents commented on the erosion of moorland grips since their initial installation, with the scouring out and undermining of peat being a particular problem when addressing restoration of blanket bog. However, there were several other respondents who considered the effectiveness of moorland grips to be quite poor, with many blocking up naturally. For example:

“A lot of drainage doesn’t seem to work … drainage on blanket bog is ineffective. So you think that if it is ineffective, what is the problem with it because it actually doesn’t work very well and most of the drains that have been put on the Dark Peak, most of the grips for instance, have actually blocked themselves. There are only a few areas that have systematic repeated drains and most of those haven’t worked…I don’t think they have contributed to blanket bog degradation.”

“Everyone is telling me that the effect on the water table of the grips is only a meter or two on either side, it does not affect the whole of the peat blanket unless they are close together, that they meet up and have a whole effect. Yes they will contribute to the drying of the peat altogether, so there is more water running off quicker, but the real danger is when the grips over-deepen through erosion so that draw-down effect is greater because it has gone deeper into the peat. So if you have a blanket bog with grips in it and the grips weren’t too close together then I can’t see that the grips are actually doing much damage to the blanket bog.”

Recreation and public access was viewed by several respondents as a potential threat to blanket bog, largely because of the increased risk of wildfire (accidental or deliberate) from increased visitor pressure, together with the localised effects of erosion of peat soils and vegetation from trampling and vehicles. It was acknowledged that the opening of the countryside through the Countryside and Rights of Way Act (2000) had not resulted in the public disturbing sensitive areas of
moorland, but it was felt that there was still a need for visitor management to encourage and direct visitors appropriately. For example, one respondent commented:

"People, they don’t realise that they are walking across blanket bog when they are doing it, but the recreation pressure is huge and we are spending significant money on trying to protect the peat from impact from humans, whether its walking, bikes, horse riders or whatever and that will never go away. It’s great that people are now enjoying it but it does cause concern on a fragile habitat."

Forestry practices and the afforestation of large areas of blanket bog were seen as an historic threat that was now in decline, particularly because of the change in land use policy by the Forestry Commission. However, some respondents thought the potential detrimental effects of deforestation of sensitive areas of bog and the replacement/expansion of deciduous woodland to be a source of continued degradation. For example:

"UK government policy is to increase UK woodland cover still and the uplands is still part of the area where people are wanting to plant. It is not just coniferous afforestation, people talk about deciduous afforestation as well. If you plant trees even in areas close to blanket bog, you are probably causing carbon to be released, so I do consider it to be an issue. I think in terms of restoration there is still not good quality research if you then deforest, restoring a bog back to its former use could be a problem."

Several respondents considered the change in agri-environment schemes and potential reduction in farm payments may potentially encourage farmers and associated land managers to sell-up and therefore reduce the number of people managing the moors, or to encourage investment in alternative sources of income and land use which may be detrimental to blanket bog, particularly on undesignated sites. It was also commented that the loss of local people could result in a decline in the knowledge base of moorland management which could be detrimental to blanket bog. One respondent commented:

"If you want the vegetation to be in good condition you need more man power. Manpower is just disappearing off the moors. Whatever anybody says about management, there will be nobody there to manage it."

Although, not within the remit of this report, 82% of respondents considered atmospheric deposition to be a long-term external threat to blanket bog and whilst it was acknowledged that sulphur deposition is in decline, the continued presence of nitrous oxides from atmospheric pollution was still considered to be a threat to blanket bog by some participants.

7.5 Influence over Threats to Blanket Bog

The participants were asked if they felt that they were in a position to influence any of the “threats” to blanket bog and, if so, how. This was in order to determine the range of approaches currently being undertaken to influence, prevent or minimise the perceived threats to blanket bog. The participants interviewed were either in management positions where a degree of authority and influence could be practised, in positions of authority with associated statutory powers, or in independent or semi-independent roles.
Many respondents considered that key to influencing the perceived threats to blanket bog was the development of agricultural policy and agri-environment schemes to encourage appropriate land management of blanket bog and instigate restoration where suitable. It was generally considered by most respondents that previous schemes had influenced the historic management of blanket bog by encouraging over-stocking and intensive grazing through headage payments, and moorland gripping and burning through Stewardship and ESA payments. However, it was also recognised that many of these historic threats could be discouraged and potentially reversed through changes in the agri-environment schemes and payments. The change from headage to cross-compliance payments was viewed as a major influence in the reduction of livestock on blanket bog. The payment under the Environmental Stewardship Scheme (Higher Level Scheme) for restoration schemes such as moorland re-wetting, seasonal livestock exclusion and shepherding was seen by the majority of respondents as the main mechanism for future sustainable management and support of suitable restoration programmes for blanket bog.

All the respondents stated that they worked in partnership with other organisations in influencing the management of blanket bog. Some participants sat on steering groups or committees of direct relevance to Upland Management and Policy e.g. the Burning Committee and the Upland CAP Steering Group. Others liaised at a more local level with land managers, NGOs, and land owners, being able to discuss local issues of land management and influence accordingly through direct management of the land, or to influence tenants or management of designated areas through management plans, environmentally sensitive farming agreements and issue of consents to burn or graze.

Many respondents participated in consultations such as the recent Heather and Grassland Burning Review by Defra and agreed that this was an appropriate process to encourage open debate and progress in management changes. For example, one respondent commented:

"Making sure that policies that are developed are based on what is actually happening from a practitioner point of view …. I think the review of the Burning Policy that Defra has just carried out was a great example of a really good piece of work – that it did ask the practitioners from a whole variety of different parts of the country how they were working and what the issues were for them and that has to be the way forward.”

Individuals involved in research generally felt that although their individual contribution to influencing the threats to blanket bog could be limited, their contribution and broadening of the knowledge base of blanket bog processes was useful in bringing certain issues to the fore that may not have previously been considered. Mention was made of carbon storage, water discoloration and sustainable catchment management. It was also recognised that there was a need to focus practices on objective science based evidence rather than short-term “anecdotal control policy with set agendas”.

Many participants considered that research institutions were adaptable and able to work with practitioners and they indicated research areas of particular interest to their organisations e.g. research into the relationship between land management and water discoloration/DOC, funded by several water companies whose catchments are located on blanket bog. Workshops organised by universities, projects such as Moors for the Future and other organisations were all considered useful means of bringing stakeholders together for discussion and implementation of decisions, instigation of appropriate research and raising awareness of key issues threatening blanket bog now and in the future.
7.6 The Restoration of Blanket Bog

The participants were asked to define what they considered to be "restoration" of blanket bog, the time scale by which this could be achieved and the scale at which it should be approached. Several concepts were identified as a result of this question, although the majority of respondents saw the restoration of blanket bog as meaning restoring to a fully-functioning blanket bog. Representative examples of responses include:

"[Restoration is the] creation of an active peat forming blanket bog; hydrologically functioning peat formations dominated by sphagnum and cotton grass."

"I think what we mean by restoration really is just thinking about getting the blanket bog back into some sort of state that is apparently more natural even though every blanket bog in England and Wales and in Scotland is kind of semi-natural anyway.... Really we are talking about trying to turn the peatland into a growing actively forming landscape so it is actively forming peat basically."

"To return all that was blanket bog to blanket bog. The complete restoration of what was there before – and restoration back to potentially how it was."

However, several respondents identified the restoration of blanket bog as being incremental and completed over a number of stages. For example, one respondent suggested that there could be several steps within a restoration programme. This required clear objectives and might include the promotion of re-vegetation through re-seeding, followed by the re-colonisation of native species and finally restoration towards an active blanket bog. For example:

"I think restoration is used in a fairly generic way to mean both the improvement in the condition of existing habitats, but also to restore severely degraded forms of the habitat which may no longer mean the habitat definition, initially back to the habitat and then back to good condition."

Other examples of short-term restoration were suggested such as grip-blocking, aimed at restoring hydrology and minimising damaging management practices before a fully-functioning blanket bog might be restored in the long-term. For example:

"Re-creation or restoration is where you intend to re-develop an intact natural system. Re-creation is to build a functioning ecosystem and if you are going to do that you should be looking at a full complement of species ... and a full complement of function, but the difficulty is of course, is "What is a blanket bog?" Is a blanket bog a super pristine site which has never been touched, of course it is, and that is your target. But you know, most blanket bogs in this country have suffered from damage so do you accept the status quo just now, is that the target you should be looking at?"

Other respondents used a pragmatic approach to define restoration, depending on the point at which the restoration was being commenced. For example a badly degraded site with extensive sheet erosion over deep peat, where the establishment of vegetation on the surface may be considered the first stage of restoration, may be compared to an intact bog in almost favourable condition where it might not be necessary to alter the physical structure, but "restore" through manipulation of land management practices, such as grazing, only. Respondents also supported a variety of restoration options, for example:
“[Restoration is] trying to restore the hydrological integrity so you want it to act as a single area of peat OR restoring the vegetation in order to not have bare peat without restoring the hydrology.”

All respondents conceded that the restoration of an active peat-forming blanket bog with a fully functioning hydrological system was likely to take a significant period of time to achieve (estimates ranged ~ 50-100 years). However, many respondents observed that some blanket bog sites were so badly degraded that it would not be feasible to restore the hydrological integrity and therefore a process of prioritisation of appropriate sites was necessary to maximise finance and resources most cost-effectively, ideally in partnership with organisations to utilise funding and co-operation.

Several respondents thought that the scale of restoration should firstly be considered at a national scale, through the UK HAP process, and then divided into Country-level with targets for England, Scotland and Wales. This could be (and indeed has been) divided into regional initiatives such as the Regional BAPs and Local BAPs to enable the maintenance of a strategic view whilst breaking down the national targets to an appropriate scale at a local level. Respondents also considered that there should be a national strategic long-term plan of blanket bog restoration to support continuity of policy and funding.

Other respondents were more specific, although opinions of the precise scale at which restoration should be conducted varied: from being site specific and the identification of bare sections of peat, or specific gully networks on hill slopes, to catchment and landscape scale restoration. For example:

“The restoration should be done on a catchment scale because of the carbon loss and hydrology. You have to consider it as a hydrological unit, although it may be possible to consider restoration at a small scale and trial it to test for specific responses because it will be easier to measure, but from a research issue we need larger scale - it is a landscape feature so lets restore on a landscape scale.”

“Restoration should be done on a large scale because of the different ownerships of land across the catchments, although there could be a problem in sourcing local heather etc at such a big scale.”

“I think that you can only think about doing anything practical on a fairly small scale of nothing greater than 20km^2….. For practicality you should be thinking at the hill slope scale where you are going to have a much greater chance of success because you are controlling the hydrology and that is the key to controlling restoration I think in these environments.”

