Ecosystem services of peat – Phase 1

Project code: SP0572

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1. Introduction

1.1. Scope

There is now wide recognition of the importance to human well-being of services delivered by the peatland environment. Despite this, there remains little ecological understanding of ecosystem services, particularly in terms of how and where they are supplied and consumed at a regional or national scale. The new cross government Natural Environment PSA28 target aims 'to secure a diverse, healthy and resilient natural environment, which provides the basis for everyone's well-being, health and prosperity now and in the future; and where the values of the services provided by the natural environment are reflected in decision-making'. Therefore, when taking action in peatlands, management should strive to achieve multiple benefits and not implement action to promote one service to the detriment of other vital services. This project is a scoping study to a bigger project on peatlands, which will inform the Defra Ecosystem Approach framework in light of the Millennium Ecosystem Assessment. It is novel and visionary work, bringing key stakeholders for peatlands together for strategic mapping and spatial analysis of public benefits. It should be emphasised, however, that as a scoping study the project evaluates and trials methodologies at case study sites and evaluates the extent to which these techniques could be rolled out to other sites. In doing so the project will also point to potential pitfalls and difficulties (e.g. data gaps) that make evaluation and mapping of some ecosystem services difficult and hence it highlights further work that is needed.

The project objectives were as follows:

1) Assess the information available on the provision and quantification of peatland ecosystem services for each site.
2) For each case study identify and map ecosystem services provided by peat.
3) Determine suitable valuation data required to undertake peatland ecosystem service valuation based on peatland maintenance and restoration.
4) Determine the flows of costs and benefits for each site.
5) Assess the capacity of each site to increase its ecosystem service provision and assess the case for restoration, outline conflicts between service provisions and compare differences in ecosystem service provision between sites.
6) Assess the transferability of results from each case study to other areas.
7) Determine a feasible programme of work that could be carried out over the next 2 to 5 years to collect additional information required on peatland ecosystem services, valuation data to be used in cost-benefit analyses and prioritisation of management and restoration actions.
8) Produce a list of the top 10 criteria for assessing peatland ecosystem service provision that allows monitoring the health of ecosystems and which could be built in to future monitoring.

1.2 Peat ecosystem services

Peatlands have been recognised as providing crucially important ecosystem services (Maltby *et al*. 1994). Peatlands are of national and international importance for provision of food and fibre, water supply, climate regulation, maintenance of biodiversity, as well as provision of opportunities for recreation, inspiration and cultural heritage. They are often of exceptional natural beauty, centres of species distinctiveness and richness, and historically have been extensively managed for food production, game or fuel extraction due to difficult terrain and thus low productivity. This is reflected in the fact that most peatlands in the UK receive national and international conservation designations. Globally, peatlands cover over 400 million ha (Bather and Miller, 1991). In the UK, peat covers 1.58 million ha, or about 7% of the land area. The main ecosystem services provided by peatlands are defined based on the commonly used categorisations of the Millennium Ecosystem Assessment (MA, 2005) and the Defra Total Economic Value (TEV) framework, which identify four major categories of ecosystem services that directly affect human well-being (Figure 1.1). The main peatland services are (Bonn *et al* 2009 a,c):

a) **Provisioning services** which result from products being obtained from ecosystems, such as food, fibre, fresh water, and sources of energy. Blanket bog peats are used for rough grazing while fen peats are more fertile and hence often converted for agriculture. Most notably, upland catchments provide over 70% of fresh water in Britain. Milled peat, especially from lowland peats provides a variety of services but the most common use is to improve the soil and provide a growing medium for horticultural services. Peatlands can also provide a source for renewable energies such as wind power, small hydro-electric schemes and wood fuel and host major transport routes.

b) **Regulating services** provide benefits from regulation of natural processes, including climate regulation, air quality regulation, water purification and natural hazard regulation. It is estimated that UK peatlands store over 5000 million tonnes of soil carbon which vastly exceeds the total carbon stored in UK woodland vegetation (92 million tonnes) (Milne and Brown, 1997). Peatlands also have a fine balance of greenhouse gas sequestration and emission (for a recent review see the 2009 Defra report SP0574 produced by Baird, Holden and Chapman at the University of Leeds). Furthermore, peatlands may play an important role in water regulation, affecting water quality and perhaps flood regulation, as well as natural hazard regulation, which including floods and wildfires.

c) **Cultural services** provide non-material benefits from ecosystems such as recreation opportunities, enjoyment of landscape aesthetics, biodiversity and cultural heritage as well as spiritual enrichment and educational experiences. While providing the largest tracts of unfragmented landscapes, they are a major tourist destination for countryside recreation.

d) **Supporting services** are defined as services that are necessary for the production of all other ecosystem services. They include services such as nutrient cycling, microclimate regulation, soil formation and photosynthesis.

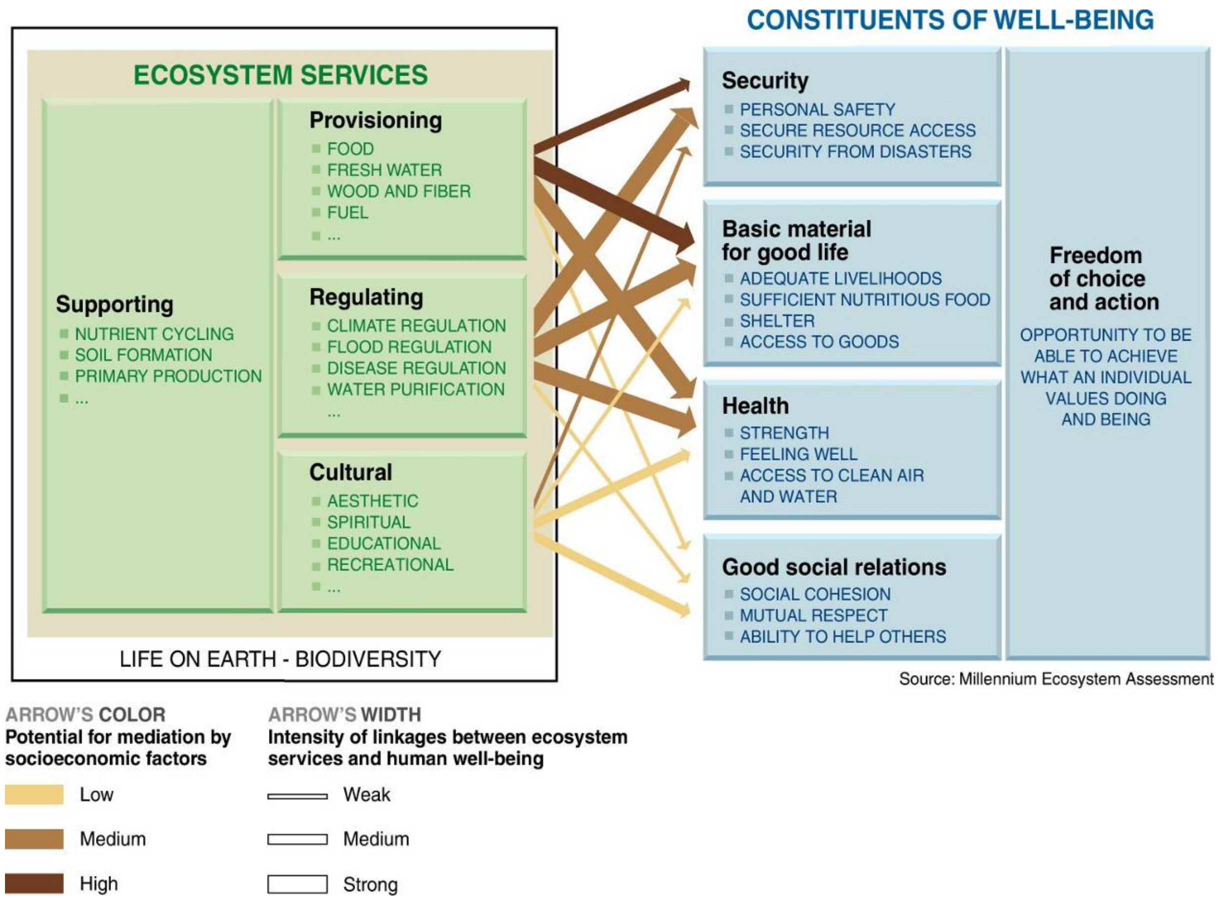


Figure 1.1: Millennium Ecosystem Assessment classification of ecosystem services

In this study we consider supporting services not as separate services, but as intermediate services, as they underpin all other services, to avoid double counting in cost benefit analyses. Supporting services do not directly provide measurable services and benefits to people, but do so through mediation of the secondary provisioning, regulating and cultural services. While enjoyment of biodiversity is often considered as a cultural service (incl. non-use values) and there are some aspects, such as genetic resources, contributing to provisioning service, biodiversity itself is not defined as an Ecosystem Service in the Millennium Ecosystem Assessment (MA, 2005). Rather biodiversity is seen as closely related to the concept of the ecosystem, and thus as underpinning the rest of the services, also as supporting services. Following discussions within the team and with study stakeholders, we perceive biodiversity to encompass more than ecosystem services, i.e. some form of nature's benefits to humans. We therefore consider biodiversity separately here.

For this scoping study we use a GIS mapping approach to map and quantify the spatially explicit distribution of key ecosystem services for each case study site, focussing in-depth on key ecosystem services, as listed in the Defra tender specifications, such as protecting carbon stores, reducing flood risks, protecting water quality and biodiversity.

Mapping the spatial distribution of ecosystem services (Balmford et al 2008, Bonn et al 2009c, Chan et al., 2006, Daily 1997; Defra, 2007a, b; Egoh et al., 2007 MA, 2005, Rodriguez et al., 2006) can help to:

- **Enhance communication and participation**
  Communicate relevance of ecosystem services
  Visualise through maps as powerful communication tool
  Facilitate cross-sectoral involvement of stakeholders/ experts
- **Develop understanding of status quo & change**
  Understand provision and quantification of ecosystem services
  Evaluate change through scenario based approaches
  Develop focused research and monitoring approaches
- **Inform costs & benefits for management options**
  Assess synergies & trade off between competing land use
  Identify affected population
  Highlight spatial disaggregation of providers and beneficiaries
- **Inform policy**
  Evaluate policy interventions
  Highlight cases for potential payments for ecosystem service schemes

2. Case study site identification

There are two main peatland types in the UK: bogs and fens. Both of these can be subdivided into further classes. For example, bogs can be subdivided into blanket bogs and raised bogs. Fens can be subdivided into basin fens, valley fens, floodplain fens and even sloping fens (Charman, 2002; Wheeler *et al*., 2009). Internationally, many other terms and classifications of peatland are used but the above provides a simple picture that is suitable for the UK, especially in terms of area and carbon storage of the different types. Blanket bogs cover approximately 16,000 km^2 in the UK while upland raised bog covers 862 km^2 and lowland raised bog covers 60 km^2. Fens cover approximately 1400 km^2 which represents the majority of fenland within Europe.

As a scoping study this project assessed the availability of data and scientific evidence on peatland ecosystem service provision as well as the transferability of the evidence base using detailed case studies. The project identified representative case study sites, which include upland and lowland peatlands in different states of degradation, namely the Peak District moorlands, Migneint and Thorne & Hatfield Moors as main case study sites and Somerset Levels as additional case study with less intensive analysis due to budget constraints (Figure 2.1). For site selection, the team considered factors including:
(a) transferability to other sites,
(b) size of site,
(c) upland and lowland,
(d) Wales and England,
(e) state of degradation,
(f) data availability especially vegetation, water table, water quality, peat type and depth, wide range of service provision data,
(g) information available from the peat restoration and management compendium,
(h) mixture of water supply versus non water supply catchments,
(i) buy-in from stakeholders,
(j) within-site variability so that maps could be varied and useful and we could trial techniques, as well as
(k) feasibility in terms of the number of sites that can be studied well.

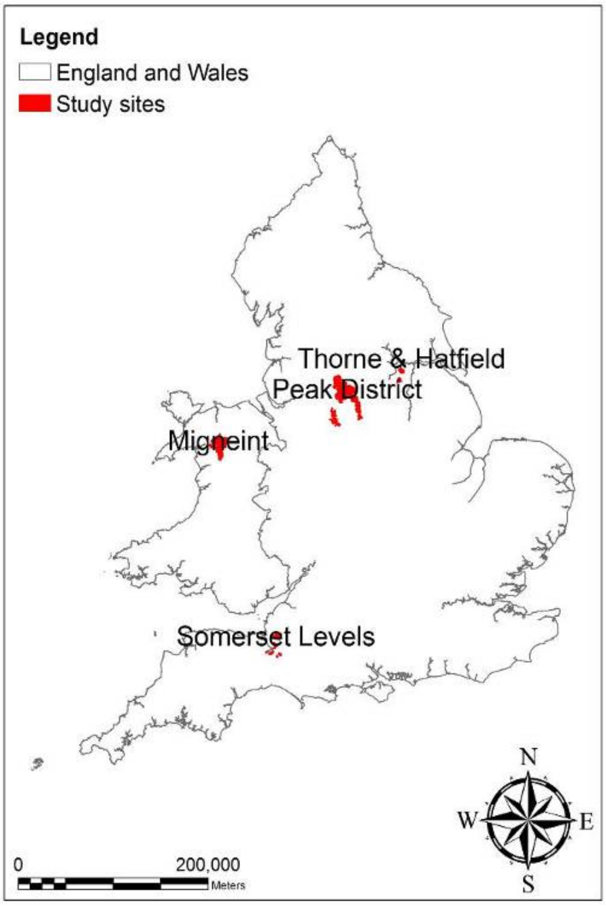


Figure 2.1: Location of the four case study areas in England and Wales

The team went through a long list of possible sites across England and Wales. It is not possible to study a range of individual lowland sites from degraded to good and a range of upland sites from degraded to good and yet include sites for each type of peatland in England and Wales (lowland raised bog, upland raised bog, valley fen, basin fen, floodplain fen, upland blanket peat, etc). This is particularly since the project is a scoping study and we have been requested to study a small number of case study sites. However, we can study lowland and upland peat in range of states from degraded to good within some larger case study sites. We judged sites on their performance to factors above, although transferability, data availability and buy-in from stakeholders were deemed more important factors in the judging. The chosen case study sites are large and within each of them they provide peat in a range of degradation states from totally eroded and bare to excellent and with a range of management conditions but with good levels of data availability for a number of parameters. The basic characteristics are given in Table 2.1 and Figs 2.2-4.

Table 2.1: Basic details on study sites

Study Site	Peatland classification	Area (km^2)	Peatland degradation and restoration issues
Migneint	Upland blanket bog	198.5	Peatland of relatively good condition despite some areas of gripping and erosion. Recent uncontrolled burns. Remote with low recreational pressure in comparison to the Peak District.
Peak District	Upland blanket bog	453.2	History of degradation through overgrazing, heather burning, wildfire, atmospheric deposition, erosion and drainage. Restoration attempts by re-vegetating, drain blocking and footpath improvement. 16 million people within 1 hour drive increase recreational pressure on the landscape.
Thorne and Hatfield Moors	Lowland raised bog	33.4	History of drainage to improve agricultural productivity. History of peat cutting for fuel and horticulture. Re-wetting since the acquisition of the site by English Nature in the 1970s. Restoration intensified since 2002.
Somerset Levels	Fen	63.9	History of drainage to improve agricultural productivity. Restoration projects include raising the water table in drained pasture, and reed planting in a former peat-extraction site to provide habitat for rare birds and improve water quality.