“It all depends on what your end-point is. If your end-point is carbon storage then you restore the lot, if it is keep the water table high then if you are a water resource manager you don’t say “Ah, I prefer that side of the valley to that side of the valley….but I tend to think it is not as important as we would like to think….We can spend a lot of time second-guessing where we should focus as opposed to getting on and doing it.”

Several respondents also emphasised the importance of considering restoration in its spatial context and not merely deciding on scale alone. That is, the connectivity of the hydrological network of the whole catchment system needed to be considered when prioritising sites for restoration. For example, one respondent commented:
“There should be a combination of scales – site by site and also catchment depending on the location and connectivity with other catchment networks. You have to judge each one on its own merits.”

7.7 The Restoration of Hydrological Function and Appropriate Techniques

The restoration of hydrological function was seen by most respondents as “vital” or “very important” to successfully restore an active blanket bog. However, several respondents emphasised that hydrology was only one component of restoration and therefore should be considered with other end-points and should not be seen as “just blocking grips”. Although all the respondents did consider grip or gully blocking as the major technique to be used for raising and maintaining water levels, they also recognised that this should be used in conjunction with changes in land management practices, such as a reduction in stocking densities or removal of sheep from restoration sites, or a change in the burning regimes and that sites should be identified and targeted, for example:

“The total extent of degraded blanket bog in the English and Welsh uplands is enormous and particularly given that some of the solutions, even just grip blocking are going to be very expensive, I think a more targeted approach would be sensible and if that can be based on consideration of hydrology then that would be sensible as well.”

One respondent considered the condition of the blanket bog and the aims of the restoration were important factors in determining the methods of hydrological restoration. For example:

“I think that depends on how it has been degraded in the first place and how the hydrology has changed so perhaps no one uniform method is appropriate, it depends on the situation. A typical response has been to block all the grips in a particular area whereas actually I don’t think that is an effective way of restoring the hydrology. In fact it is quite a costly way of doing it. You can restore the hydrology back to that of a functioning blanket bog much more cost effectively by carefully choosing which grips can be blocked based on the location of those drains within the drainage network. So rather than blocking everything that is out there you can use the topography and the landscape – you can understand how water moves across the landscape and so understand which drains are going to hold water and it allows you to prioritise.”

Several participants were frustrated by the lack of scientific evidence, or the sometimes contradictory evidence, that was available on appropriate techniques to grip-block. Other respondents commented that the lack of science-based evidence was because many of the techniques being used were innovative and had not been previously tried. Many of the practitioners confirmed that new techniques or modifications of known techniques were being trialled on sites but had not yet been published. Other respondents commented that techniques were currently being monitored but due to the nature of the environment, only short-term responses, often affected by changes in the climate, were available and it was too soon to determine what the long-term effects of gully-grip blocking on blanket bog would be due to the recent commencement of some of the blocking projects.

In addition, several respondents commented upon the lack of clarity, recommendations and the feasibility of locations to grip block, although it was recognised that the criteria for blocking could differ between sites depending on the aims and objectives and site conditions. The selection of suitable site locations was
therefore acknowledged as being difficult to model due to the huge variation at both micro and macro topographic scales.

Several respondents commented on whether the restoration of hydrological function was appropriate at all blanket bog restoration sites, particularly those sites with extensive gully erosion which some considered to be a natural feature of the landscape. For example, respondents commented,

"There is only any point in trying to restore hydrological integrity if peat is going to grow because some of these gullies are so deep, you can’t block them right up to the top straight away, you have got to do it in stages."

"Bunding and damming ... is relatively straight forward where you have got simple things like drains through landscapes. Where you have got severe gully erosion however, that is a much more difficult thing to do and perhaps almost impossible on the severely degraded landscapes to restore and get the function of hydrology back again."

In recognising the different stages of restoring blanket bog, most respondents considered the necessity of re-seeding and re-vegetation of bare areas of peat on severely degraded sites, prior to attempts at restoring hydrological function. Most respondents accepted that encouragement of Sphagnum on sites may potentially assist in re-establishing hydrological function and the formation of an actively growing peat bog. Some respondents stated that they preferred the Sphagnum to be allowed to return naturally, although the majority of respondents accepted the use of a number of techniques to help re-establish it more quickly. These included maceration and hydro-seeding of Sphagnum, although several respondents commented that such re-introductions should be trialled and conducted as a controlled experiment to determine the most appropriate methods, means of disposal and amenable conditions. One respondent commented:

"We have damaged these ecosystems and it is up to us to put it right. Yes, it will come back in due course and if we can restore the water table depth, some of the peat depth and all the rest of it, it will undoubtedly come back, but Sphagnum does not grow very quickly at all and so it could be decades or longer before it comes back so if there is a way of translocating or transplanting or seeding or whatever, then I am all for that."

7.8 The Monitoring of Land Management and Restoration

All respondents were in agreement that monitoring was an important component in determining the effects and processes occurring on blanket bog which may result from changes in land management or restoration. The importance of having a good baseline of data prior to any changes in land management or restoration was considered paramount by several respondents in determining the effectiveness of changes. However, it was acknowledged that this rarely occurred, or was for an insufficient time period prior to the instigation of changes. Representative comments by respondents are:

"Monitoring has to be done for a long enough period before any restoration is commenced to understand the system and how successful management practices are. It should continue through the restoration period and for as long as possible afterwards because you don’t know the long-term response of peat bogs to restoration practice."
“There has been problems with monitoring in the past as the schemes have been ad hoc and therefore some monitoring has been purely observational, the sampling design framework has been very poor and there has been a lack of pre- restoration monitoring, often concentrating on only a few things like the water table and little else.”

Several respondents stated that the monitoring should be considered on a long-term basis and written into management restoration prescriptions where appropriate. For example, respondents commented,

“The problem is people thinking in short-term time spans of 3-5 years. We should be thinking of 50, 100 to 200 years.”

“All vegetation change is relatively slow in the uplands and time scales required to monitor the impacts of restoration management are quite long really to enable it to demonstrate it satisfactorily.”

“I think you need to have a careful monitoring design, but we recognise that monitoring can be very expensive so you can’t necessarily do it everywhere, but you do need to have some good case studies sites where you do the proper intensive well designed scientific monitoring to really establish how the system is behaving in response to that management activity and to understand all about the processes.”

Respondents stated that monitoring should be “fit for purpose” and there was a need for both plot scale and catchment scale monitoring to determine the effects of management or restoration on blanket bog. This should be supported by repetitive, replicate sampling.

Most respondents acknowledged that intensive scientific monitoring should be conducted on a professional basis by organisations such as the Environmental Change Network (ECN) which allowed for an unbiased approach and encouraged public access to data. It was generally thought that monitoring and research should not be conducted by academics alone, due to the commission of projects by organisations with set agendas. For example, one respondent commented,

“It is not a problem of funding projects for a sufficiently long time, but problems of having actual projects that demonstrate objectives. Some management decisions are fairly short-term and don’t have time to consider the evidence before they have to make the decisions.”

Some respondents did acknowledge that the monitoring of techniques was fairly haphazard and had either not occurred, or no standardised techniques had been agreed and that there was a need for a more professional approach to monitoring in the future. However, some respondents recognised the continued importance of less intensive monitoring by practitioners to collate long-term data sets and monitor changes over time.
7.9 Raising Awareness and Publicity

The majority of respondents felt that there were difficulties in finding information with regard to the impact of management practices and/or restoration techniques on blanket bog. They believed that this had resulted in a number of similar reviews commissioned privately to determine, for example, the most suitable techniques for grip blocking. The publication of commissioned reports was seen as particularly problematic in allowing access to and sharing of information. Respondents commented that such reports were often only available internally and as "grey" literature which "can be hard to find, and easy to miss if it has gone past its sell-by date."

Many respondents considered the formation of projects such as Moors for the Future to be extremely helpful in facilitating ideas and bringing people from a wide range of backgrounds together. Respondents commented that the format of regular conferences, workshops, website and accessible staff provided opportunities for networking and debate, to present a good overview of general upland concerns rather than merely concentrating on single issues. The sharing of information such as current restoration projects and the results of research into types of land management through the presentation of papers at conferences and publication of commissioned research reports was much valued by respondents, together with the general ethos of making all funded research work publicly available.

Respondents generally agreed that similar projects e.g. Peatscapes (north Pennines) and the International Centre for the Uplands (Cumbria) have similar objectives for sustainable land management in the uplands whilst also considering the social and economic consequences of change. They considered that such projects could be set up on a regional (e.g. National Park) basis, with the Moors for the Future model acting as a template for similar projects where appropriate. Most did not envisage that the projects should be expanded to a National Moorland Project because of the importance of maintaining local networks. However, many respondents did acknowledge the need for continuity of funding, with security and a long-term view rather than the short-term support given at the start of many such projects (typically an initial funding period of, say, three years only).

Respondents were aware that scientific reports by Natural England and Defra are available on their websites, detailing information on research commissioned. Some respondents considered that such documents could be made more user-friendly to different end-users such as practitioners and landowners. Academics still focused the publication of their research in peer-reviewed journals, although it was recognised by some that this could limit the accessibility of information to various audiences such as practitioners. However, several respondents considered that this was now being addressed with the organisation and attendance of local workshops and working groups with NGOs, organisations and stakeholder groups where information could be disseminated at meetings. The attendance at conferences and presentation and publication of conference proceedings were also recognised as additional means of conveying information of research recently conducted.

Some practitioners were reluctant to publish their findings and face criticism from other organisations and individuals. Others simply did not have the time within their work schedules to allocate to the writing of reports and publication of papers in peer-reviewed journals. Several respondents did acknowledge that other methods were becoming available to facilitate information sharing, such as the "Conservation Evidence" website where practitioners can raise awareness of current projects and practices being used for habitat creation and restoration (http://www.conservationevidence.com/).

7.10 Knowledge Gaps and Future Research Needs

As might be expected from the range of specialists interviewed and the complexities of the blanket bog environment, the areas perceived to require further research were wide-ranging. Respondents indicated needs both to increase knowledge and awareness and to promote “best practice”. Some of the research questions identified by specialists were quite generic, whilst others identified specific knowledge gaps and potential research. The research requirements identified by respondents have therefore been divided into a number of categories:

7.10.1 Future Research Needs: Generic Questions

- The long-term impact of climate change on blanket bog
- The long-term effects of land management on blanket bog
- The consequences and effectiveness of gully-blocking on blanket bog
- Techniques required to get blanket bog into favourable condition and processes involved in creating that environment

7.10.2 Future Research Needs: Review of Definitions

- A national standardised definition of blanket bog with appropriate indicators to be used in conjunction with favourable condition

7.10.3 Future Research Needs: Climate Change

- The interaction of climate change on visitors and wildfires
- The effects of climate change on carbon retention and accumulation
- The effects of climate change on soil respiration, water yield and water quality
- The study of climate change in upland areas to promote suitable models based on upland responses
- Changes in vegetation composition and abundance and appropriate techniques to control invasion on blanket bog e.g. of bracken, rushes
- The effects of climate change on the restoration techniques e.g. planting of sphagnum and its survival in a changing environment,
- The effects of climate change on the physiology and presence of dwarf-shrub species
- The interaction of climate change and land management e.g. on-going changes in active deposition, changes in soil and water properties
- Potential changes (natural and anthropogenic) that are likely to occur under climate change and the implications for the future

7.10.4 Future Research Needs: Atmospheric Deposition

- The effects of atmospheric deposition on water properties, water yield and water quality
- The effects of atmospheric deposition on carbon retention and sequestration
- The effects of atmospheric deposition on vegetation communities and their recovery
- The interaction and separation of atmospheric deposition from land management activities on water yield, water quality, carbon deposition and vegetation
7.10.5 Future Research Needs: Carbon Cycling

- Carbon cycling - rates of accumulation and loss of carbon from catchments, processes involved in the accumulation or release of carbon,
- Effects of land management (short and long-term) on carbon cycling
- Appropriate upland studies of carbon cycling - further studies and replications to determine carbon budgets to assist with modelling (currently mainly based on lowland sites/outside UK)

7.10.6 Future Research Needs: Hydrological Processes

- The interaction and main factors affecting hydrology, vegetation and water quality e.g. how is water colour generated, released and transported?
- The short and long-term impacts of restoration on peat hydrology
- The hydrological processes occurring on degraded and active blanket bog e.g. flow of water through macropores and through natural soil pipes in peat
- The hydrological processes occurring on degraded and active blanket bog e.g. overland flow and through flow and how this changes with depth through the main body of the peat
- The spatial differences in flow rates between intact, undisturbed and disturbed sites
- The differences in overland flow on hill slopes (i.e. bottom, middle or top of slope) and the interaction with management activities
- The interactions of hydrology and how it is linked to intact active peat, land management, vegetation and restoration techniques

7.10.7 Future Research Needs: Prescribed Burning

- Changes in land management and the effect on blanket bog processes e.g. current burning management on soil water and biodiversity (vegetation, invertebrates, insects etc)
- The interaction of prescribed burning and soil erosion – are cool burns removing vegetation and damaging blanket bog?
- The optimum burning frequency of controlled burns to minimise damage to water quality, to maximise or at least minimise damage to carbon sequestration, and to maintain plants at the right age and structure that will recover from burning quickly
- Detailed study of prescribed burning to include the time of year of burning, size of the burns, temporal and spatial changes of burning practices
- A study of the impacts of controlled burning and defining what is or is not acceptable
- Quantification of sediment loads etc that are discharged from upland areas with implications of “polluter pays” in terms of sediment or green tax associated with burning
- A review of suitable alternatives to prescribed burning and the publication of appropriate codes and guides e.g. “The Cutting Code”
- The effects of mowing/cutting heather compared to prescribed burning and the associated effects on peat soils and water hydrology
- Paucity of information on historic land management – studies required to determine if changes in management have occurred and the relationship with degraded blanket bog conditions
7.10.8 Future Research Needs: Grazing

- The effect of under-grazing on blanket bog, particularly with regard to changes in micro-climate and species composition

7.10.9 Future Research Needs: Recreation

- Techniques appropriate to manage and minimise the impacts of different recreational users

7.10.10 Future Research Needs: Deforestation

- The effects of deforestation and restoration of sites back to their former use – on soil and water properties, hydrological integrity, vegetation colonisation

7.10.11 Future Research Needs: Restoration

- Techniques appropriate to restore a ‘natural’ vegetation community e.g. the re-establishment of sphagnum and associated natural species
- A study of soil properties and sites to determine where sphagnum is likely to grow
- The effects of gully-blocking on soil respiration, water yield and water quality
- A long-term study of grip blocking to determine changes in water table levels and restoration of hydrological function
- Techniques and circumstances appropriate to achieve the objectives of blanket bog restoration
- Techniques appropriate to select priority areas for grip blocking
- The short and long-term effects of lime and fertiliser on soil and water properties, and carbon release
- The re-wetting policy and its potential to harm blanket bog by creating unstable structures, altering the hydrology, causing loss of soil structure and potential landslides
- Re-wet areas – are they sufficient to reduce the risk of wildfire and associated impacts

7.10.12 Future Research Needs: Review of Monitoring Techniques

- A review and standardisation of techniques used to monitor restoration work
- More large-scale controlled experiments to consider changes occurring at landscape scales
- Establishment of a “control” area where no management is practised to determine the effects of soil, water and vegetation processes on blanket bog and to assess the feasibility of a bog to restore naturally
- Long-term experiments to understand the impacts on blanket bog and the time-frames needed before blanket bog begins to recover and return to favourable condition
- A wide range of “case study” sites to monitor on a short and long-term basis, studying a wide range of variables
- Micro-scale research on small-scale variations of soil and water properties on blanket bog
7.10.13 Future Research Needs: Feasibility Studies

- Feasibility studies/modelling to determine the feasibility of restoring degraded or severely degraded blanket bog to favourable condition or active growth
- Cost effective modelling to determine if restoring water quality to a previous standard (e.g. 30 years ago) would be cost-effective to a water company in terms of costs of sustainable land management and treatment work costs
- Cost effective modelling to determine the benefits of increased carbon sequestration through restoration and the incentives associated with carbon taxes
8 Conclusions and Recommendations for Further Research

8.1 Introduction

This report has described the main factors influencing the management and restoration of blanket bog in England and this section will summarise the main threats to blanket bog and will make recommendations for appropriate field-based research to support sustainable upland management and restoration projects in the future.

8.2 Threats to Blanket bog

As a result of the review of the literature and specialist persons consulted, the principal threats to blanket bog and the sustainability of the water, soils and vegetation that make up these complex systems are considered to be as follows:

- Climate change is seen as being fundamental in influencing changes in blanket bog both now and in the future, and may have a significant affect on the restoration of hydrological function and re-vegetation of bog plant species associated with this habitat. An escalation in the erosion processes and degradation of blanket bog and its contribution to climate change (bogs changing from sinks to sources of carbon) is a well referenced theory, although there is some discrepancy in estimates of carbon loss from these organic peat soils. Many contributors to the project see climate change as an over-riding threat to the continued existence of blanket bog within the UK, and wish to prioritise further research that examines the actual processes occurring in organic soils which cause the release of dissolved, particulate and atmospheric carbon and methane. Land management and restoration practices may require consideration and revision to compensate for predicted changes in climate, in order to maintain carbon sequestration and minimise degradation or loss of the blanket bog habitat.

- Wildfire is also recognised by many contributors as a major threat to blanket bog. Many believe that incidences of wildfire are likely to increase with ‘abnormal’ seasonal fluctuations such as prolonged periods of warm, dry weather and low rainfall during the normally wet autumn/winter, when groundwater would normally recharge and water tables rise close to the bog surface. Research indicates that incidences of wildfire and recreation access are closely linked, and the consequences of such fires are severe due to the loss of vegetation and soils from large areas which are extremely slow to recover. Although there have been a reasonable number of projects at a range of scales, aimed at the re-vegetation of these bare areas (e.g. Moorland Erosion Study in the Peak District National Park in the 1990s and the current re-vegetation of Bleaklow by Moors for the Future), many contributors are concerned about the lack of baseline and on-going monitoring to study the effects of applying seed combinations, lime and fertiliser on the soils, water and vegetation.

- Past and present land management is seen as peripheral compared to the two main threats above. Afforestation of blanket bog has not been recognised as a serious threat in England and Wales and is likely to be even less so due to changes in tax incentives and changes in polices adopted by the Forestry Commission. There may be a continuing threat from the removal of conifer plantations and transplant of broad leaved species on degraded bog.

- Similarly, sheep grazing is no longer viewed by many as a threat to blanket bog, with livestock densities recently being reduced and headage payments no longer available. Research findings seem to support this although in some
areas there is still a legacy of erosion scars, created by sheep, which have failed to re-vegetation and continue to erode.

- Prescribed burning and whether to practice burning on a blanket bog appears to cause division of perception, opinion and research. Central to the argument seems to be the recognition of what is classified as an “active” bog (where it is generally agreed that controlled burning should not occur) compared to a “degraded” bog which, although classified as a bog under the definition of having >50 cm peat, may not be actively accumulating peat and may have the appearance of an upland heath. In these conditions, many land managers condoned the burning of blanket bog, in order to achieve their objectives of restoring heather to the uplands.

- Recreation is considered by many to be a threat to blanket bog only in selected, popular areas. Perhaps the south Pennine blanket bogs are under the greatest threat from people pressure, due to the large numbers of visitors this area attracts. There is an obvious link between visitor numbers and wildfire, but generally the threat from recreation is considered minor compared to the global threat from climate change and land management. The foreseen threats of open access from the CRoW Act (2000) have not materialised and many upland areas remain relatively undisturbed from recreational pursuits.

8.3 Further Work/Research Requirements

The following areas have been identified from the literature review and comments from contributors as requiring further information or clarification and are described below.

8.3.1 Definitions
- The concept of “condition” or “fit for purpose” is not clearly understood and the evidence for assessing land types is not readily available. The JNCC now provides a detailed analysis of the conditions of SSSIs, but this is largely based on biological quality. Further guidance is required to clarify blanket bog and the assessment of an “active” or “degraded” blanket bog. Consideration should be given to the regional variation of climate, vegetation and soils during the condition assessment, taking into account differences in topography and hydrology, rather than a “blanket” assessment for all bogs.
- Many practitioners are unclear of the soil depth on their land and the use of <50cm peat depth to distinguish areas of blanket bog from shallower areas of organic peat soils may encourage inappropriate land management and so impede peat accumulation and carbon sequestration. In contrast, those sites obviously <50cm peat depth, but in a degraded condition, may require further protection and guidance as to appropriate management to protect these vast reservoirs of carbon stored in the uplands.