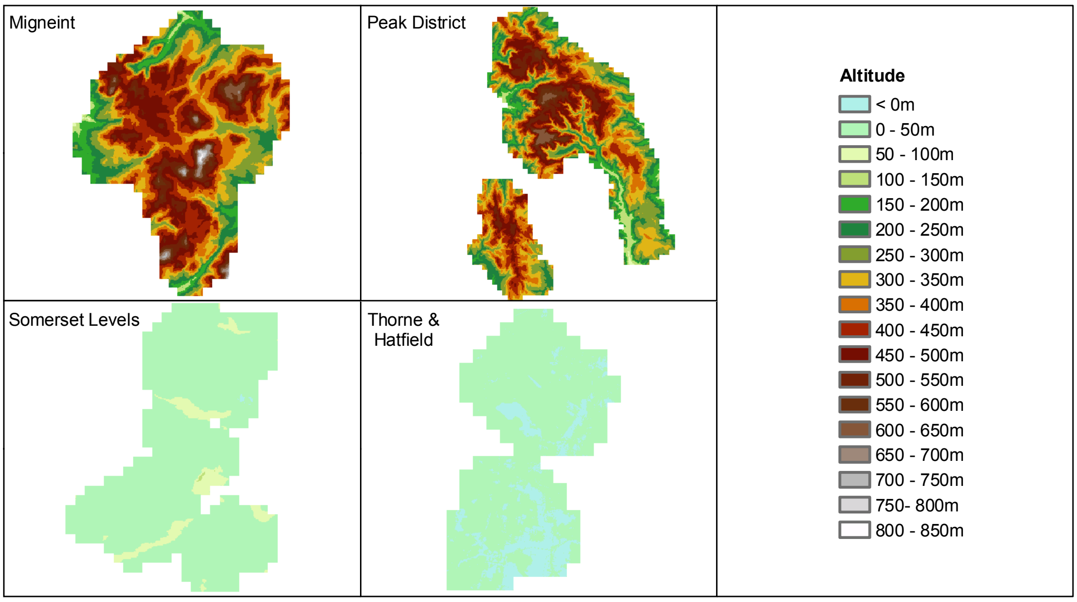


Figure 2.2: Topography of study sites

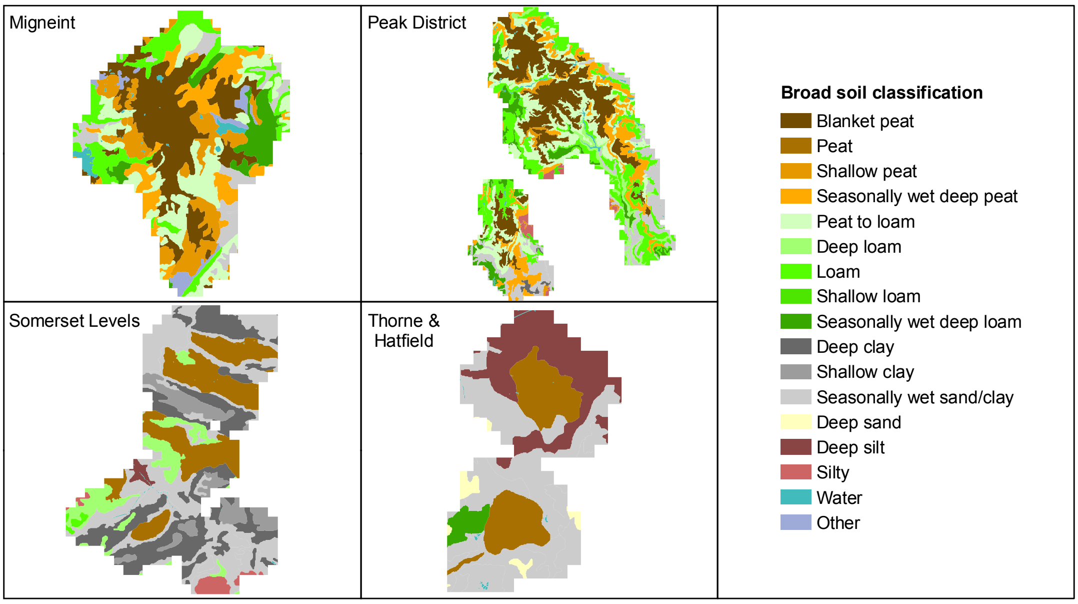


Figure 2.3: Distribution of peat soils in study areas (adapted from NSRI Soil Series NatMap vector data set)

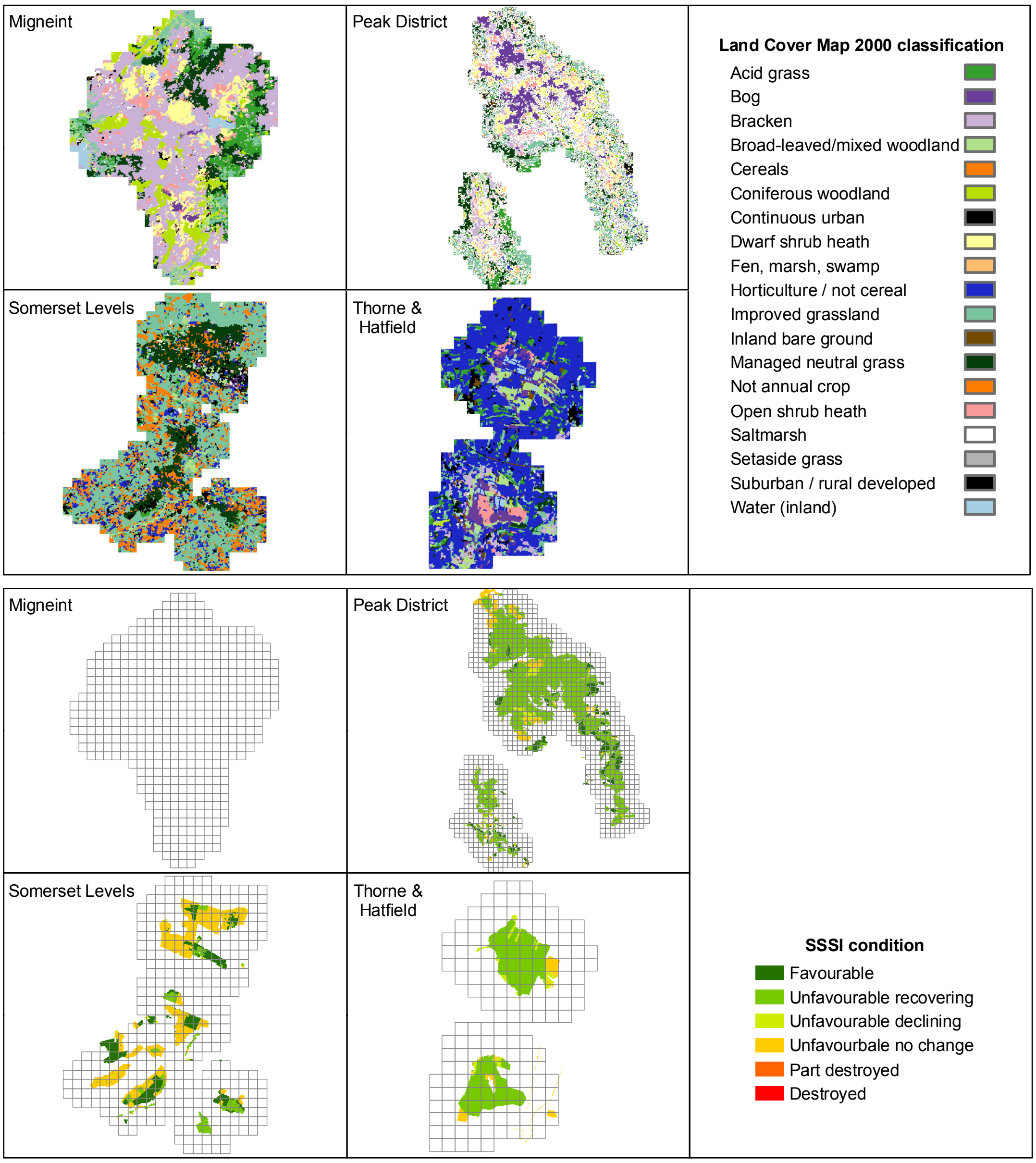


Figure 2.4 a,b: a) Broad habitat distribution within case study areas (Land Cover Map 2000) and b) SSSI condition as assessed through Common Standards Monitoring (CSM, Natural England 2009 data)

2.1 Migneint
The Migneint SAC, in Snowdonia, is one of the largest blanket bogs in Wales. The site is in is relatively good condition, but with extensive areas of gripping, some localised erosion and a recent uncontrolled burn. Much of the Migneint is utilised for low-density summer sheep grazing. Two water supply reservoirs are located within the SAC, while substantial additional runoff enters major downstream reservoirs at Llyn Celyn (used for flood regulation, flow transfer for water supply in the lower Dee valley, and hydropower) and Llyn Trawsfydd (also used for hydropower). The River Conwy, which has its source on the Migneint, has experienced significant flooding problems, with £5M spent on flood protection measures in recent years following damaging floods in 2004 and 2005. There is no management burning within the SAC, and habitat condition is generally good, supporting a range of rare plant, animal and bird species. A small part of the area is under conifer plantation, but recently part of this has been cleared and restored to moorland as part of an EU-LIFE project led by the RSPB. The northern part of the Migneint is owned by the National Trust, who are undertaking ongoing grip-blocking. This area also includes the Centre for Ecology and Hydrology (CEH) Upper Conwy peatland 'Carbon Catchment' monitoring site, with intensive land-atmosphere and riverine C flux measurements, peat mapping, hydrological monitoring, and experimental studies of the effects of acidity and water table changes on fluvial and gaseous carbon fluxes.

2.2 Peak District
The Peak District moorlands are important for their biodiversity and landscape value and receive national and international designation as National Park, SSSIs, SPA and SAC. The Peak District includes highly degraded deep blanket peat where there are decades of data on erosion, vegetation cover and hydrology. As one the most popular National Parks, the Peak District receives over 10M day visit per year and therefore provides a quite different example to that of the Welsh site. Following a historic legacy of atmospheric pollution, inappropriate land management through overgrazing, intensive burning and wild fires, large parts of the Peak District moorlands are degraded and in 2000 over 9km^2 were assessed as bare peat devoid of any vegetation. There have now been concerted efforts by the Moors for the Future partnership to restore and manage the peatland and a major surge of scientific interest has ensued. This includes carbon flux modelling and measurements, detailed vegetation and water quality monitoring, leisure activity monitoring within the National Park and there are major interests from United Utilities, Yorkshire Water and many other major partners. CEH has set up a comprehensive climate change experiment (GANE) on Bleaklow adjacent to the River Etherow Acid Waters Monitoring Network site. The Peak District peatlands are also a major case study site for two RELU projects examining socio-economic processes and functions and so this project could take advantage of earlier and ongoing work at the site providing data for our scoping study. Through the Moors for the Future Partnership and successful collaborations with universities and research institutes a comprehensive baseline database has been established. Furthermore, Moors for the Future and the wider MFF stakeholder partnership harnesses first hand experience in practical peatland management and restoration.

2.3 Thorne and Hatfield Moors
These are the largest remaining lowland raised bogs in Britain. Large areas of peat have been lost through drainage in order to improve it for agricultural use and peat cutting has been carried out at the site, primarily for fuel, since the medieval times. In the 1880s small companies started commercial peat extraction by hand, and this continued until the 1960s when production of peat for horticultural purposes was mechanised. The removal of peat resulted in a major network of drainage ditches. In 1970 the moor was acquired by English Nature as a Site of Special Scientific Interest (SSSI) and it started 'rewetting' work, designed to restore the wetland to its original condition. Re-wetting involved damming some of the drainage ditches and the formation of water-retaining compartments. As part of the restoration work peat-forming bog species, including Sphagnum mosses and cotton grasses, have been actively encouraged. In 2004, large-scale peat extraction ceased and 1900 ha of the SSSI are home to rare plants, invertebrates and birds (such as nightjars, a ground nesting bird which needs open habitats to breed upon). Thorne Moor is also a Special Protection Area (SPA) under the European Birds Directive, Special Area of Conservation (SAC) under the European Habitats Directive and a Wetland of International Importance under the terms of the Ramsar Convention. The site has an excellent record of data (climate, water table elevation data going back 15 years, vegetation and vegetation change in response to management, invertebrate and bird surveys, visitor numbers, power station deposition etc) and ongoing restoration work, with the University of Leeds currently carrying out research at the site. Natural England were very happy for us to use the site as a case study and very helpfully supplied their data and staff time for this purpose for which we are grateful.

2.4 Somerset Levels and Moors
The Somerset Levels and Moors are one of the most important UK wetland conservation areas (Taylor, 1999). The CEH Wetland Research Facility comprises two sites (Tadham Moor and Ham Wall) located on fen peats within a SSSI, with research dating back to 1986, and ongoing hydrological, carbon and ecological

monitoring. Restoration projects include raising the water table in drained pasture, and reed planting in a former peat-extraction site to provide habitat for rare birds and improve water quality.The topography is generally flat with some slightly raised areas, called "burtles”. The Moors lie between sea level and 6 m below. They were inundated first when sea level rose after the last ice age (around 10,000 years BP) depositing peat on top of marine clay (Campbell *et al*., 1998). The peak of the peat formation took place in swamp conditions around 6,000 years BP. Land use is dominated by grazing pastures separated by ditches, lined by willow trees. The Levels are sand and clay bar about 6 m above mean sea level, separating the Moors from the coast. The area is prone to winter floods of fresh water and occasional salt water inundations. The area is drained by two main river systems; the River Brue and River Parrett basins. Large artificial channels, such as the River Huntspill and King's Sedgemoor Drain have been constructed to augment drainage. Some 35,000 ha of the Somerset Levels and Moors have been designated as a Ramsar site under the International Convention on Wetlands, particularly for the large populations of wintering and breeding water birds that it supports. The area is a candidate for a World Heritage Site for its cultural heritage and landscape features.

It should be noted that with the funding and timescale available for this scoping study we have been able to apply more detailed modelling work on Migneint, Peak District and Thorne and Hatfield, than we have been able to do for the Somerset Levels. Therefore, much of the ecosystem service provision discussion for the Somerset Levels is descriptive based on existing data. Nevertheless, we have still been able to produce highly appropriate and useful maps for all sites for many of the services.

3 Participatory stakeholder involvement: Workshops & participatory GIS, data collation and creation of UK Peat Geonetwork database

Section 3 deals with the overall methodological approach to the project with information about data provision and the new data management system produced by this project. The individual methodologies adopted or tested for each ecosystem service are described in the relevant subsections of Section 4.

3.1 Participatory stakeholder involvement

Ecosystem services are a matter of societal choice. Therefore, to engage in a transdisciplinary approach to the project, we organised three start-up meetings with key stakeholders and their GIS officers, at the three main case study sites (Thorne & Hatfield - 13 March 09, Peak District - 19 March 09, Migneint - 23 March 09). This facilitated the incorporation of best local expertise and engendered a sense of ownership and commitment throughout the study. The meetings were followed by requests for compilation of key datasets. A good partnership approach also facilitated informed participation, at the stakeholder start-up meetings, throughout the project and at the project conference, and fed into Objectives 5-9. Many users appreciated the direct benefits of this project for their own area and wider peatland research issues and were helpful in providing data, feedback and contact links.

The final project conference was held on 15-16 Oct 2009 to explore the relevance and transferability of the project results with case study stakeholders and national experts, and to develop priorities for a phase II programme. The conference was seen as the best way to facilitate knowledge exchange between users and the science community. Appendix 1 provides a list of workshop and conference participants.