8.3.2 Mapping
- Mapping of the coverage of blanket bog at a national, regional and local scale should be much more rigorous in order to quantify and assess the changes in land cover and restoration of blanket bog. Remote sensing techniques should continue to be developed to assess the temporal and spatial changes in land cover by determining vegetation cover, past and current management practices (e.g. Hymap – McMorrow et al 2005), soil erosion, grip and gully networks, grip and gully blocking (e.g. LiDAR and CASI).

8.3.3 Restoration
- Financial and resource restrictions mean that it is not possible to restore all blanket bog and in some cases it seems appropriate that no attempt should be
made to restore blanket bog in severely degraded/unfavourable condition. Many contributors support a policy of prioritisation of restoration and advocate that this should be lead by government organisations with a co-ordinated strategy and policy of research on a national basis.

- However, many restoration programmes are currently completed on a piecemeal basis with little consideration for the wider landscape effects, particularly downstream of restoration sites. A scoping exercise to determine the effects of restoration work is recommended and has already been introduced for other habitats, for example, conversion of unimproved pasture to arable land. An Environmental Impact Assessment (EIA) is suggested as a means of collating and assessing the likely significant environmental effects of a restoration programme.
- Despite the large number of restoration projects being completed on blanket bog in the UK there has been very little monitoring of schemes (scientific or otherwise). It is recommended that funding for restoration schemes should include a requirement for suitable scientific monitoring to be conducted as a means of securing funding and so improve the knowledge and understanding of restoration techniques and processes involved in the recovery of blanket bog.
- The monitoring of a site should preferably commence prior to any restoration work in order to establish a baseline of data of prevailing conditions pre-restoration and so further the understanding of changes in processes and vegetation that may occur post-restoration. At present most projects establish objectives and targets based on conditions measured during or following the completion of the restoration work. Many do not fully consider the aims and objectives of the restoration programme and therefore monitoring, if done, may be inappropriate.
- Grip and gully blocking have been identified as techniques in restoring hydrological function of blanket bog, but there is a lack of published research to determine the effectiveness of these techniques. There is a general concern that much of the focus of restoration has centred on grip and gully blocking without having the evidence-based research to support such a programme.
- There is a need to understand more fully the soil, hydrological, hydrochemical and vegetation processes and changes that may occur at a plot scale and a larger catchment scale, together with the effects of gully/grip blocking further downstream e.g. on sediment flux, DOC, POC and water colour release. A particular concern is the potential increase in soil pipes on drained sites and the effects of grip-blocking on the soil pipe network in terms of runoff, erosion, oxidation and site degradation.
- Further research needs to be completed into the most cost-effective and efficient techniques to be used for grip/gully blocking and whether it is feasible to encourage the natural re-vegetation of some sites, for example, by re-profiling gully sides. Natural re-vegetation of gullies and grips needs further study to understand the processes involved in the natural colonisation of flora and sediment accumulation in order to encourage and expand such processes on a catchment scale.
- Further research is required with regard to the effects of lime and fertiliser (used to help raise soil pH and improve conditions for re-colonisation of vegetation on areas of bare peat) on soil and water processes both in the short and long-term. In addition, little is known what effect these applications have on Sphagnum, invertebrates and the microbial organisms within the peat structure.

8.3.4 Climate Change

- The estimates of carbon flux from organic soils in the UK have largely been derived from intact sites, but the potential role of peatlands as carbon sinks or sources requires precision in the measurement and estimation of carbon flux in order to meet the future international agreements on climate change e.g. Kyoto.
There is a need to develop practical approaches to the long-term responses to climate change and to monitor changes occurring at degraded or restored sites in addition to those considered active or intact.

- Long-term carefully designed scientific experiments and monitoring need to be developed to determine the effects of blanket bog management and restoration on the soil carbon balance. Such long-term experiments will require appropriate support through funding and site allocation and continuing use of sites such as Moor House NNR by the ECN will assist in providing baseline data.
- The impacts of climate change include predicted increased frequency and intensity of storm events, prolonged periods of drought, high temperatures etc. These need to be monitored with regard to the changes in ‘natural’ weathering processes resulting from these changes and how they might be disengaged from the effects of land management.

**8.3.5 Prescribed Burning**

- The recent debate and review of the Heather and Grassland Burning Regulations and Code has generated much interest regarding the potential impacts of prescribed burning on blanket bog. However, there still remains a dearth of information on the impacts of burning on the vegetation composition of blanket mire species, or the soil and hydrological processes affected by the frequency and intensity of burn.
- Although limited research has started to address the impacts of some processes, this is largely funded by private businesses and it is recommended that further research be conducted, funded from government sources. An impartial scientific evaluation of the impacts of burning on the soil and hydro-chemistry (e.g. DOC, carbon and sediment erosion flux, pH, Fe, oxidation, humification) of peat needs to be investigated, together with an evaluation of the hydrological responses of burning at a range of scales e.g. plot scale run-off regimes to sub-catchment and whole catchment scales in order to assess the cumulative impact locally and regionally. An assessment of soil filtration under a range of burns, throughflow dynamics and water table fluctuations require investigation.
- Further use of digital infrared (IR) photography to assess vegetation and areas burnt under a cool/hot burn and the recovery rate for the areas concerned could be developed to assess the temporal and spatial changes in burning patterns and rates of recovery.
- In addition, further scientific evaluation is needed of the impacts on soil, hydrology and hydrochemical processes that occur where both prescribed burning and grazing occur together.

**8.3.6 Wildfire**

- Comprehension of the history, extent and frequency of wildfires in the UK, and a national database of strategic moorland management plans and fire prevention strategies may need further development. Recent work has been completed by Mc Morrow et al (2006) considering moorland wildfire with visitor numbers and climate change in the south Pennines and may be suitable for developing at a national level.

**8.3.7 Grazing**

- The effects of sheep grazing on vegetation structure have been investigated but there needs to be a scientific evaluation of the effects of sheep grazing on blanket bog erosion, particularly the initiation and acceleration of erosion. In addition, following the reduction in stocking densities, the legacy of intensive grazing continues to be a factor in many designated areas remaining in unfavourable condition. Further long-term research is required to determine the time required for blanket bog to recover following the removal or reduction in livestock.
• Further scientific evaluation of the effects of intensive grazing and/or the removal of livestock has on the soil, hydrological and hydrochemical processes of peat soils is required.
• Further work is required to determine the optimum stocking rates and breeds of sheep grazed under a range of conditions, taking account of differences in geology, topography, soil and vegetation type.

8.3.8 Deforestation
• Although restoration and monitoring schemes are now well established on many sites managed by the Forestry Commission, the long-term effectiveness of these bog restoration projects cannot yet be fully assessed as most post-forestry projects are too recent (within the last 10 years or so). Although the monitoring indicates limited recovery of vegetation and associated fauna in the early stages, there is a need for a long-term monitoring programme to fully assess the recovery and provide information for reviewing bog restoration policy on previously afforested sites in the future. Further research is required on the influence of bog restoration operations on nutrient availability and release, and the impacts on hydrological processes, stream flow and sediment flux.
• The policy to replace existing conifer plantations with broad leaved species and potentially to continue use of degraded blanket bog for these 'new' plantations will provide an opportunity for further research to determine the soil, hydrological, hydrochemical and vegetation changes that may occur on a temporal and spatial scale from such planting schemes.

8.3.9 Recreation
• Further information needs to be provided on a national basis for the best practice of footpath repair on heavily used, sensitive sites such as blanket bog in areas of the south Pennines and the economic feasibility of restoring popular pathways.

8.3.10 Private Enterprise
• Further research is required to understand the effects of sustainable catchment management (potential changes to prescribed burning, grip/gully blocking, manipulation of stocking densities) as an appropriate tool to supplement traditional water treatment processes and so improve water quality (by the reduction of water colour and POC) from the blanket peat moor catchments. A range of sites across the country and replicate plots on a catchment and plot scale are required to improve the knowledge of the hydrological and hydrochemical processes responsible for the production of water colour and increased erosion.
Acknowledgements

This review was funded by Defra and particular thanks go to the Rural Development Service for their support and information provided.

The review team is also grateful to the following specialists who were interviewed and gave their opinions on the values of blanket bog and the threats to peat accumulation and carbon sequestration, together with future research needs to improve our understanding of peatland processes and the impact of anthropogenic activities upon them.

### Name | Organisation
--- | ---
Mrs Penny Anderson | Penny Anderson Associates
Dr Aletta Bonn | Moors For the Future
Dr Mike Billett | CEH, Edinburgh
Mr Matt Buckler | Moors For the Future
Mr Ian Condliffe | RDS, Leeds
Mr Alistair Crowle | English Nature
Dr Martin Evans | University of Manchester
Mr Geoff Eyre | Landowner/farmer
Dr Sarah Gardener | Consultant
Mr David Glaves | RDS, Exeter
Dr Joe Holden | University of Leeds
Mr Mike Innerdale | National Trust
Prof Rob Marrs | University of Liverpool
Mr Richard May | Moorland Association
Mr Martin McGrath | United Utilities
Mr Richard Pollitt | English Nature
Dr Kate Snow | United Utilities
Mr Simon Thorpe | The Heather Trust
Mr Steve Trotter | New Forest NPA
Mr Andrew Warren | Severn Trent Water
Dr Fred Worrall | University of Durham
Dr Adrian Yallop | Cranfield University

We would also like to thank the following people who assisted with queries and provided information or reports of relevance to the review:

Jon Walker (Moors for the Future), Gail Butterill (EA), Dr Liz Chalk (EA), Neil Cowie (RSPB), Russell Anderson (FC), Audrey Watson (RSPB), Simon Stainer (NE), David Smith (Exmoor NPA), Sally Johnson (JNCC), Dr Chris Evans (CEH), James Plowman (SNH), Lindsay Kinnes (South Scotland Bog Scheme), Gordon Simpson (SNH), Jon Rothwell (CCW), Alastair Driver (EA), Paul Leadbitter (Peatscapes).
References


http://www.askoxford.com/results/?view=searchresults&freesearch=blanket%20bog&branch=&textsearchtype=exact


International Panel on Climate Change (IPCC) (2006) Climate change and Variability – Natural or manmade. [Accessed 20 July 2006] Available at: http://www.oceansatlas.org/servlet/CDSServlet?status=ND0yMDU1LjIwMjImNj1lbiYzMz13ZWItc2I0ZXMmMzc9aW5mbw


JNCC (2006b) Common Standards Monitoring for Designated Sites: First Six Year Report, No.4 Habitats. JNCC Peterborough, 1-76


Moss, C E (1913) *The Vegetation of the Peak District*. Cambridge


APPENDIX I – CURRENT RESEARCH AND CASE STUDIES
Practical Restoration and Research in Progress

Time constraints have limited the amount of information that could be gathered with regard to current relevant work on blanket bog management and restoration. The following organisations and institutions are therefore not an exhaustive list of those currently involved, or who have recently completed projects/research into aspects of blanket bog restoration, but it does summarise some of the main work. Additional details of some of the projects can be referred to in appendix I case studies.

Restoration and Research by NGO, private and charitable organisations

Countryside Alliance published the Rural Policy Handbook giving recommendations on sustainable land management, environmental and landscape conservation. They have also funded independent research on the sustainability of moorland uses and part-funded a GIS based survey of moorland management in order to promote a coherent moorland strategy to policy makers. Other research investigated into accidental fires and completed a scientific review of moorland land users with the MLURI (GFARACE), which analyses the state of moorlands.

Caithness and Sutherland LIFE Peatlands Project – see case study 12

Heather Trust is involved in the Sustainable Moorland Management Project, funded by RDS, Defra from May 2001 – Apr 2006. This set up 4 demonstration moorland sites in England and Wales. It aimed at enhancing sustainable dwarf shrub heath communities, achieving better all-year grazing, improve biodiversity, address cattle/sheep ratios, conversion of Molinia and Nardus to grass/heath mixtures, establish best practices for heather burning and cutting.

Game Conservancy Trust conducts original applied science including ecological studies which are field based and published in peer reviewed literature. It has an independent Scientific Advisory Committee (Dr David Barnes). Several relevant publications include “Conserving the Uplands” (jointly with Countryside Alliance) which considered shooting on upland estates and the implications for habitat management and the distribution of breeding birds. Research was based on a study of 371 upland shooting estates in England, Wales and Scotland, and focused on grouse/deer moors and their management, but included studies in burnt areas/grazed and gully/grip blocked areas.

Moorland Association has been involved in the Northern Uplands Regeneration Project. This is a 3 year project aimed at regenerating and sustaining 185 000 acres of heather moorland (funded through the Objective 5b Project (ADAS and MAFF). Potential for a similar project in the south Pennines and for a Welsh Upland Moorland Regeneration Project with CCW, ADAS and private landowners.

Moors For the Future is a partnership in the Peak District funded by, amongst others, Heritage Lottery grants. It funds research by universities and carries out its own practical trials as well as undertaking educational activities. See Box 6 and Case study No. 6 regarding the Bleaklow Restoration Project. Restoration of fire damaged sites includes Joseph Patch, Shelf Moor, Lawrence Edge, YelloCllacks, Hen Stones, Torride Grain, Sykes Moor, Shining Clough, Saddleworth Moor and Arnfield Moor. Footpath restoration sites include Shining Tor path, Higger Tor path, and Cut Gate path.

National Trust completed a report on the effect of CAP reform on the uplands and pioneered techniques used in gully-blocking on deep peat in south Pennines “Gully blocking in Deep Peat” (Evans et al 2005). It also encouraged changes in grazing,
drainage and burning regimes e.g. High Peak Regeneration Project (see Box 5 in section 6 and case study 5).

**RSPB** is actively involved in restoration projects of degraded blanket bog e.g. Forsinard reserve, Caithness, Scotland, on blockage of drains and deforestation (see case study 12), and the Lake Vyrnwy LIFE Project (see case study 11).

**Severn Trent Water** are major funders of the High Peak Partnership (see box 6 and case study 6).

**United Utilities** funded the Whitendale Trial (see box3 in section 6) and SCaMP Project (case study No. 4)

**Restoration and Research by Government and Statutory Bodies**

**Cairngorms National Park Authority** is a partner in the Cairngorms Moorlands Project (2003 to August 2006). The project provides a demonstration programme to develop and demonstrate moorland management techniques on two representative moors by linking grouse and agricultural management with conservation and landscape values.

**Countryside Council for Wales** is involved in the Welsh Grouse Project, where grip and gully blocking techniques are being used to restore blanket bog for suitability of black grouse.

**Environment Agency** is involved as lead partner in many drain-blocking restoration projects on upland peat catchments in England and Wales e.g. Upper Wharfedale Project (see case study 9), Newbiggin Common and Widdybank Fell (EA North East Region).

**Forestry Commission** is a partner in the Border Mires Active Blanket Bog Rehabilitation Project (LIFE funded). This included restoration of blanket bog in afforested areas and commenced in 1999 with ditch blocking using plastic piling (3400 dams) to reinstate hydrology. It involved deforestation of 250ha to enlarge bog areas and removal of self-sown conifer seedlings from open bog. Hydrological and vegetation monitoring indicated that water table levels had not risen significantly and may only have had a local effect. Mono-specific stands of *Sphagnum* had grown from plants persisting under conifer canopy. Brash and timber remains may delay the revegetation and recolonisation of *sphagnum* (eg. Anderson *et al* 2000, Thompson *et al* 2004).

**Natural England** recently completed the "Nature for People" scheme with an objective to restore and recreate valuable habitats. Three projects of relevance to the uplands and blanket bog within the scheme are:

i) Peak District project to re-vegetate large areas of bare peat

ii) North Pennines and Lake District project to determine environmentally sustainable grazing levels

iii) North Pennines – blocking drains on steep moorland slopes – Geltsdale, north Pennines (see case study No. 1)

Natural England have also undertaken or funded numerous small blanket bog restoration projects e.g. gully blocking on High Peak Estate (in partnership with National Trust), grip blocking in north Pennines (Geltsdale), grip blocking in Goyt valley.
**Scottish Natural Heritage** has several areas of current or recent research, for example:

i) Jenny Bryce: R06AC209 Investigation of the role of deer trampling on blanket bog vegetation


R06AC101 Review of soil management guidance for habitat conservation

R06AC104 Climate change, land management and erosion of organic soils (Phase I)

iii) Andrew Coupar: F05AC203 Upland site condition monitoring

R06LB01 Implementation of the Peatlands of Caithness and Sutherland Management Strategy

iv) Andrew McBride: R06AC202 Review of hydrological monitoring on Scottish lowland wetlands

v) Francis Thin: F05AA301 Land management for land managers

**Restoration and Research by Universities and Institutes**

**Cranfield University** has a range of research relating to blanket bog including: remote sensing for conservation monitoring; assessment of drivers of enhanced DOC in upland catchments; appraisal of extent of current and historical prescribed burning in the English uplands (following from White et al 2003, including Yallop et al 2005)

**Macaulay Institute (MLURI)** has several areas of research relating to processes occurring in organic soils. These include: Soil, plant and microbial interaction (a novel stable isotope probing method which links the flow of carbon from plants to soil microbes is being developed); carbon release into soil from plant roots (rhizodeposits) and how microbes use the carbon flow to help carbon sequestration within the soils; monitoring landscape change systematically to provide consistent and repeatable results using remote sensing data resources; grazing and upland birds (project leader Peter Dennis); Moorland colonisation including invasion of pine and birch woodland onto moorland (research in partnership with CEH at Banchory); Understanding grazing behaviour including effects of social behaviour of sheep to assist in the understanding the impacts of grazing and the development of biodiversity patterns.

**Nottingham Trent University** has a range of research relating to blanket bog including the impact of prescribed moorland burning, grazing densities and gully blocking on the hydrology and discoloration of surface waters in upland catchments; changes in moorland erosion and sediment delivery following gully blocking on upland blanket peat; sedimentation in upland reservoirs (eg. Butcher et al 1992, Labadz et al 2002, O’Brien et al 2005, Yeloff et al 2005).

**University of Durham** has various on-going research on peatlands with regard to the carbon biogeochemistry of peats and surface waters. Current research at Moor House NNR on the Northumbrian Water Sustainable Solutions Project (case study 7) and Peatscapes Project (case study 8) and Bleaklow Project (case study 6) to monitor soil nutrient, carbon flux and hydrology post-restoration; geomorphology of upland peat; sediment budgets of eroding moorland; peat mass movements and geomorphological impacts of extreme rainfall. Published work includes that of Burt 1995, Warburton et al 2004, Worrall et al 2007).

**University of Edinburgh** conducts research on the use of fire management in the uplands; biodiversity and carbon flux from blanket bogs; the effects of management on the carbon budget of blanket bog.
**University of Leeds** has a range of research relating to blanket bog including: impact of large scale catchment change on upland ecosystems; the carbon catchment of peatland pipes; grip blocking in upland catchments – a cost benefit analysis; impact of peatland management on coloured and non-coloured components of DOC in rivers; a study into the influence of management on the enzyme decay processes in upland blanket peat; monitoring different grip blocking techniques; sustainable upland management for multiple benefits; monitoring hydrological recovery of drain blocking by heather; impact of stocking density on re-vegetation and runoff production in eroded moorland; artificial drainage and wetland restoration in managed upland wetlands. Published work includes Holden 2006 etc.

**University of Liverpool** conducts a range of research relating to blanket bog including: bracken control and moorland restoration; the effect of cool burns on moorland vegetation.

**University of Manchester** has a range of research relating to blanket bog including: geomorphological controls on revegetation dynamics of eroding gully systems in peatlands; hyper-spectral remote sensing of upland peatlands; water quality and surface water acidification in the Peak District moorlands; assessment of connectivity of sediment systems and prediction of sediment flux from eroding peat; fluvial carbon flux from eroding peatlands; storage and release of heavy metals from eroding peat; analysis of peat erosion pattern from airborne images and DEM, modelling spatial risk of moorland wildfire; Identification of the best strategy for mitigating moorland wildfire risk. Published work includes Evans et al 2005, 2006.

**UK Popnet** is a network of institutions including Universities of Aberdeen, East Anglia, Leeds, Sheffield and York. The project of relevance to blanket bogs is a study to examine the feasibility of large scale upland manipulations to assess the impacts of land use and management practices on biodiversity and provision of ecosystem services. Monitoring will be conducted on the nutrient cycling, biogeochemical processes and functional diversity on the Bleaklow study site (case study 6) and Lake Vyrnwy (case study 11).
## Case Studies

### CASE STUDY 1

<table>
<thead>
<tr>
<th><strong>Project Name</strong></th>
<th>Geltsdale &amp; Glendue Fells</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Country</strong></td>
<td>England</td>
</tr>
<tr>
<td><strong>Current Land Designations</strong></td>
<td>AONB, Geltsdale &amp; Fells SSSI, North Pennines SPA, candidate SAC</td>
</tr>
<tr>
<td><strong>Location</strong></td>
<td>North Pennines</td>
</tr>
<tr>
<td><strong>Year Project Commenced</strong></td>
<td>1975</td>
</tr>
<tr>
<td><strong>OS Grid Ref</strong></td>
<td>NY 596517</td>
</tr>
<tr>
<td><strong>Project Funding</strong></td>
<td>RSPB, DEFRA (CSS), English Nature, SITA, ALSS</td>
</tr>
<tr>
<td><strong>Area Under Management</strong></td>
<td>5000 ha</td>
</tr>
<tr>
<td><strong>Collaborating Organisations</strong></td>
<td>University of Leeds</td>
</tr>
</tbody>
</table>

### Habitats Present
- Blanket bog, dry and wet heath, upland farmland, grassland, native woodland

### Project Management
- **Ownership** – RSPB (sporting rights for whole estate), some private landowners
- **Management** – Tenant farmers, RSPB, English Nature

### Project Aims
- To restore blanket bog by grip blocking and minimise “death trap” pools to livestock and wildlife. To manage upland heath and blanket bog for hen harrier, black grouse, skylark and reed bunting.