3.2 Desk based review, collation and evaluation of available data

The aim of the study was to produce a spatially explicit framework for quantifying the ecosystem service provision of peatlands in England and Wales. As such the project focused on four key case study areas where one of the driving factors for site selection was data availability (see above). There is a wide range of potential UK data sources for mapping ecosystem services (Appendix 2). The project team collected relevant data where possible at a national scale (England and Wales) as well as site specific data for the case study sites.

The four areas represent upland and lowland regions as well as semi-natural and eroded peatlands and therefore provided an insight into the different methodological approaches required to assess ecosystem services. As the total study area under investigation is relatively large, this consequently reduces the specificity of any models because the analyses are still occurring at a landscape scale.

A landscape scale approach was chosen due to the scale of the project, and ecosystem service provision of peatlands was mapped at a $1km^2$ grid cell resolution. A 1km grid cell was deemed a scientifically meaningful unit of measure because any intervention to improve/increase service provision will occur at a landscape scale. This was also deemed to be the appropriate unit by the Defra Peat Partnership at our project start-up meeting. In addition, UK environmental data are usually produced at a 1km resolution; other assessments of service provision have been analysed at a 1km scale (Eigenbrod et al, 2009) or $4km^2$ (Anderson et al, 2009) and it allows all services to be compared at the same scale. It should be noted, however, that although the study compared ecosystem service provision at a $1km^2$ scale in a complementary way, the majority of the modelling occurred at a higher resolution and was re-gridded for the analysis stage. Therefore, many of the individual approaches could be adopted for higher resolution applications if required, but the overall assessment has been carried out at $1km^2$ resolution.

For data collation and selection, the following criteria were applied:

- **National data sets**: datasets which were available at a national level. This was to ensure mapping could be easily extended over sites across England and Wales if required for phase II, without the need for additional data collection.
- **Availability & compatibility**: The remit was to produce an assessment of ecosystem service provision based on the best available data that covered the four sites, as the project had no scope for collection of new data. For some case study areas higher resolution data were available, but the national datasets were sometimes used in this scoping study so as to assess transferability for phase II.
- **Format & resolution**: Data format needed to be suitable for inclusion into GIS for spatial mapping and modelling of variables and parameters. Polygon data were converted to 1km grid resolution.
- **Accuracy**: All data, where applicable, were checked for their spatial accuracy with spot checks using high resolution aerial photographs in areas known to the team. This resulted in a few cases in choice of alternative datasets.

- **Licencing**: As with every major data collation, data access agreements took a majority of the project time. Most Defra datasets became available in April/May 2009 and some datasets could only be accessed in September 2009. Some data were not available due to anti-terrorist legislation (e.g. the water yield and distribution of water from reservoirs).
- **Commercial sensitivity**: Some data were deemed commercially sensitive and could not be released. These included corporate business monitoring and research data and data on costings.

All datasets, custodian organisations, points of contact and the spatial coverage of data are described in Appendix 2 and in more detail on the ukpeatgeonetwork, including some of those that were not used in the study but which may prove useful for future studies. In total, the study involved 110 geographic datasets from 27 organisations and details of the data are also available at www.ukpeatgeonetwork.org.uk (detailed metadata associated with each data source).

3.3 Creation of web-based meta-database www.ukpeatgeonetwork.org.uk

As available data and their copyright was spread across organisations, a transparent and high quality database management approach was pivotal. The study used data from an array of different sources, which were made available at differing resolutions, accuracy and format (Appendix 2). Therefore, one of the key objectives of Phase I of the assessment of the ecosystem service benefits of peat was to produce a database that could be employed in Phase II. This was organised in a GIS and is available to Defra on a mobile disk. Access agreements were negotiated for the Phase I study only.

A second aim was to provide a web-based data portal, the UK Peat Geonetwork, that researchers and practitioners in peatland research within the UK can use to share and communicate information about research data. The database was constructed around the geonetwork software (http://geonetwork-opensource.org/). This tool, developed by FAO and WHO, complies with EU INSPIRE Directive regulations for metadata and forms a fundamental tool for sharing and visualising information on data and their availability between the project team, stakeholders and Defra, while maintaining strict copyright and data ownership. As such it provides a standardised tool for the management of spatial information and related sources defined in the OGC (Open Geospatial Consortium) reference architecture. As the portal complies with the EU INSPIRE metadata scheme for cataloguing data it therefore future proofs the database for subsequent phases of the project (see Appendix 2 for description of fields recorded).

The UK Peat Geonetwork database is hosted on a dedicated remote server at www.ukpeatgeonetwork.org.uk , which is accessible through a user interface controlled via an administrator. At present the Moors for the Future Partnership are coordinating the administration and controlling user access. Under full user access, contributors are able to create new entries, update entries, view all maps and download data they are licensed to use as part of this project. To maintain data privacy and copyright, one of the key factors of the database is that data under license is not available to unlicensed parties and can only be obtained by contacting the custodian directly. However, unlicensed parties are still able to access detailed descriptions of data sources and obtain information on data coverage, owner/custodian, spatial resolution, license restrictions and contact details. Additional help files for users are available on the website. By providing different access accounts, the UK Peat Geonetwork provides capacity for updates and expansion by users. This web-based database forms an excellent basis for the Phase II project and provides a visualisation tool for data and projects.

A research note has been produced to communicate the aims of this tool to the peatland community and is available in print and as digital copy for download from www.moorsforthefuture.org.uk and www.peatlands.org.uk (see Appendix 3a). Appendix 3b provides a break down of follow-on maintenance costs for continuation of the UK Peat Geonetwork. While this is a user managed website, some GIS administration is desirable for the first period to establish and maintain this as high quality web portal for peatland research.

4. Ecosystem Services

Using a GIS mapping approach, the project mapped and quantified the spatially explicit distribution of ecosystem services focussing in-depth on key services, as listed in the Defra tender specifications, such as protecting carbon stores, reducing flood risks, protecting water quality, recreation opportunities and biodiversity and others as listed below. Where possible we derived maps for each case study site. Work on the Somerset Levels was more light touch as this case study was included to raise issues about a wider set of peatland types.

Each section below reviews the available evidence on the provision and quantification of peatland ecosystem services, identifies metrics and methodologies for ecosystem service measurement as well as drivers of change affecting the sustainable delivery of ecosystem services. We test and develop techniques to map and quantify the flows of ecosystem services, outline the modelling approach, including available data, model assumptions and limitations. In order to inform the valuation of ecosystem services, a scenario-based approach was taken, to assess the cost and benefits of marginal change. In collaboration with Defra and Natural England the scenarios in Table 4.1 were agreed. More detail on the scenario approach is provided in Section 5 below.

As advised by Defra, these scenarios are based on management actions for peatland restoration and management. They are therefore not fully developed scenarios with inclusion of socio-economic, political and cultural aspects. The term ‘Conservation led Rewilding’ was discussed and adopted due to lack of a better alternative, as the implied management actions of removing all grazing and burning do not necessarily reflect optimal management for conservation (see discussion 4.6), nor is the active restoration through revegetation and drain blocking coherent with the strict sense of rewilding. Also – as for all scenarios – management for recreation, e.g. through footpath management, ranger service etc, is not excluded. Overall, these management scenarios were chosen to portray a wide range of possible management actions and assess their potential effect on ecosystem service provision. In reality, a mix of actions will probably be more realistic.

Table 4.1: Scenarios employed to assess change in ecosystem service provision for different peatland restoration and management options.

Scenarios	Peak District / Migneint	Thorne & Hatfield / Somerset Levels and Moors
Business as usual (BAU)	baseline today	baseline today
Restoration (water table)	gully/grip blocking	raise/ keep water table
Restoration (vegetation)	bare peat re-vegetation / forest clearance (Migneint only)	scrub clearance
Conservation-led rewilding	no sheep, no burning + restoration (water table & re-vegetation)	extend current restoration mgmt over whole site, otherwise use baseline today
Food security	increase grazing across site	increase grazing across site
Arable	not deemed applicable due to poor soils	cultivation (assume bare peat across area)
Economy (grouse economy for uplands, peat extraction for lowlands)	increase burning, apply for all areas with heather cover	historic scenario of peat extraction and low water tables, bare peat
Maximise Carbon	This approach maximises for a given ES and then evaluates the suggested changes in land mgmt on analysis, e.g. no burning, revegetation and manipulation of water table through grip blocking/ pumping.	

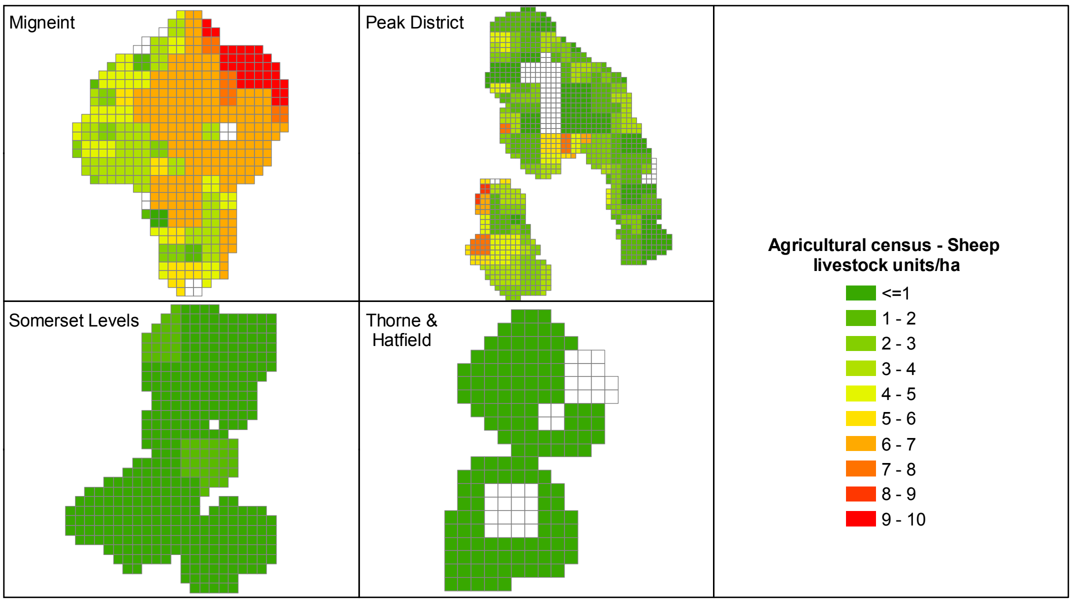
4.1 Provisioning services
4.1.1 Provision of land management products

4.1.1.1 Food provision – Livestock

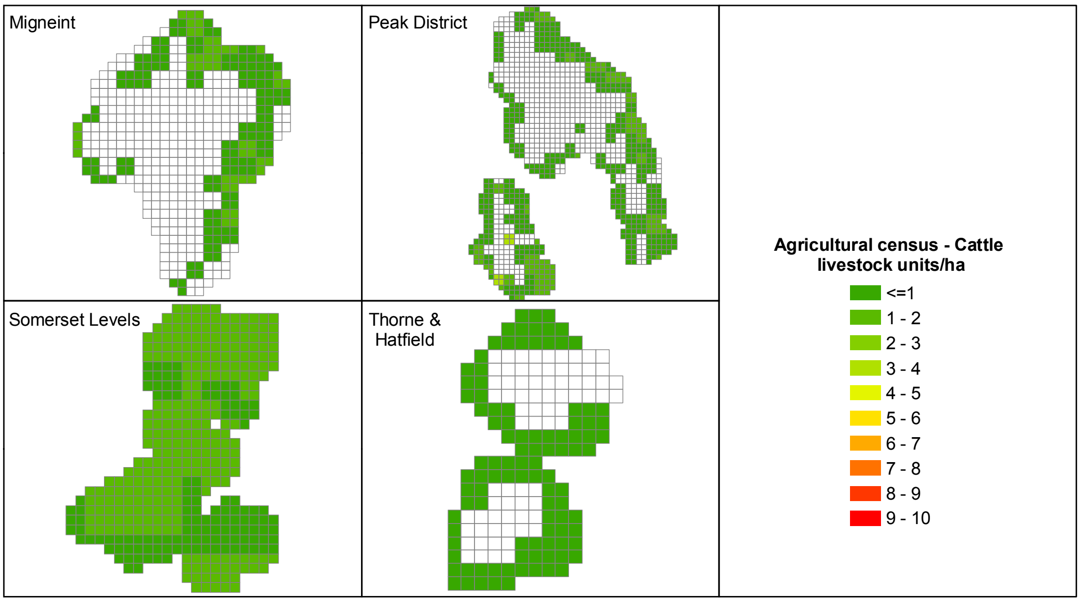
Peatlands naturally have a low agricultural productivity due to soil properties, water logging, and – especially in the uplands - access, topography and climatic conditions. Upland peatlands are therefore generally classed as very poor quality agricultural land, i.e. land with very severe limitations which restrict use to permanent pasture or rough grazing (Agricultural Land Classification, MAFF 1988, Figure 4.1). Unimproved lowland peatlands also have a poor agricultural land classification value, however, drainage, warping and lime and fertiliser treatment can increase their productivity to highly productive agricultural soils such as those around both Thorne and Hatfield Moors and Somerset Levels (Figure 4.1). This opportunity for food production poses different external pressures on land conversion on upland and lowland peatlands, and therefore only few lowland peatlands in England and Wales have remained in semi-natural conditions. Apart from cultivated lowland peatlands used for crops (4.1.1.2), peatlands have been used for grazing by livestock with mainly sheep in the uplands and dairy and beef cattle in the lowlands (Fig 4.2), a management which has shaped the distinct habitats and landscapes of today.

In most English and Welsh uplands, decades of subsidies led to steady intensification of farming with grants available for improvement of land and infrastructure, and subsidies or guaranteed payments for livestock (1946 Hill Farm Act, 1947 Agricultural Act, 1972 EEC livestock headage payments, 1975 EC Directive with introduction of Less Favoured Area Scheme (LFA) and UK Hill Livestock Compensatory Allowance scheme (HLCA) for summary see Condliffe 2009). This led to large-scale drainage schemes in the uplands and increases in stocking densities of up to 400% (Condliffe 2009), and overgrazing, along with other factors, resulted in extensive areas of severely degraded upland peatlands. In 1987-1991, the first agri-environment schemes were launched with the Environmentally Sensitive Area (ESA) scheme, which rewards farmers for caring for the environmental, historical and cultural features on their land, while reducing stocking numbers The ESA scheme covers a large proportion of English upland peatlands, and the Tir Goffall scheme covers large parts of Welsh uplands (see extent of scheme uptake in study areas in Fig 4.3). Today, stocking densities in the Peak District peatlands are much reduced, while the Migneint has still higher stocking densities (Fig 4.2, 4.4). This may be attributed to the level of degradation of Peak District moorlands and therefore encouragement to take part in ESA schemes, socio-economic or cultural preferences by farmers, which may also be determined by alternative income sources, as opportunities for additional incomes for farming families through farm diversification (e.g. tourism) or jobs in surrounding conurbations may be more prevalent in the Peak District due to its geographical location.