### Project Methodology
1. Blanket bog restoration through drain (grip) blocking using heather bales along entire length of grip;
2. Reduction in grazing pressures (reduction of sheep numbers);
3. Reduction in cutting and burning of heather;
4. Introduction of cattle

### Target Species
- Species of moss, black grouse, hen harrier, merlin, peregrine, golden plover, ring ouzel

### Associated Research/Monitoring
University of Leeds monitored hydrology of site and found overall discharge of the blocked grip had decreased following blocking, low flows were maintained during summer, although high flows were also maintained during winter indicating that the grips remained an important conduit for water despite being blocked.

Water table increased and was maintained in the blocked grip.

### Links to Further Information
- [www.rspb.org.uk/england/north/about/geltsdale.asp](http://www.rspb.org.uk/england/north/about/geltsdale.asp)
- [www.eurosite-nature.org/article.php3?id_article=266](http://www.eurosite-nature.org/article.php3?id_article=266)

### Contact for Site
- Simon Stainer, Natural England simon.stainer@natural-england.org.uk
# CASE STUDY 2

<table>
<thead>
<tr>
<th><strong>Project Name</strong></th>
<th>Border Mires Active Blanket Bog Rehabilitation Project</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Country</strong></td>
<td>England</td>
</tr>
<tr>
<td><strong>Current Land Designations</strong></td>
<td>SAC, SSSI, Ramsar site, part of National Park</td>
</tr>
<tr>
<td><strong>Location</strong></td>
<td>Cumbria-Northumberland border</td>
</tr>
<tr>
<td><strong>Year Project Commenced</strong></td>
<td>1970s</td>
</tr>
<tr>
<td><strong>OS Grid Ref</strong></td>
<td>NT 684 013</td>
</tr>
<tr>
<td><strong>Project Funding</strong></td>
<td>Forestry Commission, DEFRA, LIFE funding</td>
</tr>
<tr>
<td><strong>Area Under Management</strong></td>
<td>4555 ha</td>
</tr>
<tr>
<td><strong>Collaborating Organisations</strong></td>
<td>Forestry Commission, Northumberland Wildlife Trust, Northumberland National Park, Natural England, Newcastle University, RAP Spadeadam</td>
</tr>
<tr>
<td><strong>Habitats Present</strong></td>
<td>Peat bogs, transition mire and quaking bogs, marshes, heath, scrub, coniferous woodland</td>
</tr>
</tbody>
</table>
| **Project Management** | Ownership – Forestry Commission  
| **Project Aims** | To restore the blanket bog to favourable condition and safeguard carbon sequestration, and encourage vegetation and wildlife associated with blanket bog back to the area. |
| **Project Methodology** | i) Active blanket bog regeneration through drain (grip) blocking to restore natural hydrology – plastic piling and peat plugs; 3400 plastic piling dams installed  
ii) Removal of grazing pressures (sheep removed for 40-60 years);  
iii) Grazing allowed on small areas for comparison with ii);  
iv) Removal of conifer crops to allow mires to restore  
v) Removal of self-sown conifer seedlings |
| **Target Species** | Large heath butterfly, sundew, bog bush cricket, mire pill beetle |
| **Associated Research/Monitoring** | Hydrological and vegetation monitoring indicated water table levels had not risen significantly and may only have had a local effect, mono-specific stands of *Sphagnum* had grown from plants persisting under conifer canopy. Brash and timber remains may delay the revegetation and recolonisation of *sphagnum* |
| **Links to Further Information** | [www.forestry.gov.uk/website/wildwoods.nsf/LUWebDocsByKey/EnglandNorthumberlandKielderKiedler](http://www.forestry.gov.uk/website/wildwoods.nsf/LUWebDocsByKey/EnglandNorthumberlandKielderKiedler)  
[www.wildlifetrust.org.uk/northumberland/Reserves10.htm](http://www.wildlifetrust.org.uk/northumberland/Reserves10.htm) |
| **Contact for Site:** | Gillian Thompson Northumberland National Park Authority  
gill.thompson@nnpa.org.uk |
| **Additional Information** | A wide range of techniques and costings for tree felling and brash removal on very wet sites were completed. |
**CASE STUDY 3**

<table>
<thead>
<tr>
<th><strong>Project Name</strong></th>
<th>Cors Dyfi</th>
<th><strong>Country</strong></th>
<th>Wales</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Current Land Designations</strong></td>
<td>None</td>
<td><strong>Location</strong></td>
<td>Machynlleth</td>
</tr>
<tr>
<td><strong>Year Project Commenced</strong></td>
<td>1999</td>
<td><strong>OS Grid Ref</strong></td>
<td>SN 701 985</td>
</tr>
<tr>
<td><strong>Project Funding</strong></td>
<td>Heritage Lottery Funding, Countryside Council for Wales</td>
<td><strong>Area Under Management</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Collaborating Organisations</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Habitats Present</strong></td>
<td>Open water, bog, swamp, wet woodland, scrub and gorse</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Project Management</strong></td>
<td>Ownership – Montgomeryshire Wildlife Trust</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Project Aims</strong></td>
<td>To restore active blanket bog to previously afforested site, and enhance biodiversity of site.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| **Project Methodology** | i) Drains cleared and then blocked to re-wet the reserve;  
ii) Conifer plantation removed;  
iii) Creation of new ponds; |
| **Target Species** | Nightjar, reed bunting, warblers, snipe, bog myrtle |
| **Associated Research/Monitoring** | Not known |
| **Links to Further Information** | www.montwt.co.uk/cors_dyfi.html |
| **Contact for Site** | Montgomeryshire Wildlife Trust Email montwt@cix.co.uk |
**CASE STUDY 4**

<table>
<thead>
<tr>
<th><strong>Project Name</strong></th>
<th>SCaMP Project</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Country</strong></td>
<td>England</td>
</tr>
<tr>
<td><strong>Current Land Designations</strong></td>
<td>SSSI, SPA, cSAC,</td>
</tr>
<tr>
<td><strong>Location</strong></td>
<td>Bowland (N Pennines), Longendale &amp; Goyt (S Pennines)</td>
</tr>
<tr>
<td><strong>Year Project Commenced</strong></td>
<td>2005</td>
</tr>
<tr>
<td><strong>Project Funding</strong></td>
<td>Amp 4 &amp; others (£24 million)</td>
</tr>
<tr>
<td><strong>Area Under Management</strong></td>
<td>58,000 ha</td>
</tr>
<tr>
<td><strong>OS Grid Ref</strong></td>
<td>various</td>
</tr>
<tr>
<td><strong>Collaborating Organisations</strong></td>
<td>United Utilities, National Trust, Natural England, RSPB, Peak District NPA</td>
</tr>
<tr>
<td><strong>Habitats Present</strong></td>
<td>Blanket bog</td>
</tr>
<tr>
<td><strong>Project Management</strong></td>
<td>Management – United Utilities, Ownership – United Utilities</td>
</tr>
<tr>
<td><strong>Project Aims</strong></td>
<td>To improve the management of land through integrated management in order to ameliorate water quality (particularly discoloured water) and benefits to wildlife.</td>
</tr>
<tr>
<td><strong>Project Methodology</strong></td>
<td>i) Reduce grazing density and exclude cattle from land undergoing restoration, ii) Manipulate grazing regimes both spatially and temporally, iii) Restore wetlands through blocking grips and drains, iv) Reduce moorland erosion and restore degraded areas of moorland to active blanket bog, v) Create buffer zones around watercourses and abstraction points, vi) Agree long-term plans with farming tenants to support implementation of SCaMP ideals.</td>
</tr>
<tr>
<td><strong>Target Species</strong></td>
<td>twite and hen harrier</td>
</tr>
<tr>
<td><strong>Associated Research/Monitoring</strong></td>
<td>Detailed monitoring (2005-2010) to assess the impact of applying different management and restoration techniques. Hydrological and vegetation monitoring through approved EN techniques, and bird monitoring by RSPB</td>
</tr>
<tr>
<td><strong>Links to Further Information</strong></td>
<td><a href="http://www.unitedutilities.com/corporate/?OBH=2768">http://www.unitedutilities.com/corporate/?OBH=2768</a></td>
</tr>
<tr>
<td><strong>Contact for Site</strong></td>
<td>Mr Martin McGrath Project manager email: <a href="mailto:martin.mcgrath@unitedutilities.co.uk">martin.mcgrath@unitedutilities.co.uk</a></td>
</tr>
</tbody>
</table>
## CASE STUDY 5