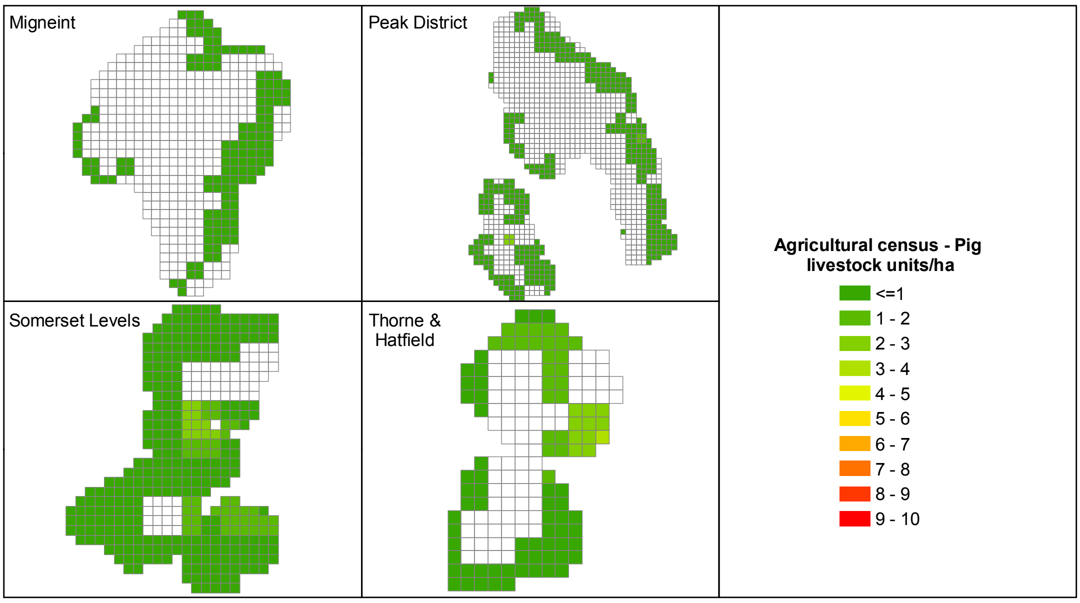
Figure 4.1: Agricultural land classification (derived from Defra (2002) & WAG (1992) provisional land classification, see MAFF 1988)



a) sheep



b) cattle



c) pigs

Figure 4.2a-c (previous page): AgCensus data - total a) sheep, b) cattle and c) pig numbers per hectare across each ward, derived from AgCensus data (Defra 2004, Welsh Assembly Government 2006). The grid square agricultural census data, as converted by Edinburgh University Data Library, are derived from data obtained for recognised geographies from the Department of Environment, Food and Rural Affairs (DEFRA), The Welsh Assembly Government, and The Scottish Government (formerly SEERAD), and are covered by Crown Copyright.

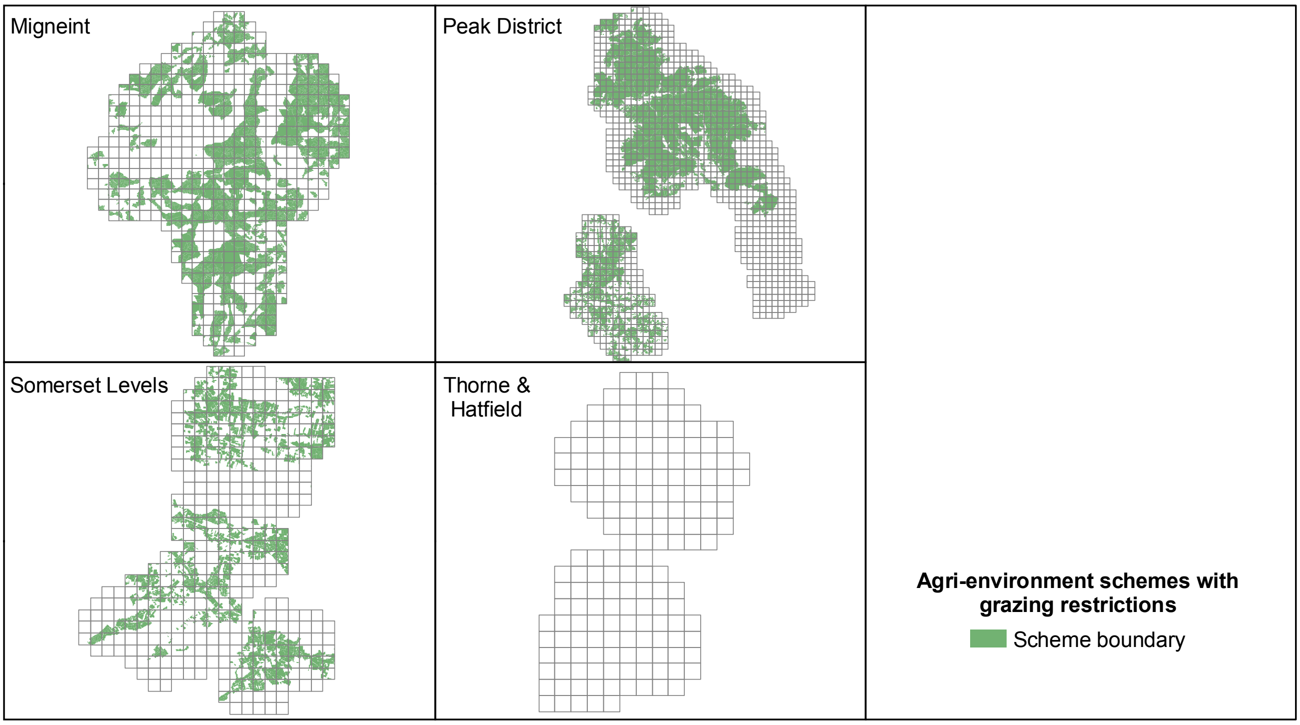


Figure 4.3: Agri-environment agreements cover much of the upland areas and part of the lowland areas (mainly ESA in England, Tyr-Gofal in Wales).

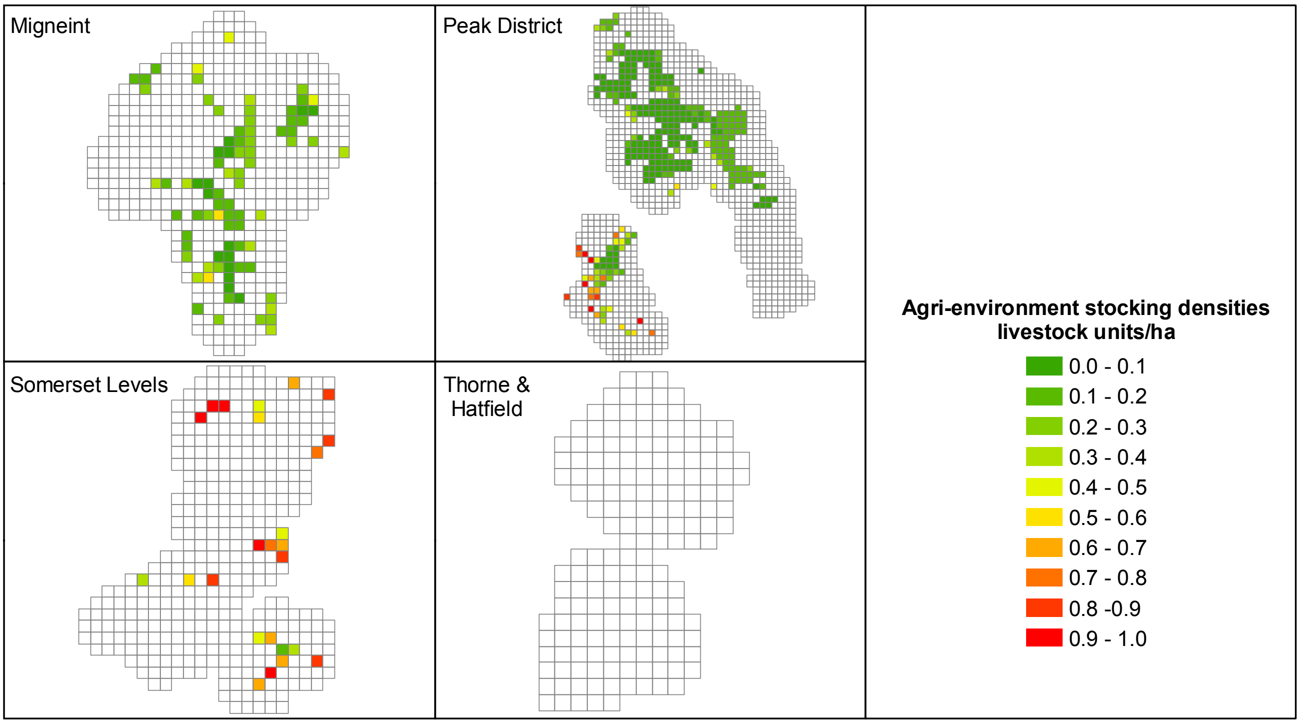


Figure 4.4: Livestock units per hectare in case study areas derived from ESA and Tyr-Gofal agreements (data supplied in May 2009 by Defra and WAG).

For mapping food production and distribution of livestock units, the Defra AgCensus data is the most commonly used national data set available. However, AgCensus data are recorded at ward level and each farm is linked to a ward by its postcode. Therefore, variation in sheep numbers across a ward are not depicted. Subsequently, some grid cell areas in the case study sites show exaggerated grazing densities on the map, which are not realised on the ground. In contrast, ESA data, are more closely linked to the individual landholdings with details on maximum grazing densities for agreement areas (see comparison of Fig 4.2 and 4.4). While ESA data also do not accurately determine the exact location of grazing animals, which may be important for interaction with other ecosystem services and biodiversity, this dataset is much more accurate. While ESA data are only available for parts of the areas, they should be used whenever possible for ecosystem service assessments, or, when available, data on subsequent agri-environment schemes such as HLS.

Many upland peatland grazing situations today would not be economically viable without support (Acs et al 2009, Condliffe 2009, Gardner et al 2009). Therefore, payments to undertake environmental stewardship management are highly attractive and taken up by land managers, as seen in the high coverage of Environmental Sensitive Area (ESA) payments scheme in uplands (Figure 4.3).
The introduction of agri-environment schemes and the recent decoupling of subsidies from production has already led to reduced stocking rates (Condliffe 2009). Gardner et al (2009) examined with field experiments and modelling the effects of different grazing regimes on vegetation and farm economics, while Acs et al (2009) used hillfarm data from the Peak District to model the impact of policy changes on farm production. Acs et al (2009) predict a further reduction in livestock and a change to mix in livestock management. Alternatively, the food security scenario in this project assumes intensification of grazing. This change in farming practice may lead to changes in ecosystem service provision. Shifts in grazing intensity to other vegetation types may alter for example hydrological run-off potential and water quality, while appropriate grazing regimes can also deliver conservation goals (see below).
Ultimately, farming is driven by policy, subsidies and (local and global) markets. However, farming does not only provide provisional services through food production, but also cultural services through contribution to e.g. landscape character, sense of place and habitats for some wildlife. This provides important social and economic assets for local communities as well as for visitors and the tourism industry, which may not be captured through markets (LUPG 2009). Overall, this situation may offer opportunities for the development payments for ecosystem services (PES) and other incentives to secure multifunctional and sustainable land use in the future with the CAP reform.

For lowland peatlandsfood provision services tend to be more diverse and complex than for upland sites. This is particularly the case for drained sites. The primary means of food production on the Somerset Levels and Moors is the grazing of dairy and beef cattle. Until the 19th century, the Somerset Levels and Moors were used principally for summer grazing, due to extensive winter flooding. Indeed, the name Somerset (derived from old English *Sumorsaete*) means *land of the summer people*. The milk from the cattle has been used for cheese making at Cheddar since at least 1086 when it was listed in the Doomsday Book. The cheese was originally matured in the caves in Cheddar Gorge and has always been a valuable product. At that time, Cheddar cheese had to be made within 30 miles (48 km) of Wells Cathedral, but is now a global brand.

To intensify agriculture during the 20th century, and particularly after World War II, large pumping stations, such as Gold Corner, were built on the Somerset Levels and Moors to lower water levels and allow access to machinery throughout the year (Williams, 1970). This desiccation of the wetlands changed their ecological character. During the 1980s, the Environmentally Sensitive Areas scheme (ESA) was introduced to provide incentives to encourage agricultural practices that would safeguard and enhance areas of particularly high landscape, wildlife or historic value. Under ESA, land owners were encouraged to raise water levels to restore the natural wetland vegetation for which they could receive annual subsidies of up to £700 per hectare. A replicated block experiment was set up in 1994 at Tadham Moor to test the impact of raised water levels on biodiversity and agriculture, thus affecting a comparison of ecosystem services between wet and drier peatlands. In the experiment, water levels were raised in three blocks of fields and compared with unaltered dry control blocks. A programme of hydrological monitoring underpinned the ecological, agricultural and soil studies. Reductions in both hay yield (*ca* 10%) and live-weight production from the hay re-growth (>40%) were found under raised water levels. However, the raised water level conditions appeared to provide greater predictability in hay production compared with non-raised meadows. Previously fertilised grass-dominant plots showed both a greater negative response to raised water levels when they were first established, and then greater variation between years than unfertilised meadows (Tallowin, 1997; Mountford and Cooke, 2003).

4.1.1.2 Food provision – Arable crops

Arable cultivation is mainly a lowland peatland land use, as the soils can be easily converted / ‘improved’ through liming, fertilising and warping into highly productive agricultural land. Both Thorne and Hatfield Moors as well as the Somerset Levels are fringed with a belt of fen peat which is richer in nutrients than the raised peatland (Figure 4.1). Around Thorne Moors, the area of fen peat has been enlarged by reclamation of the raised peatland by warping. Warping involves the laying of mineral soil on top of the peat either by digging topsoil from one area and carrying and tipping it onto the peat surface (dry warping) or by controlled flooding from the nearby silt laden tidal rivers (wet warping). In wet warping the tide is allowed in, the sluice gate at the mouth of the warping drain is closed and the silt settles out leaving a thin layer (1-3 mm). Opening the sluice gate at low tide allows the water to leave the area leaving the alluvium. This process is repeated daily over a period of months until up to 30 cm of silt have been laid down. The resulting agricultural land is then sown with a mix of grass and clover and grazed for a few years, to allow the salt to wash out, after which the land is used for arable crops (Eversham, 1991).

Around Thorne, large scale warping took part in the late eighteenth and early nineteenth centuries and by 1845 nearly 4000 acres of land had been warped (Gaunt, 1987). This land was wet warped due to the low elevation of the land which is at or just below the high-tide level of the surrounding rivers. In addition, much of the peat had been cutover prior to warping, making flooding easier. It is estimated that about 50% of the original area of Thorne Moors peat had disappeared by 1800 due to warping (Gaunt, 1987), much of which is now highly productive arable land (Class 1, 2 or 3 – see Figure 4.1) and today this land produces the following high profit crops; wheat (~£6000 per ha), peas, potatoes, sugar beet and oilseed rape. Warping was still occurring in the area until the 1960s and because the drainage network still exists, warping could occur today. In fact, warping and agricultural use was discussed as an option for ‘reclamation’ of the site once all the peat had been removed by Fisons. In contrast, expansion of the peatland area is difficult because of the presence of the warp soils surrounding the Moors.

4.1.1.3 Timber provision

In the past, the uplands were targeted for significant expansion of woodland production, starting with the creation of the Forestry Commission in 1919, to create strategic reserve of timber as a matter of national security (Condliffe 2009). Alongside drainage for agricultural purposes, large scale afforestation schemes in peatlands were launched, predominantly with conifer plantations. Over the past years forestry has become economically unviable or ecologically undesirable, and some plantations are being felled for conservation purposes or converted to broad leaved woodland. A change in market and policy with new demands for timber, wood fuel, carbon capture goals and potentially flood risk attenuation may see a change in peatland forestry again (see Scottish Government afforestation goals). However, planting on deep peat is being discouraged due to negative effects on soil properties, long term GHG flux (there may be short term gains) and biodiversity goals (see below and section 6.6).

For mapping the provision of timber in the case studies, the accuracy of the Ordnance Survey (OS) Mastermap topography “Natural Environment” layer and the Forestry Commission National Inventory of Woodland and Trees (NIWT) was assessed by systematically comparing the woodland compartments in each dataset with NEXTMAP aerial imagery collected during 2005. The analysis showed that the Natural Environment layer was more representative of the real situation. The assessment of timber was therefore based on any planting that has been classified as woodland in the OS Mastermap. The woodland data was extracted from the “Natural Environment” layer by selecting all of the polygons that referred directly to woodland (the data selected are shown in Figure 4.5 below). Since polygons could have up to five combinations, only polygons that had woodland as one of the two highest classifications were used in the analysis (the order of the classification in the topography layer referred to its relative significance in describing that polygon). The OS topography classifications included a) Coniferous Trees, b) Coniferous Trees (Scattered), c) Coppice, d) Non-coniferous Trees, e) Non-coniferous Trees (Scattered), f) Orchard. The extracted woodland classifications were intersected in ArcView 9.3.1 with the 1km grid cells to calculate the present woodland density.

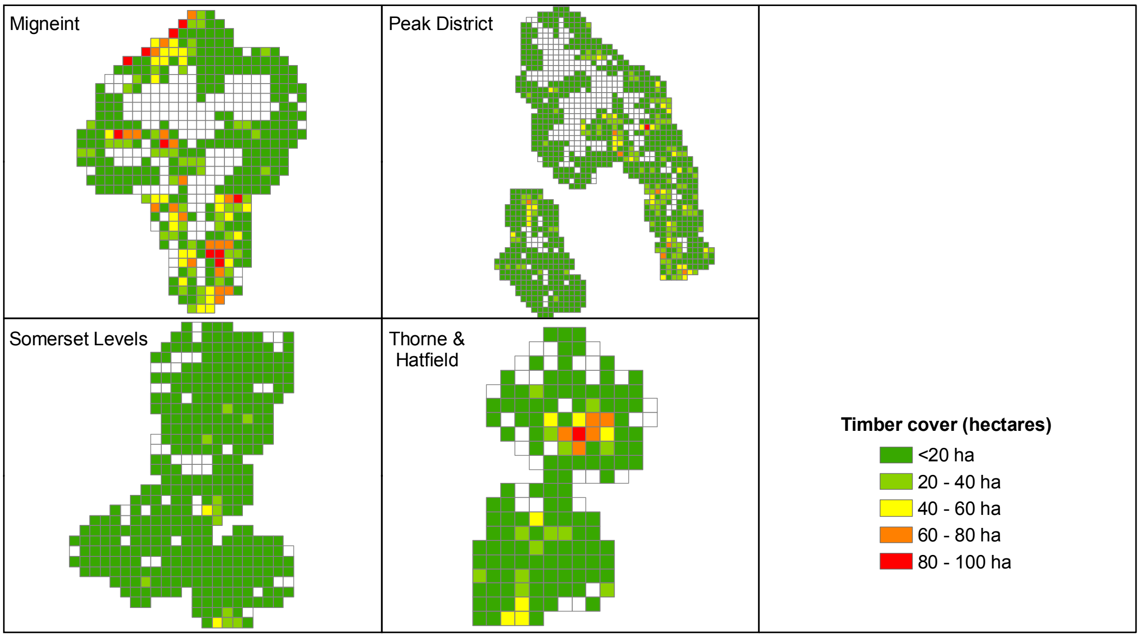


Figure 4.5 Woodland and timber distribution in case study areas (derived from the Natural Environment layer of the Ordnance Survey Master Map 2009, see text)

<u>Potential for woodland creation and clough woodland afforestation, exemplified for the Peak District</u>
To produce a predictive map of potentially viable landscapes for afforestation a layer of potentially sustainable woodlands was created by combining information on soil characteristics, slope and altitude by (Figure 4.6, taken with permission from Winn 2008). Most sites are on slopes and organo-mineral soils adjacent to peat soils. This mapping approach takes into consideration aspects of conservation of peat, wildlife and landscape aesthetics as well as viability of planting schemes. The feasibility to expand upland oakwood woodland are explored in detail and explicit GIS maps are provided by Winn (2008).
In general, this is in line with the Natural England 2060 Upland Vision, that envisages woodland and scrub developing on bracken covered slopes, preventing soil erosion, filtering water, storing carbon and providing wildlife habitat (Natural England 2009a). The Peak District Local Biodiversity Action Plan and the Peak District Landscape Strategy (PDNPA 2009) envisage 25% increase of native woodlands in the Peak District, mainly in cloughs and on slopes, but not deep peat, including management and conversion of conifer plantations.

There are of course issues with planting trees on both deep and shallow peat for carbon sequestration and water quality (Holden et al., 2007). It is well known that coniferous plantations on peat have resulted in river water acidification. It is not known how large scale planting of deciduous trees on shallow peats will impact the local hydrology and biogeochemical cycles. Furthermore, the drainage of peat required for some tree planting (or caused by enhanced evapotranspiration from the trees themselves) is likely to lead to a long term loss of carbon from the soil store that is greater than the amount taken up into the tree biomass store. This is because peats are very sensitive to slight modification in the water balance and can easily switch from carbon sinks to carbon sources (Baird et al., 2009). Therefore, areas for tree planting have to be carefully selected to avoid such a major conflicts in service provision.

<u>Tree and scrub removal from peatlands</u>
The peat restoration compendium () produced for Defra showed that tree and scrub removal was common in lowland peatlands. However, often the materials were left on site and used to create boardwalks or other on-site features and it was rare for tree and scrub removal from lowland peatland to lead to timber products that were being taken of-site and hence providing a timber service.

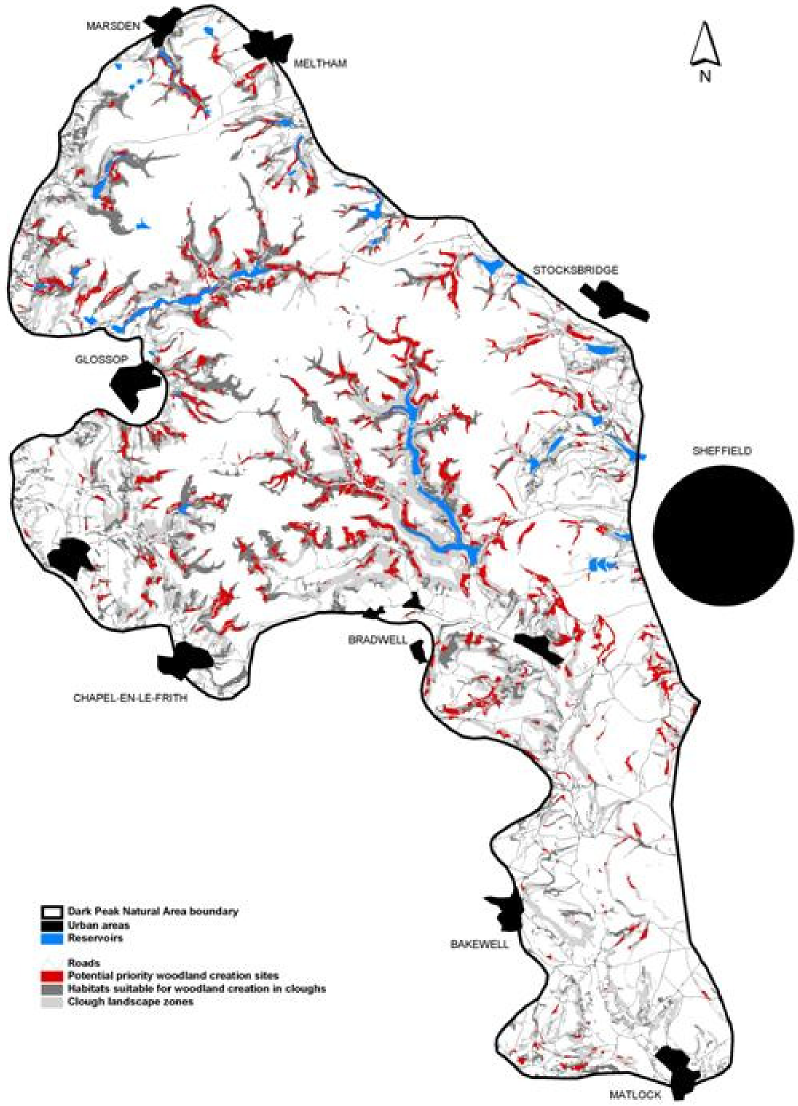


Figure 4.6: Potential for woodland creation sites (red) and clough woodland afforestation in the Peak District (with permission from Winn 2008; red – potential priority woodland creation sites, dark grey - Habitats suitable for woodland creation in cloughs, light grey - clough landscape zones).

4.1.1.4. Fibre - Sheep wool, withies and teasels

Sheep wool is closely associated with sheep meat production in upland peatlands, but has by now become a by-product with little market value. Except some high quality wool products from special breeds, which are however not very hardy for thriving in upland peatland environments, there is currently little demand for sheep wool. This decline in market and demand is due to the wide availability and inexpensive production of synthetic fibres for clothing and carpets, as well as other alternative products such as cotton. However, sheep wool may become more important as insulation material in the future.

Willow from lowland peatlands has been used on the Somerset Levels and Moors as a construction material, particularly for basket making for many centuries (Coles, 1990). Willow is harvested by coppicing, in which tree is cut back to the main trunk. New shoots of willow, called "withies", grow out of the trunk and are cut periodically for use. During the 1930s over 36 km^2 of willow were being grown commercially. Following the replacement of baskets with plastic bags and cardboard boxes, the industry has declined severely since the 1950s. By 2000, only around 1.4 km^2 were grown commercially; the Somerset Levels and Moors is now the only area in the UK where basket willow is grown commercially. The main species for weaving is *Salix triandra* (Almond Willow, *Black Maul*), while *Salix viminalis* (Common Osier) is used for handles and furniture and hurdles. Products including baskets, eel traps, lobster pots and furniture, were widely made from willow throughout the area in the recent past. The willow industry, around Stoke St Gregory, Kingsbury Episcopi and North Curry remains a source of employment, with about 100 people making their living from it (hurdles, artist's charcoal, baskets, furniture, cricket bats, and hot air balloon baskets) though this is a much smaller number than historically. Teasel (*Dipsacus fullonum*) was formerly widely used as a natural comb for cleaning, aligning and raising the nap on textiles. An unusual crop is the growing of teasels around the River Isle near Chard on the heavy clay soils around Fivehead. These are used to provide a fine finish on worsteds and snooker table cloths.

4.1.2 Provision of renewable energy – Wind energy as a case study

Climate change is one of the greatest environmental, social and economic threats facing the planet. Legislation is in place to promote the reduction in the use of fossil fuels through greater energy efficiency and to move towards more renewable sources of energy. As set out in the Climate Change Bill, the UK target is to cut emissions by at least 80% below 1990 levels by 2050. Wales and England have renewable energy targets of 10% by 2010 and 15% by 2020, which could occur particularly through wind energy developments, which could contribute 30% of the UK's energy by 2020 and more beyond (CCC 2008).

This section therefore focuses on wind energy as one example for scoping mapping opportunities, which could be taken forward for other renewables in Phase II.

Other renewable energy schemes are small-scale hydropower generation, in addition to existing large-scale hydropower schemes in the Migneint area. Hydropower schemes, however, are often more feasible further downstream of peatlands in streams with greater and more regular discharge patterns to achieve suitable turbine power, to which peatland run-off contributes (National Energy Foundation & Land Use Consultants 2009, see also forthcoming report by Friends of the Peak District). Other alternatives are bioenergy production with *Miscanthus*, willow coppice and brash harvesting (see section 4.6.1 for wood fuel). The recent Peak District climate change study (National Energy Foundation & Land Use Consultants 2009) concluded that the peatlands, namely the Dark Peak area, are largely unsuitable for energy crops due to physical constraints. Small-scale schemes would only be feasible on shallow slopes (organo-mineral soils) or valleys, but the study assessed that overall - due to landscape sensitivity and predominantly unsuitable ground - , there will be no contribution from energy crops from Peak District peatlands.

Regarding wind energy, development will have to be through large-scale wind farms in order to meet the government targets, because small-scale projects can only provide a limited but valuable contribution (PPS22, ODPM 2004). To date England and Wales have 749MW (107 developments) and 334MW (29 developments) respectively installed, with another 702MW and 216MW consented (BWEA- http://www.bwea.com/ref/tech.html). In order to meet the targets agreed for 2010 and 2020 a far greater number of developments would be required to gain consent and this rapid expansion is likely to influence the peatlands of England and Wales. The UK has the greatest wind resource in Europe and is therefore an ideal for wind exploitation. However many areas with high wind speeds occur on swathes of land that fall under statutory protection, which creates conflict (see discussion below).

England and Wales currently have 107 and 29 onshore developments respectively of which none have been constructed within the boundaries of the four study sites. Information available on present built, approved and refused onshore wind farm developments were obtained from the British Wind Energy Association (BWEA), which is the trade body that represents the UK wind energy industry. The data made available from BWEA was as a centroid for each development and did not include proposed turbine locations. Within the database, which was up-to-date as of August 2009, three sites have been approved with 3 turbines producing 7.5MW on the Eastern edge of the Peak District and 38 turbines producing a total of 114MW the Northwest and West of Thorne Moor.

4.1.2.1. Modelling wind energy potential – physical parameters

We employed a two-stage process in model construction, where the initial model was built around physical and planning constraints (excluding statutory designations) and the second stage added in any statutory designations. The rationale for a two-stage process was not to confine the model by statutory designations at its earliest stage because this would preclude the development of wind renewables sites on all sites under investigation in the study. The two-stage process allows the potential to be calculated and then address aspects of biodiversity, hydrology and recreation separately. Modelling was completed at what was deemed the lowest permissible threshold to recreate the likely resource opportunity as assessed by a wind farm developer.

Turbine specification

The study is looking exclusively at large scale developments because small-scale developments offer limited renewable potential and need to be in close proximity to habitation, which is atypical of the peatland environment in England and Wales. The model focuses on the present average turbine specification of 75m, with an energy potential of between 1.13 and 1.85MW (BWEA- http://www.bwea.com/ref/tech.html). Rotor radius is not modelled as it is assumed that this will not directly impact the peatlands because recreation or biodiversity affects are not directly related to length of rotor but more to tower height. The assumed average spacing for a turbine is set at 326m as derived from the SNH Windfarm Footprint dataset, a GIS datasets describing the location of 3071 separate turbines in Scotland. The Windfarm Footprint dataset was used to calculate the average nearest neighbour for all developments greater than one turbine. The model does not include the installation of overhead/underground cabelling or access tracks even though they may have negative impacts on the local hydrology and recreation through visibility – instead these factors are discussed in the outputs.

Wind resource

The main criteria for the location of a wind turbine is the wind profile and the ability of the turbine to generate electricity. As such we have chosen to only class areas with an average wind speed of $7ms^{-1}$ or greater as areas suitable for development (Peak sub-region climate change report). The wind profile data was obtained from the Department of Business Innovation and Skills Windspeed Database (BERR link), which is available at a 1km resolution, and converted into an ascii grid for use in ESRI ArcView 9.3.1. The Windspeed Database was then reclassed from a floating point raster to a binary score of 1 or 0, where 1 equals greater than or equal to $7ms^{-1}$ and therefore suitable for wind energy generation. Higher resolution wind profile data can be collected but this would require the installation of a meteorological mast or LiDAR wind profiler and this would be site specific. Therefore the BERR data is the most comprehensive dataset covering the four sites.