<table>
<thead>
<tr>
<th><strong>Project Name</strong></th>
<th>High Peak Partnership</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Country</strong></td>
<td>England</td>
</tr>
<tr>
<td><strong>Current Land Designations</strong></td>
<td>SSSI, SPA, cSAC,</td>
</tr>
<tr>
<td><strong>Location</strong></td>
<td>Derbyshire</td>
</tr>
<tr>
<td><strong>Year Project Commenced</strong></td>
<td>2002-2007</td>
</tr>
<tr>
<td><strong>OS Grid Ref</strong></td>
<td>SK08 93 – SK11 92</td>
</tr>
<tr>
<td><strong>Project Funding</strong></td>
<td>Severn Trent Water</td>
</tr>
<tr>
<td><strong>Area Under Management</strong></td>
<td>5km²</td>
</tr>
<tr>
<td><strong>Collaborating Organisations</strong></td>
<td>Severn Trent Water, National Trust, English Nature, Nottingham Trent University</td>
</tr>
<tr>
<td><strong>Habitats Present</strong></td>
<td>Blanket bog</td>
</tr>
<tr>
<td><strong>Project Management</strong></td>
<td>Management – National Trust, English Nature, farming and shooting tenants</td>
</tr>
<tr>
<td></td>
<td>Ownership – National Trust</td>
</tr>
<tr>
<td><strong>Project Aims</strong></td>
<td>To investigate the role of blanket peat moorland management in the generation and amelioration of discoloured surface water supplies.</td>
</tr>
<tr>
<td></td>
<td>Enhance wildlife value</td>
</tr>
<tr>
<td></td>
<td>Restore bog to favourable condition.</td>
</tr>
<tr>
<td><strong>Project Methodology</strong></td>
<td>i) Conduct a paired catchment study with 3 control catchments and 3 catchments on which land management is manipulated.</td>
</tr>
<tr>
<td></td>
<td>ii) Manipulate land management by removing grazing from one entire catchment</td>
</tr>
<tr>
<td></td>
<td>iii) Manipulate land management by stopping prescribed burning on an entire catchment</td>
</tr>
<tr>
<td></td>
<td>iv) Manipulate land management by blocking naturally eroded gullies</td>
</tr>
<tr>
<td><strong>Target Species</strong></td>
<td>None</td>
</tr>
<tr>
<td><strong>Associated Research/Monitoring</strong></td>
<td>Nottingham Trent University – results pending, but see Box 5</td>
</tr>
<tr>
<td><strong>Links to Further Information</strong></td>
<td><a href="http://www.swig.org.uk/Helen%20O%27Brien.pdf">http://www.swig.org.uk/Helen%20O%27Brien.pdf</a></td>
</tr>
<tr>
<td><strong>Contact for Site</strong></td>
<td>Mike Innerdale, NT High Peak Estate Manager email: <a href="mailto:michael.innerdale@nationaltrust.org.uk">michael.innerdale@nationaltrust.org.uk</a></td>
</tr>
<tr>
<td></td>
<td>Dr Jillian Labadz Nottingham Trent University email: <a href="mailto:jillian.labadz@ntu.ac.uk">jillian.labadz@ntu.ac.uk</a></td>
</tr>
</tbody>
</table>
### CASE STUDY 6

<table>
<thead>
<tr>
<th><strong>Project Name</strong></th>
<th>MFF – Bleaklow Restoration Project</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Country</strong></td>
<td>England</td>
</tr>
<tr>
<td><strong>Current Land Designations</strong></td>
<td>SSSI, cSAC, within Peak District National Park</td>
</tr>
<tr>
<td><strong>Location</strong></td>
<td>Bleaklow, Peak District, south Pennines</td>
</tr>
<tr>
<td><strong>Year Project Commenced</strong></td>
<td>2003</td>
</tr>
<tr>
<td><strong>OS Grid Ref</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Project Funding</strong></td>
<td>Heritage Lottery, DEFRA, English Nature</td>
</tr>
<tr>
<td><strong>Area Under Management</strong></td>
<td>3 km²</td>
</tr>
<tr>
<td><strong>Collaborating Organisations</strong></td>
<td>Moors for the Future Partnership, English Nature, National Trust, United Utilities, Yorkshire Water – plus partnership organisations – see website</td>
</tr>
<tr>
<td><strong>Habitats Present</strong></td>
<td>Blanket bog</td>
</tr>
<tr>
<td><strong>Project Management</strong></td>
<td>Management – National Trust, English Nature, Peak District National Park Authority</td>
</tr>
<tr>
<td><strong>Ownership</strong></td>
<td>National Trust</td>
</tr>
<tr>
<td><strong>Project Aims</strong></td>
<td>To restore badly degraded moorland</td>
</tr>
<tr>
<td><strong>Project Methodology</strong></td>
<td>i) Re-vegetate bare peat</td>
</tr>
<tr>
<td></td>
<td>ii) Exclude grazing to 35km² of moorland</td>
</tr>
<tr>
<td></td>
<td>iii) Block naturally eroded gullies to restore hydrological function</td>
</tr>
<tr>
<td></td>
<td>iv) Provide a moorland sustainability baseline to the pattern, processes and planning or moorland degradation and restoration</td>
</tr>
<tr>
<td><strong>Target Species</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Associated Research/Monitoring</strong></td>
<td>Moors for the Future, University of Leeds, University of Manchester, University of Durham, UKPopnet</td>
</tr>
<tr>
<td></td>
<td>MFF conducted soil and vegetation monitoring post restoration work (see Box 6). Universities of Manchester and Durham to commence a one year pilot study to monitor carbon flux, soil pH, nutrient composition, water chemistry and hydrological conditions on treated and untreated sites.</td>
</tr>
<tr>
<td><strong>Links to Further Information</strong></td>
<td><a href="http://www.moorsforthefuture.org.uk">www.moorsforthefuture.org.uk</a></td>
</tr>
<tr>
<td><strong>Contact for Site</strong></td>
<td>Mr Matt Buckler Project Officer email: <a href="mailto:Matt.Buckler@peakdistrict.gov.uk">Matt.Buckler@peakdistrict.gov.uk</a></td>
</tr>
</tbody>
</table>

**Additional Information**
**CASE STUDY 7**

<table>
<thead>
<tr>
<th><strong>Project Name</strong></th>
<th>North Pennines AONB Peatscapes Project</th>
<th><strong>Country</strong></th>
<th>England</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Current Land Designations</strong></td>
<td>SSSI, SPA, cSAC,</td>
<td><strong>Location</strong></td>
<td>North Pennines</td>
</tr>
<tr>
<td><strong>Year Project Commenced</strong></td>
<td>Feb 2006 – March 2009</td>
<td><strong>OS Grid Ref</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Project Funding</strong></td>
<td>Natural England, Countryside Agency, Northumbrian Water, Environment Agency, County Durham Environmental Trust</td>
<td><strong>Area Under Management</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Collaborating Organisations</strong></td>
<td>North Pennines AONB Staff Unit, University of Durham, Natural England, Environment Agency, RSPB, Durham County Council, Northumbrian Water</td>
<td><strong>Habitats Present</strong></td>
<td>Blanket bog</td>
</tr>
<tr>
<td><strong>Project Management</strong></td>
<td>Management – North Pennines AONB Staff Unit</td>
<td><strong>Ownership</strong></td>
<td>various landowners</td>
</tr>
<tr>
<td><strong>Project Aims</strong></td>
<td>To conserve and enhance blanket bog within the North Pennines AONB</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| **Project Methodology** | i) Promote best practice by supporting the provision of mgt advice on upland peatland to form basis of practical mgt works – block drainage ditches, and change management regime with regard to grazing and prescribed burning.  
ii) Support and disseminate current and new research into peatland processes, ecology and management  
iii) Support restoration and mgt work by promoting existing agri-environmental schemes and sourcing additional funds held by project. |
| **Target Species** | None |
| **Associated Research/Monitoring** | Monitor effects of grip blocking, and manipulation of grazing and burning regimes on blanket bog with regard to carbon flux and water colour in particular.  
Supporting peatland research on gripping, carbon budgets etc |
| **Links to Further Information** | [http://www.northpennines.org.uk/media/pdf/n/e/NPN_Spring_Summer06_1to8.pdf](http://www.northpennines.org.uk/media/pdf/n/e/NPN_Spring_Summer06_1to8.pdf) |
| **Contact for Site** | Project manager Paul Leadbitter email: paulpeatscapes@northpenninesaonb.org.uk |
### CASE STUDY 8

<table>
<thead>
<tr>
<th><strong>Project Name</strong></th>
<th>Northumbrian Water Sustainable Solutions Project</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Country</strong></td>
<td>England</td>
</tr>
<tr>
<td><strong>Current Land Designations</strong></td>
<td>Location Northumberland</td>
</tr>
<tr>
<td><strong>Year Project Commenced</strong></td>
<td>OS Grid Ref</td>
</tr>
<tr>
<td><strong>Project Funding</strong></td>
<td>Northumbrian Water</td>
</tr>
<tr>
<td><strong>Area Under Management</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Collaborating Organisations</strong></td>
<td>Northumbrian Water, University of Durham</td>
</tr>
<tr>
<td><strong>Habitats Present</strong></td>
<td>Blanket Bog</td>
</tr>
<tr>
<td><strong>Project Management</strong></td>
<td>Management – Ownership –</td>
</tr>
<tr>
<td><strong>Project Aims</strong></td>
<td>To reduce the level of water discolouration from peat-covered catchments</td>
</tr>
<tr>
<td><strong>Project Methodology</strong></td>
<td>i) Introduce voluntary changes in land management which are considered to influence water discolouration, that is, manipulate stocking densities, prescribed burning. \n</td>
</tr>
<tr>
<td><strong>Target Species</strong></td>
<td>None</td>
</tr>
<tr>
<td><strong>Associated Research/Monitoring</strong></td>
<td>University of Durham</td>
</tr>
<tr>
<td><strong>Links to Further Information</strong></td>
<td><a href="http://www.jncc.gov.uk/PDF/SustainableCatchment_CS.pdf">http://www.jncc.gov.uk/PDF/SustainableCatchment_CS.pdf</a></td>
</tr>
<tr>
<td><strong>Contact for Site</strong></td>
<td>Dr Chris Spray Northumbrian Water</td>
</tr>
<tr>
<td><strong>Additional Information</strong></td>
<td>Cost of project is £200 000.</td>
</tr>
</tbody>
</table>
**CASE STUDY 9**

<table>
<thead>
<tr>
<th><strong>Project Name</strong></th>
<th>Upper Wharfedale Best Practice Project</th>
<th><strong>Country</strong></th>
<th>England</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Current Land Designations</strong></td>
<td>NNR, SSSI, SPA, cSAC,</td>
<td><strong>Location</strong></td>
<td>Yorkshire</td>
</tr>
<tr>
<td><strong>Year Project Commenced</strong></td>
<td>1998-2002</td>
<td><strong>OS Grid Ref</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Project Funding</strong></td>
<td>NERC, Environment Agency, National Trust</td>
<td><strong>Area Under Management</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Collaborating Organisations</strong></td>
<td>Environment Agency, National Trust, English Nature, Yorkshire Dales National Park,</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Habitats Present**
Blanket bog

**Project Management**
Management –
Ownership – various

**Project Aims**
To demonstrate the principles, techniques and benefits of an integrated way of achieving good land and water management in an upland catchment area.