Physical constraints

Windfarms are large structural installations in the environment and as such they can be both affected by and affect local environmental and physical parameters. As such we have chosen to buffer these constraints to reduce the potential negative interaction between the environment and any windfarm installation. The factors that we have considered and their buffer are outlined below:

- *Residential dwellings:* There is no agreed distance at which turbines must be set away from residential dwellings, but there is a notionary buffer of 2km provided by the Scottish government (as laid out in PAN45), where developments closer than this are still considered. This was deemed too precautionary in this model because we are dealing with a dwellings database based on the Ordnance Survey Mastermap postcode where all buildings with a postcode were mapped and as such any building, no mater how remote, would have to have a 2km buffer applied. Consequently, we have opted for a 500m buffer, which we believe is appropriate for peatland areas where dwellings are sparse.
- *Watercourses:* Rivers and their tributaries have the potential to affect and be affected by windfarm developments and as such we have opted for a 50m buffer around all watercourses. The buffer was chosen in order to reduce; the impact of pollutants, disturbance of biodiversity and the potential for onsite flooding of infrastructure. The watercourse layer was constructed from the Environment Agency Detailed River Network layer (DRN), plus a 50m buffer around all rivers. The modelling exercise did not include the Environment Agency flood maps as an input because flooding is uncommon on upland peatlands and lowland sites are classed as flooded because of the careful water management regimes in place at Thorne & Hatfield and the Somerset Levels.
- *Scheduled ancient monuments:* Peatland areas are of significant importance in relation to archaeological and cultural heritage with 247 of such sites falling within the four case study sites. Any development can affect the aesthetics and the structural integrity of a site and as such need protecting. Archaeological and cultural sites were extracted from the English Heritage and CADW databases of Scheduled Ancient Monuments from English Heritage & Cadw. A buffer of 500m was applied around all designated Scheduled Ancient Monuments.
- *Accessibility and slope:* The construction of a windfarm development is very much dependent on the local infrastructure already in place because heavy machinery is required. As such, the availability of suitably accessible roads is paramount and therefore all roads present within the Ordnance Survey Mastermap layer (classified as a road) were buffered by 1km, where no development could occur outside of that buffer. This was because any development should minimise the potential negative impact on the surrounding environment through road construction. Previous studies have employed a 500m buffer (Peak sub regional committee) but this is no longer realistic as developers are prepared to construct larger access roads, as the development requires. However, access roads constructed on peat systems have an upper gradient threshold, beyond which machinery access is not possible and this has been estimated to be 12.5^o (English Nature et al 2001). Consequently, areas with a slope greater than 12.5^o are inaccessible and as such have been modelled based on a 5m (pixel size) digital elevation model where the slope has been calculated, with ArcGIS Spatial Analyst 9.3.1 for every pixel and areas greater than 12.5^o removed.

4.1.2.2. Modelling wind energy potential – legislative parameters

Legislative restrictions that can affect the likelihood of a windfarm being consented fall into two categories: planning restrictions associated with the protection of airspace and those associated with statutory designations for environmental protection.

Radar and military designations

The UK airspace is used by both civil and military airplanes and as such has a comprehensive network of radars in place for this purpose. In addition there is also a network of weather radars located strategically through the landscape. All of these features therefore have to be taken into consideration when planning a windfarm development as they can result in a windfarm development being rejected, but this is not always the case. As the decision on acceptance and rejection is not clear, we have chosen to map the four constraints and attached a rank according to the number of designations that each 1km cell intersects. The designations considered are; aerodrome radar coverage, RAF air traffic control, low flying zones and meteorological masts. All data employed in this section were derived from GIS layers and raster images obtained from the Restats renewable research forum (www.restats.org.uk).

- *Civil aerodrome restrictions:* The UK has 141 civil aerodromes of which 37 have a safeguarding zone of 30km where adequate radar coverage is required to permit the safe transit and use by aeroplanes of the aerodrome. Consequently, all aerodromes with a radar have a 30km buffer and as such this is the buffer used in the ranking.
- *RAF restrictions:* The RAF has their own aerodromes alongside areas designated as requiring air traffic coverage. These areas are outlined in the Ministry of Defence Air Traffic Control and Aerodrome Radar coverage dataset. The information relating to restrictions was obtained from a raster map where the model considered all maps that showed restrictions for turbines of a height of 140m above ground for the distance to the turbine blade tip. Any areas that overlap the restrictions will be added to the ranking. In addition to radar coverage the RAF have areas that are designated as low flying zones for training and this dataset was incorporated into the GIS from a raster image, where overlap into a no flying zone is included in the ranking.
- *Meteorological masts:* The UK Meteorological Office has 16 weather radars situated strategically throughout the British Isles, and has a buffer of 10km. Any windfarm that is proposed within these boundaries will be added to the ranking.

Statutory designations

England and Wales have an extensive network of statutory designations to protect biodiversity and the cultural landscape from inappropriate development. Consequently, the final aspect of the modelling phase was to include statutory designations - as outlined earlier they were not included at the start because they would preclude all development on the four peatland sites. The designations that are included in the model and overlap with the four study areas are: Sites of Special Scientific Interest, Special Protection Areas and National Parks. This clearly highlights ecological conflict at the sites deemed suitable for wind energy generation.

4.1.2.3 Model creation and results

All modelling work was conducted in ESRI ArcView 9.3.1 and ArcView 9.3.1 Spatial Analyst extension. The model drew upon both raster and vector data, and consequently a spatial accuracy of 10m was adopted because of the size of the study area under investigation (2197km^2). The datasets used had complete geographical coverage of the four study sites. Models were based on turbines which an output ranging from 1.13 to 1.85MW. Actual outputs obtained are, of course, dependent on the consistency of the wind resource. 1MW can provide enough energy for approximately 550 homes.

The present number of large-scale renewable energy installations within the four study sites is zero, although a potential of 121.5MW has been approved (e.g. for Thorne and Hatfield Moors).
The outline maps are presented in five different formats:

- Potential excluding any designations (Fig 4.7)
- Potential including aerodrome designations (Fig 4.8 a,b)
- Potential including statutory designations (Fig. 4.8 c,d)

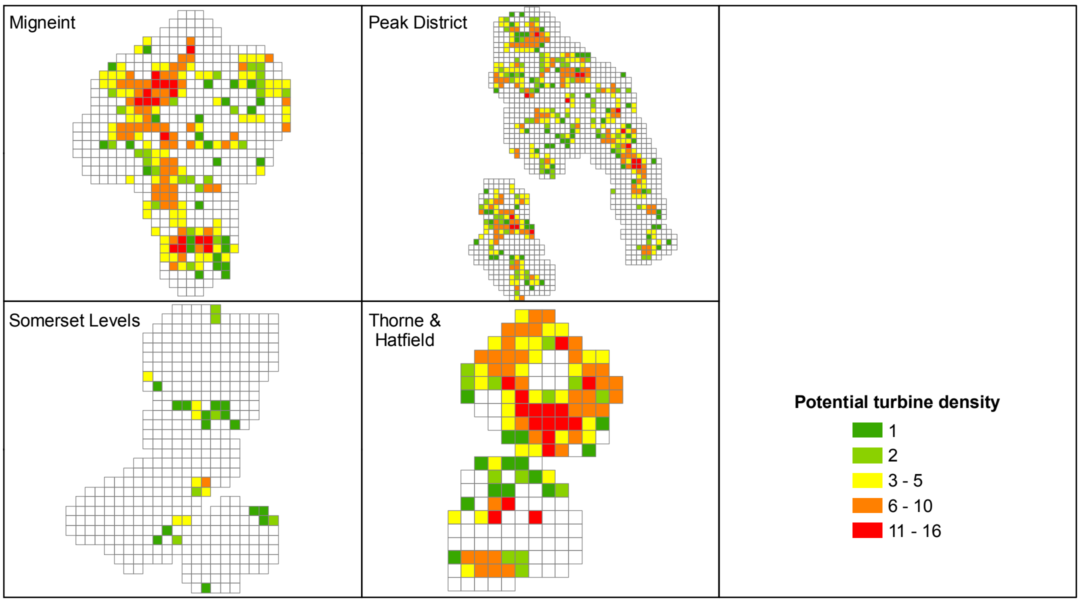


Figure 4.7: Overall potential for feasible turbine density excluding consideration of legislative and other constraints, such as designations (see text)

Figure 4.8a,b: Turbine constraints based on a) aerodome safeguarding zones and b) RAF low flying areas

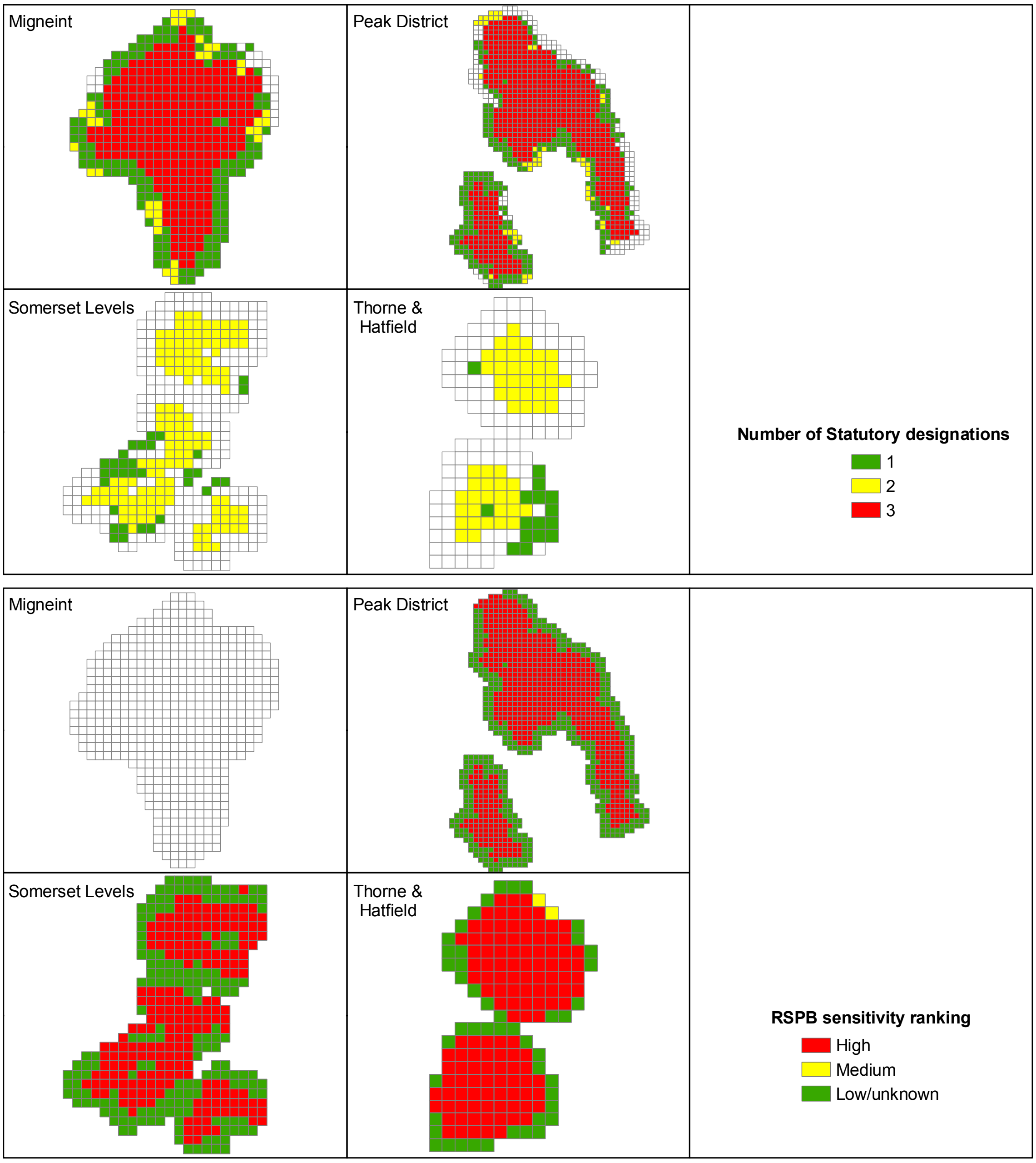


Figure 4.8c,d: Constraints mapping for wind energy, based on c) statutory conservation designations (SSSI, SAC, SPA, National Park) and d) RSPB sensitivity maps (Bright et al 2009).

There are a number of potentially negative impacts of wind farm developments on peatlands such as on changes to the local hydrology caused by access tracks, with resultant impacts on biodiversity, slope stability (e.g. Derrybrien peat slide occurred on a wind farm site during construction) and carbon sequestration potential (Nayak et al., 2008). Many of these impacts are poorly understood in terms of the exact nature of wind farm impacts but work has shown enhanced dissolved and particulate carbon loads from peats where wind farms have been installed (Greive and Gilvear, 2008). Significant trade-offs of wind energy schemes are apparent with landscape character and aesthetics, tranquillity and potentially historic environment, which in turn may affect enjoyment through recreation and have socio-economic repercussions with respect to tourism or residential house prices. The strong impact of large scale wind farms on landscape character is one of the main reasons that there are currently no wind farm developments in National Parks, and in general no developments are granted on deep peat areas.

Therefore, any development needs to accurately assess the potential for greenhouse gas emission reductions through wind farm creation against potential negative interactions with other ecosystems services resulting from disturbance to the peat substrate, hydrology, biodiversity and appearance of the landscape.

The model depicting the potential for wind farm developments within the four study sites has drawn on national datasets exclusively and the model is based on fixed criteria, which are not influenced by site specific information (and do not need to be) such as standard buffering distance and wind potential. Therefore this model provides excellent transferability to be expanded to include all peatland sites within England and Wales.

4.1.3 Peat Extraction

Peat extraction has a dramatic impact on the biodiversity of peatlands and is also a significant contributor globally to the emission of carbon dioxide (a greenhouse gas). Therefore, Defra is committed to preserving the stores of carbon in peatlands and peat soils (Defra, 2007). In addition, the UK government is committed to reducing peat use under the Biodiversity Action Programme and has set targets of total market requirements for soil improvers and growing media to be supplied by non-peat materials. The target for 2005 was set at 40% and was met in that year and the very ambitious target for 2010 was set at 90%. In 2007, the total volume of peat and alternatives used in growing products (soil improvers and growing media) was 6.61 million m^3, up from 6.46 million m^3 in 2005 (Defra, 2007). However, the overall proportion of peat in the products fell from 53% to 46%, and the proportion of alternatives rose to 54%, extending above the BAP target of 40% for 2005. It is also interesting to note that the greatest consumption of peat was by amateur gardeners (69% of the total peat used by all sectors) (Defra, 2007).

There is a long history of peat extraction from Thorne and Hatfield Moors that dates back to about the 14th century (Eversham, 1991). Peat was initially dug by hand, was small scale and used for fuel. On Thorne Moors, cutting for fuel peaked at about 20, 000 tons in 1800. Between 1850 and 1950, peat cutting at Thorne Moors continued by hand, but was used for animal litter. In 1900 the British Moss Litter Company was formed and cutting peaked at 70 000 tons in 1920. In 1965, Fisons bought Thorne and Hatfield Moors and all the peat cutting planning permission, and all the mills, from the British Moss Litter Company for about £250,000. Fisons developed the market for horticultural compost rapidly and mechanised the cutting operation with peat milling being introduced to Hatfield in 1980 and to Thorne around 1985. In this method the whole surface of an area was regularly skimmed taking a depth of about 4-6 cm of peat each time, repeating the routine on a 3-6 week cycle. In 1999, Scott's UK bought-out Fisons and in 2001 an agreement between Scott's and Natural England ended commercial milling of peat at Thorne in 2001 and Hatfield in 2004. Although Defra bought out the peat extraction rights for Thorne and Hatfield Moors for the sum of £17.3 million, Scott's still have cutting rights on some small areas on both Thorne and Hatfield Moors.

Peat has been used as fuel in and around the Somerset Levels and Moors for many centuries, having a calorific value of around 20 MJ kg^{-1} (Ekono, 1981), which is similar to wood and lignite. Production of peat for fuel peaked in the 18th and 19th centuries and then declined with the advent of electric power. During the 20th century, peat extraction was primarily for horticultural use, with UK production of 170,000 tons in 1980 (Williams, 1970). During the 1960s, major commercial companies introduced intensive methods of extraction replacing shallow hand sod cutting with deep trenches. Although this can be considered as exploiting an ecosystem service, the concept of ecosystem services is that they provide long term benefits to humans, whereas intensive extraction may be considered as short term and unsustainable as it rapidly destroys the natural ecosystem. During the 1980s and 1990s, campaigns were launched to save the surviving peatlands (e.g. Friends of the Earth, 1990). With pressure to conserve remaining peat stocks, new extraction licences were not granted. The UK Biodiversity Action Plan (www.ukbap.org.uk) contains targets for the replacement of peat in the UK horticultural industry, including supplies for amateur use; a reduction of 40 per cent by 2005 and to 90 per cent by 2010 (Alexander et al, 2008). Furthermore, ownership of many of the former peat workings was transferred to nature conservation organisations, such as Natural England and RSPB (Robertson, 1993). Current (2009) prices of peat for horticultural compost are £7.50 for 60 litres.

4.1.4 Freshwater Provision

Peatlands, particularly blanket bogs, are significant water supply sources in the UK, notably in northern England. This ecosystem service is related to high rainfall amount, low evapotranspiration and upland landscape position. Water provision is greatest following rainfall events, as blanket bog hydrology is dominated by saturation-excess overland flow or near surface through-flow which produces a flashy hydrological regime (Evans et al., 1999; Holden and Burt 2003a, c). Upland blanket peatlands are not good regulators of water supply during dry periods as the hydraulic conductivity of the peat is very small at depth and hence water does not freely drain from it (Holden and Burt, 2003b).

The Peak District National Park holds 55 reservoirs and serves as major water source to surrounding conurbations. Abstraction licences total to over 450 Billion litres of raw water per year (Table 4.3; Figure 4.9) and the Bamford Severn Trent Water treatment works alone abstracts approximately 180M litres of raw water per year. Due to legislation and commercial sensitivity, it was not possible to obtain more information on water supply, but United Utilities kindly provided Figure 4.10 depicting the receiving area of population from Peak District catchments. Water supply from one catchment does not necessarily feed just one water customer region, and water supply networks across the country produce a continuous supply in case of drought in some catchments. Using the available data on maximum abstraction per year, and assuming a use of 96,000l/year/person of drinking water, the Peak District provides 4Million people with drinking water, whereas drinking water supply from the Migneint and especially the much smaller and lowland peatlands is currently much less.

However, due to a combination of low lying topography near the outlet of river basin, permeable peat soils and good rainfall (1325 mm per year), the Somerset Levels and Moors are characterised by abundant water availability for most of the year. This makes the site attractive for water supply provision. During the Second World War, a munitions facility was constructed at Puriton. Production required a guaranteed all year-round clean water supply of 20 million litres per day. A 8 km long, 200m wide reservoir was excavated (River Huntspill). At the inland end of the river a pumping station, at Gold Corner, maintains water levels in the summer by pumping from the moors. During the winter, the Huntspill acts as a storage for floodwater that can drain by gravity drain to the sea. There is little groundwater resource as the wetlands are underlain by impermeable marine clays. Acreman *et al.,* (2003) have shown that replacing dry grassland by wet grasslands and reed beds can reduce overall water resource availability downstream.

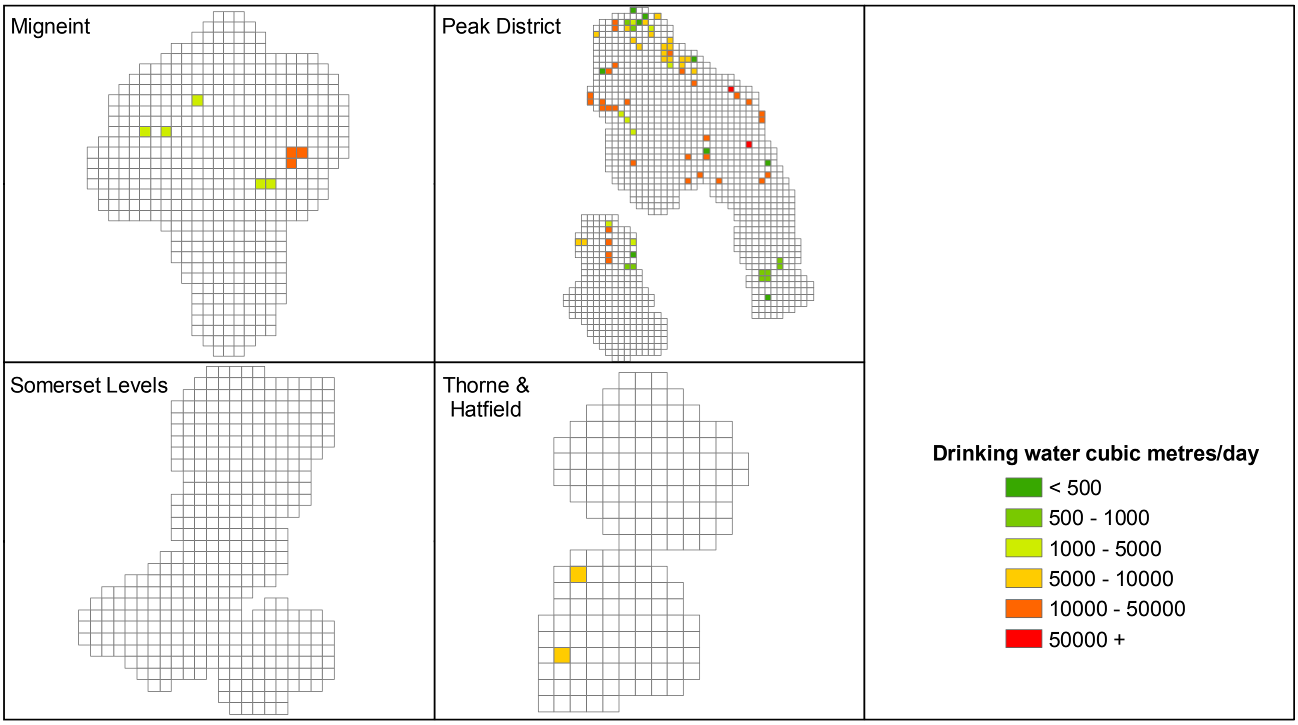


Figure 4.9: Licensed water abstraction within case study areas (EA abstraction licence dataset, correct as of April 2009)

Table 4.3: Abstraction licences for case study sites (EA abstraction licence dataset, correct as of April 2009). All water units are in m^3/year = 1000litres/year). The number of beneficiaries of drinking water were calculated assuming an annual use of $96m^3$/year/person

Site	Agriculture	Amenity	Environ-mental	Industrial, Commercial and Public Services	Production of Energy	Drinking Water Supply	Total Water	Number of beneficiaries
	[m3/year]	[m3/year]	[m3/year]	[m3/year]	[m3/year]	[m3/year]	[m3/year]	[no people]
Migneint	1,558,733	29,200	31,622,396	2,009,581	17,727,649	23,070,482	76,018,039	240,318
Peak District	10,042,574	7,275,034	91,250	17,404,551	24,982,024	386,661,181	446,456,576	4,027,721
Somerset Levels	532,681	31,500	467,711	62,744	27,500,013	0	28,594,648	0
Thorne & Hatfield	1,236,109	0	4,563	1,062,187	0	6,636,759	8,939,617	69,133
Total	**13,370,096**	**7,335,734**	**32,185,919**	**20,539,025**	**70,209,648**	**416,368,421**	**560,008,879**	**4,337,171**

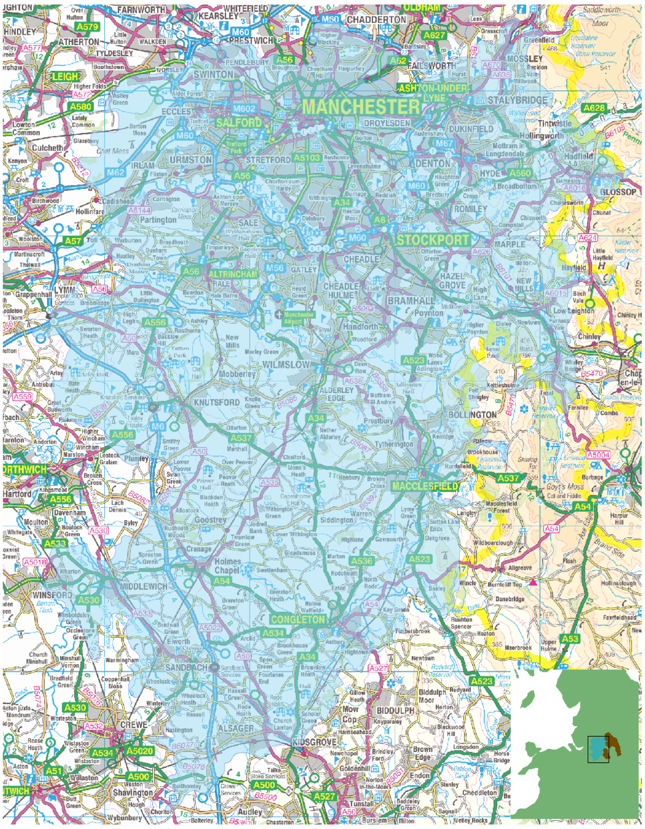


Figure 4.10: United Utilities water provision from Peak District catchments. The population of the green area is approximately 1.6 million and the Peak District catchments supply around 43% of the water to this area, i.e. around 700,000 people (figure courtesy of United Utilities).

4.2 Regulating Services
4.2.1 Climate regulation through carbon storage & greenhouse gas sequestration

4.2.1.1 Climate regulation
Within the terrestrial biosphere the northern peatlands are the most important terrestrial carbon store and as such are an important sink of greenhouse gases. Gorham (1991) has estimated that 20-30% of the global terrestrial carbon is held in 3% of its land area. The northern peatland carbon store is estimated to be approximately 4.5 Gt C and over the Holocene northern peatlands have accumulated carbon at an average rate of 0.96 Mt C per year, making this ecosystem not only a substantial store but also a large potential sink of atmospheric carbon. Furthermore, peatlands can be a large store of nitrogen and the inherently wet conditions of peatlands mean that many peat soils are a source of nitrous oxide (N_2O – a powerful non-carbon greenhouse gas). Many areas of the northern hemisphere peatlands are subject to land management systems that have not always been conducive to carbon storage, and therefore to the regulation of climate (Holden et al., 2007). For example, a common land management technique in peatlands is the use of open drainage channels (Holden et al., 2004).

Land management practices represent both a threat and an opportunity with respect to the carbon budgets of peat soils, a threat because the management may damage the peat and cause a decrease in the magnitude of the carbon sink or even convert the peat soil to a net source of carbon. However, land management can also represent an opportunity as the management practise can more readily be reversed than external drivers such as increases in air temperature and so land management represents an opportunity to improve carbon uptake in these vital terrestrial carbon stores. Furthermore, damage to peatlands can be restored, for example, active revegetation after damage by wildfire. Therefore, this sub-section has focused upon the storage of carbon greenhouse gases within peat soils and the potential impact upon greenhouse gas fluxes of a range of land use and land management scenarios.

4.2.1.2 Methodology
The approach taken by the model is to use the Durham Carbon Model as developed by Worrall et al. (2007) and as updated in Worrall et al. (in press). The model considers all carbon uptake and release pathways from a peat soil, including: uptake of CO_2 primary productivity (GPP); release of CO_2 by net ecosystem respiration (NER); release of CH_4; the fluvial flux of dissolved organic carbon (DOC), particulate organic carbon (POC) and dissolved CO_2. The carbon budgets calculated by the models above are for total carbon. This is not the same as carbon exchanged with the atmosphere and therefore not necessarily atmospherically active carbon. Greenhouse gas fluxes are normally expressed not as tonnes C km^{-2} yr^{-1} but as tonnes CO_2 equivalent km^{-2} yr^{-1}. Therefore the following steps were carried out: 1) tonnes C were converted to tonnes CO_2, (by multiplying by a factor of 3.67); 2) CH_4 is a stronger greenhouse gas than CO_2 and has a different atmospheric residence time. This study uses a factor of 24 to convert methane fluxes to CO_2 equivalents (Houghton et al., 1995); 3) the dissolved CO_2 was calculated as the excess dissolved CO_2, i.e. that present in excess over and above that present at equilibrium with the atmosphere); and 4) the atmospherically active portion of the DOC and POC fluxes was calculated using the approach of Worrall et al. (2006). Therefore this study takes a conservative viewpoint and the GHG budget is calculated as:

$$CO_{2equi} = CO_{2resp} + CO_{2CH_4} + 0.4CO_{2DOC} + CO_{2diss.CO_2} - CO_{2PP} \qquad \text{(i)}$$

where: CO_{2equi} = total carbon budget of the area (tonnes equivalent CO_2 km^{-2} yr^{-1}); CO_{2x} = annual equivalent CO_2 budget of component x where x is: pp = primary productivity; resp = net ecosystem respiration of CO_2; CH_4 = annual methane flux; DOC = annual DOC production; diss.CO_2 = annual dissolved CO_2 flux. It should be noted that nitrous oxide (N_2O) is a powerful greenhouse gas released from peats that is not estimated in this approach.

4.2.1.3 Parameterisation
The model was run on 1km^2 grid scale for 3 major study areas – Migneint, Peak District and Thorne and Hatfield Moors. For each modelled grid square where peat soils represented at least 10% of the soils, as defined by HOST classification (Boorman et al., 1995), the geo-referenced aerial photographs were examined to assess land use (i.e. presence of burning, presence and spacing of drainage, and the presence of erosion gullies). The presence of burning as identified from aerial photographs does not give an indication of the frequency of burning in that area. Therefore, it was assumed that burn frequencies would be between 10 and 20 years and the exact frequency of burning was randomly estimated as an integer value from a uniform distribution between these two values. Further, the year of burning was randomly assigned within the study period.

Within each selected grid square it is possible that there is not continuous cover of vegetation and that bare peat areas will exist. Indeed the model for POC flux assumes this. The presence of bare soil would mean that primary production would be overestimated, and so the primary production predicted for each selected grid square was weighted according to the area of bare peat. This weighted primary production value was used in the budget calculation for that grid square. Maps of bare peat were produced for the Peak District using the method of Chapman et al. (2009) and this information was used to stochastically assign proportion of bare soil in each model grid square of the Migneint study area. However, for the lowland peat sites a default value of 2% bare soil was used unless bare soil proportion was dictated by the particular scenario being considered.

The default position of the model is that all calibrations are provided from ongoing, long-term monitoring at the Environmental Change Monitoring site at Moor House in the North Pennines. However, Moor House being in the North Pennines is generally colder and wetter than most of the study sites. Additional parameterisation was available for the Bleaklow Plateau within the Peak District study area, but not within other study areas.

The budgets calculated within this study are calculated for the 10 years, 1998 – 2007. By using a 10 year period the model can average across inter-annual variability caused by changes in the local weather. A monthly weather record was generated for each modelled grid square using the climate generator proposed by Worrall et al. (in press). This climate generator extrapolates from nine, northern English long term climate stations to give the rainfall and temperature record for any location at any altitude in the UK.