**Project Methodology**
i) Block drains (grips) and gills to re-wet blanket bog using peat dams
ii) Reduce grazing to a sustainable level

**Target Species**

**Associated Research/Monitoring**
University of Leeds

**Links to Further Information**
http://therrc.co.uk/newsletters/issue15.pdf

**Contact for Site**
Liz Chalk  Technical Specialist Biodiversity Team, Environment Agency
Email liz.chalk@environment-agency.gov.uk
## CASE STUDY 10

<table>
<thead>
<tr>
<th><strong>Project Name</strong></th>
<th>River Swale Regeneration Project</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Country</strong></td>
<td>England</td>
</tr>
<tr>
<td><strong>Current Land Designations</strong></td>
<td>SSSI, SPA, cSAC, Yorkshire Dales National Park</td>
</tr>
<tr>
<td><strong>Location</strong></td>
<td>Yorkshire</td>
</tr>
<tr>
<td><strong>Year Project Commenced</strong></td>
<td>OS Grid Ref</td>
</tr>
<tr>
<td><strong>Project Funding</strong></td>
<td>DEFRA, English Nature</td>
</tr>
<tr>
<td><strong>Area Under Management</strong></td>
<td>150 Ha</td>
</tr>
<tr>
<td><strong>Collaborating Organisations</strong></td>
<td>Yorkshire Dales National Park, Environment Agency, English Nature, Yorkshire Wildlife Trust</td>
</tr>
<tr>
<td><strong>Habitats Present</strong></td>
<td>Blanket bog</td>
</tr>
<tr>
<td><strong>Project Management</strong></td>
<td>Ownership – various</td>
</tr>
<tr>
<td></td>
<td>Administration – Yorkshire Dales National Park</td>
</tr>
<tr>
<td><strong>Project Aims</strong></td>
<td>To reduce the rate of surface runoff and reinstate the hydrological function</td>
</tr>
<tr>
<td><strong>Project Methodology</strong></td>
<td>i) Drains (grips) blocked by scooping peat and vegetation from side and in-filling ditch</td>
</tr>
<tr>
<td><strong>Target Species</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Associated Research/Monitoring</strong></td>
<td>Environment Agency (Dales Area) and University of Leeds to conduct research on Wharfe catchment (where more catchment data are available)</td>
</tr>
<tr>
<td><strong>Links to Further Information</strong></td>
<td><a href="http://www.riverswale.org.uk/project09.html">http://www.riverswale.org.uk/project09.html</a></td>
</tr>
<tr>
<td><strong>Contact for Site</strong></td>
<td>Research - Dr Joseph Holden University of Leeds</td>
</tr>
<tr>
<td></td>
<td>Email: <a href="mailto:J.Holden@leeds.ac.uk">J.Holden@leeds.ac.uk</a></td>
</tr>
</tbody>
</table>
## CASE STUDY 11

<table>
<thead>
<tr>
<th><strong>Project Name</strong></th>
<th>Vyrnwy LIFE Project</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Country</strong></td>
<td>Wales</td>
</tr>
<tr>
<td><strong>Current Land Designations</strong></td>
<td>SSSI, SPA, SAC,</td>
</tr>
<tr>
<td><strong>Location</strong></td>
<td>Berwyn &amp; Migneint</td>
</tr>
<tr>
<td><strong>Year Project Commenced</strong></td>
<td>2006 - 2011</td>
</tr>
<tr>
<td><strong>OS Grid Ref</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Project Funding</strong></td>
<td>LIFE funding LIFE/NAT/UK/000134</td>
</tr>
<tr>
<td><strong>Area Under Management</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Collaborating Organisations</strong></td>
<td>RSPB, Severn Trent Water</td>
</tr>
<tr>
<td><strong>Habitats Present</strong></td>
<td>Blanket bog</td>
</tr>
<tr>
<td><strong>Project Management</strong></td>
<td>Management – RSPB</td>
</tr>
<tr>
<td></td>
<td>Ownership – Severn Trent Water and various</td>
</tr>
<tr>
<td><strong>Project Aims</strong></td>
<td>To establish the natural hydrology of blanket bog</td>
</tr>
<tr>
<td><strong>Project Methodology</strong></td>
<td>i) To re-establish natural hydrology of blanket bog by blocking drains</td>
</tr>
<tr>
<td></td>
<td>ii) Removal of forestry plantations</td>
</tr>
<tr>
<td></td>
<td>iii) Minimise scrub invasion – active control of Rhododendron</td>
</tr>
<tr>
<td></td>
<td>iv) Re-seeding of heather</td>
</tr>
<tr>
<td><strong>Target Species</strong></td>
<td>Not known</td>
</tr>
<tr>
<td><strong>Associated Research/Monitoring</strong></td>
<td>Hydrological monitoring University of South Wales (Aberystwyth)</td>
</tr>
<tr>
<td></td>
<td>UKPopnet – soil respiration and carbon flux</td>
</tr>
<tr>
<td></td>
<td>More detailed hydrological monitoring – to be arranged by open tender</td>
</tr>
<tr>
<td><strong>Links to Further Information</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Contact for Site</strong></td>
<td>Audrey Watson RSPB Regional Manager email: <a href="mailto:Audrey.Watson@rspb.org.uk">Audrey.Watson@rspb.org.uk</a></td>
</tr>
</tbody>
</table>
## CASE STUDY 12

<table>
<thead>
<tr>
<th><strong>Project Name</strong></th>
<th>Caithness and Sutherland Peatland Management Scheme</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Country</strong></td>
<td>Scotland</td>
</tr>
<tr>
<td><strong>Current Land Designations</strong></td>
<td>SAC, SPA, SSSI, Ramsar site, Natura 2000 site</td>
</tr>
<tr>
<td><strong>Location</strong></td>
<td>Caithness &amp; Sutherland</td>
</tr>
<tr>
<td><strong>Year Project Commenced</strong></td>
<td>1992, re-launched 2001</td>
</tr>
<tr>
<td><strong>OS Grid Ref</strong></td>
<td>NC866402</td>
</tr>
<tr>
<td><strong>Project Funding</strong></td>
<td>Scottish Natural Heritage, LIFE Project &amp; partnership organisations</td>
</tr>
<tr>
<td><strong>Area Under Management</strong></td>
<td>400 000 ha</td>
</tr>
<tr>
<td><strong>Collaborating Organisations</strong></td>
<td>SNH, RSPB, SEPA, CC, SEERAD, SAC, FC</td>
</tr>
</tbody>
</table>

### Habitats Present
- Inland water bodies, Blanket bog, marsh, heath, scrub

### Project Management
SNH, RSPB, SEPA, CC, SEERAD, SAC, FC

### Project Aims
To enhance and promote the special values of the peatlands through the promotion of sustainable land management...

### Project Methodology
1. Drain blocking to restore the bogs water table
2. Restoration of cut over peat workings to encourage re-colonisation of *Sphagnum* mosses
3. Removal of redundant fences where ground is being damaged by animals tracking along the fenceline.
4. Encourage best practice of livestock management and muirburn which will benefit a range of peatland habitats of conservation interest
5. Encourage peatcutting practice which will minimise the impact on the peatland habitat and encourage peat-forming vegetation to become re-established
6. Restoration of afforested areas

### Target Species
- *Sphagnum* sp, golden eagle, golden plover, hen harrier, merlin and more

### Associated Research/Monitoring
Within Forsinard reserve 202ha of afforested peatland clear felled and 20 km of hill drains blocked using a range of techniques – monitoring indicates a return of blanket mire plant species, increase in golden plover and dunlin where trees removed.

### Links to Further Information
- [http://www.snh.org.uk/about/ab-pa09a.asp](http://www.snh.org.uk/about/ab-pa09a.asp)

### Contact for Site:
- Peatland Management Scheme Officer James Plowman [James.Plowman@snh.gov.uk](mailto:James.Plowman@snh.gov.uk)
- RSPB – Warden Forsinard Reserve Norris Russell [forsinard@rspb.org.uk](mailto:forsinard@rspb.org.uk)
- Pete Mayhew, Snr conservation Manager [Pete.Mayhew@rspb.org.uk](mailto:Pete.Mayhew@rspb.org.uk)

### Additional Information
GENERAL

Question
What is your job title and who do you work for?

Question
What is the role of the organisation?

Question
What are your responsibilities with regard to blanket bog habitat?
e.g. making decisions? e.g. forming policy? e.g. managing the habitat?
e.g. practical implementation e.g. research

Question
How large an area/region are you (or your organisation) responsible for?

Question
Are any of the Blanket Bog areas for which you are responsible designated for example, as SSSIs, SACs, SPAs, AONB etc?

Question
Is any of the area defined as blanket bog in your area/region undesignated and if so, is this managed any differently from the designated areas?

Question
Does your organisation work in partnership with other organisations – particularly relating to blanket bog restoration, if so, which ones?

Question
What would you say are the key features of a blanket bog habitat?

VALUES

Question
What does your organisation see as the value of this habitat?

Question
What, in your opinion, is the appreciation of the value of this habitat amongst others such as landowners, organisations and the general public?

THREATS

Question
What do you consider to be the main threats to this type of habitat and what harm do they cause?
(burning/grazing/gripping/erosion/recreation/atmospheric/peat extraction/forestry/scrub invasion)

Question
Are you in a position to influence any of these threats? If so, how?
RESTORATION

Question
What does the meaning of “restore” or “restoration” mean to you or your organisation?

Question
To what do you think Blanket Bog ought to be restored to?

Question
What is the main aim of your organisation with regard to Blanket Bog restoration?

Question
Does your organisation have any targets to “restore” Blanket Bog in areas where it is unfavourable or degraded?

Question
What do you think is the best scale to restore and why?
  e.g. local site/county or regional level?

Question
How significant, in your opinion, is the restoration of hydrological function?

Question
What methods might you suggest to restore hydrology on a blanket bog?

Question
Does your organisation take any action or recommend action to restore Sphagnum?
  If so, what?

MANAGEMENT

Question
Are you directly responsible for managing Blanket Bog?

Question
How large an area of Blanket Bog habitat is it and how was the area calculated?

Question
Do any of the threats you have described to Blanket Bog occur on the land you are responsible for?

Question
Is anything being done within your area to reduce the threats you have described?

Question
What sort of incentives are there for organisations or individuals to manage Blanket Bog habitats effectively? e.g. Environmental Stewardship HLF scheme
MONITORING

Question
How does your organisation judge whether restoration techniques are a success?

Question
Does your organisation recommend or implement any monitoring of the Blanket Bog prior to taking action?

IF YES

Question
What sort of monitoring have you been doing and for how long?

Question
Who is responsible for the monitoring?

Question
How often do you monitor and how do you record the results?

Question
Do you publish the results or make them publicly available – if so, where?

RESEARCH/THE FUTURE

Question
What are the biggest gaps in our knowledge and/or understanding of Blanket Bog and its restoration?

Question
What would you prioritise?

Question
What incentives or mechanisms would encourage such research?

Question
Is there anything else you would like to add that has not been asked during the interview?