4.2.1.4 Model scenarios based on management actions

The study uses the model parameterised and calibrated as described above to consider the range of management scenarios listed above (Table 4.1). They are interpreted in the following ways:

- *Business as usual (BAU)* – the land-use is as set as described from the aerial photographs with no intervention;
- *Restoration (no drains)* – the scenario assumes no drains or gullies of any type in the study regions and that that all drains or gullies have been infilled with no transitionary sink;
- *Restoration (revegetation)* – the percentage bare soil is decreased to the default value of 2%;
- *Conservation led rewilding* – all present management is removed, this includes: grazing, managed burning. However, active restoration through drain blocking and revegetation is pursued, and – as in all other scenarios – recreation management is not necessarily excluded.
- *Food security* – this scenario cannot be modelled for either the Migneint or the Peak District study sites where there is no possibility in modelling changes in the grazing intensity other than to model its presence/absence, while for the Thorne and Hatfield site this scenario is assumed to be the same as the arable scenario below.
- *Arable* – for the Thorne and Hatfield site only, an arable scenario was considered whereby all peat was assumed to bare soil and to be drained just as if soils were being used for row crops;
- *Economy* – for the Migneint and Peak District sites this scenario was taken as the imposition of managed grouse shooting and grazing wherever possible which means that not only was grazing imposed upon every grid square but so to was managed burning wherever there was not forestry. This scenario would be the same as the arable scenario for Thorne and Hatfield.
- *Optimal management for carbon* – there is no reason to believe that the blanket removal of a management strategy such as grazing, or all of the possible interventions will be the best possible action with regard to carbon for each and every grid square being considered. Therefore, the results of all possible scenarios for each study site are examined and the scenario with the maximum carbon sink was noted. This could be no intervention or all possible interventions or only one intervention. For each grid square the scenario providing the maximum sink was recorded. Further, only when an intervention provided an improvement that was greater than the acceptable error value for the present CO_2 sink with no intervention was that particular intervention selected.

For the Somerset Levels and Moors no explicit spatial modelling of greenhouse gas or carbon budgets was undertaken. Alternatively, a single 1 km^2 area of peat soil was considered under two scenarios. Firstly, in pristine condition with full vegetation and as such no erosion, and secondly a cutover peat soil where the peat is both drained and left bare.

4.2.1.5 Uncertainty analysis

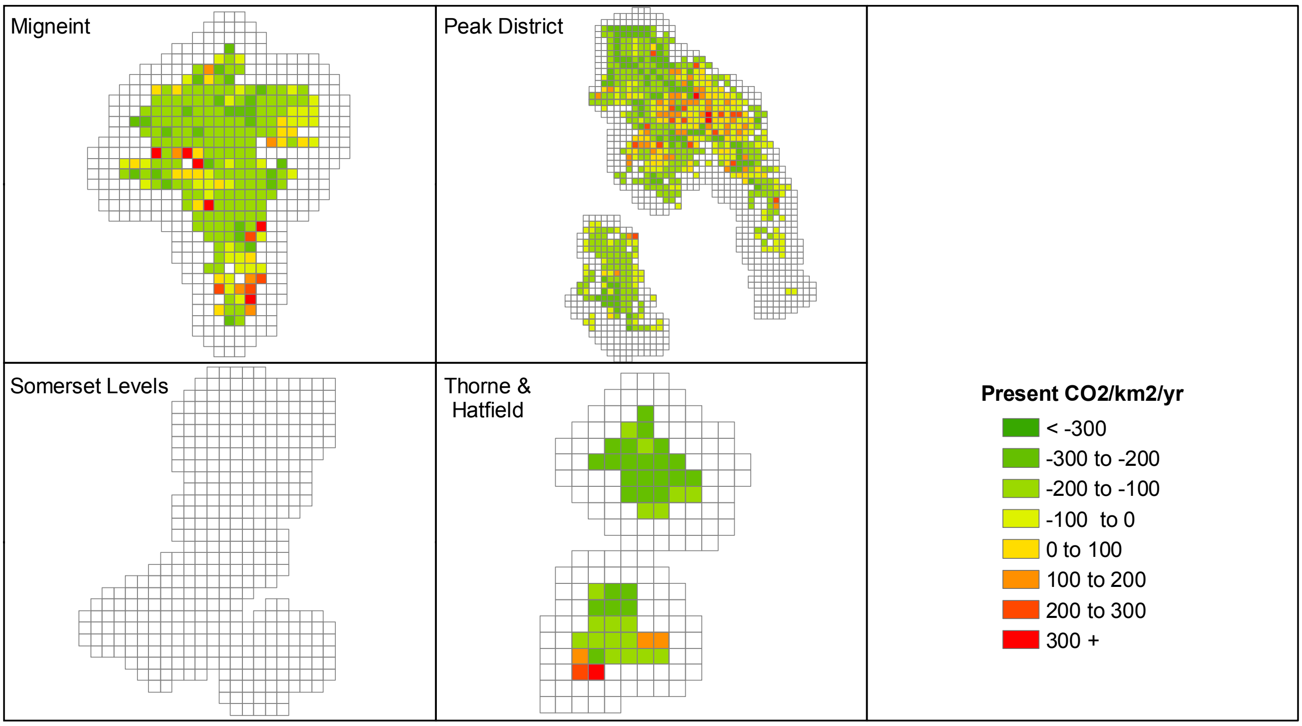
This study only allows for two sources of uncertainty in the calculation. These are the variation in the burn frequency and the extrapolation of the climate time series to each grid square. In order to estimate the uncertainty in the results a 25km^2 subset of the Peak District study area was selected at random and the model is run for this area 10 times and the results for each run recorded and these used to estimate the uncertainty in the other results.

4.2.1.6 Results

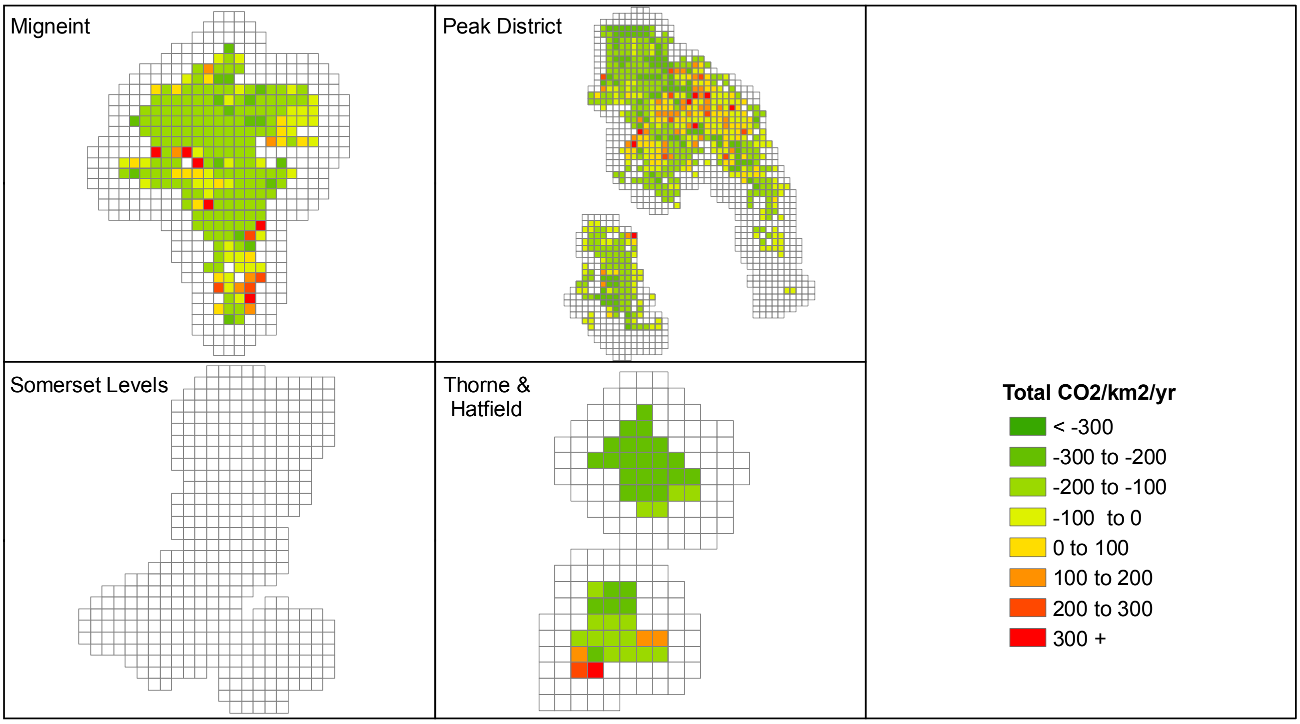
The repeated running of the model for the 25km^2 subset suggests that error due to the uncertainty in the burn frequency and climatic data is: ± 22% for C export; and ± 6% for equivalent CO_2 export. In each case the error is expressed as the range of values calculated. Furthermore, by convention all equivalent CO_2 budgets are judged relative to the atmosphere and so a negative value represents a loss to the atmosphere or a sink to the soil.

Results of the modelling for each study are given in Table 4.4. Each of the three main sites is presently estimated to be a net sink of CO_2 equivalents. The Thorne and Hatfield site represents the largest present sink per area of equivalent CO_2, but this maybe due to the fact that much of the restoration has already been done, by the same measure the Peak District represents the smallest current per area sink as less restoration has been undertaken and also represents the largest per area gain. It is not clear why the optimal equivalent CO_2 budgets for the Peak District are larger than those for either the Migneint or Thorne and Hatfield sites. One possibility is the greater altitudinal range of the Peak District plus more grid squares that are 100% peat. The values given in Table 4.4 could be recalculated not as the average of the study area but as the average export of the equivalent peat area within each study site. For the Somerset Levels values appear very large but these are calculated for the extreme cases of a 1km^2 area that is 100% peat soil with 100% of the given management scenario operating within them. However, the difference between the areal exports illustrated in Table 4.4 does suggest that large gains can be made for lowland peats in poor condition.

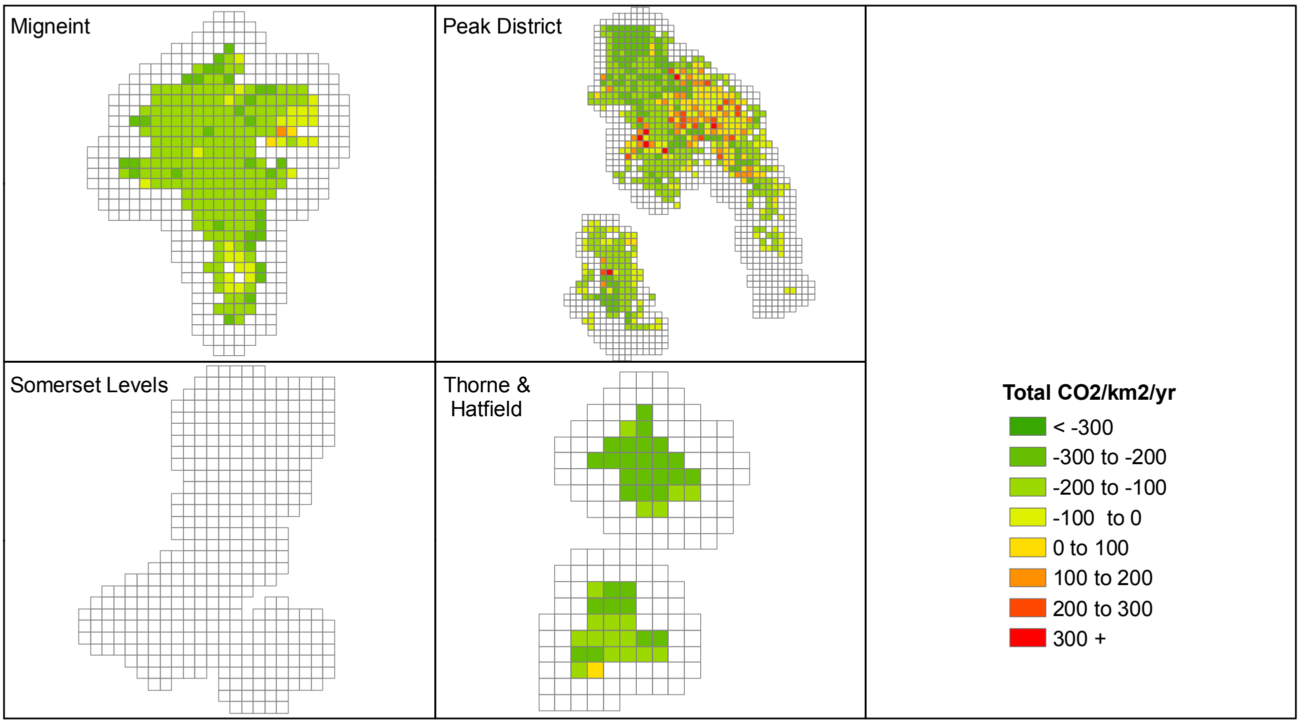
The comparison of present versus optimal, or maximum, equivalent CO_2 budgets is shown in Figure 4.11.



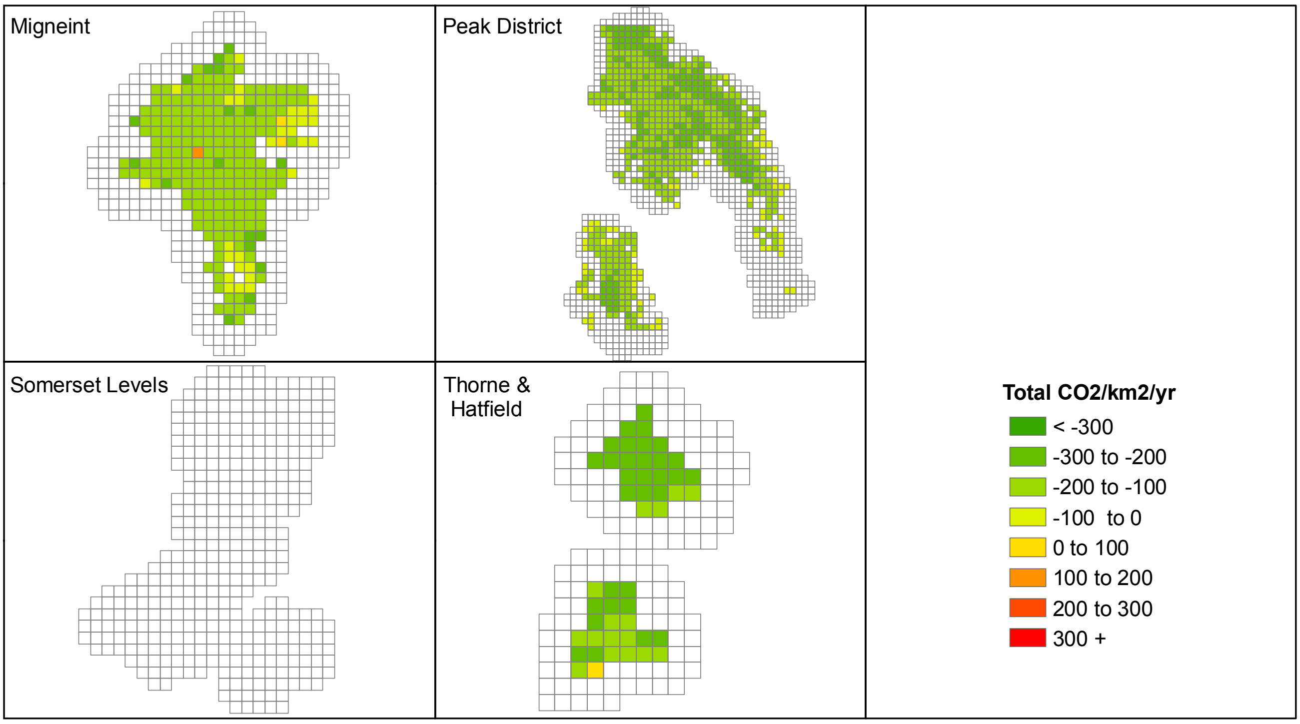
a) present day (Business as usual)



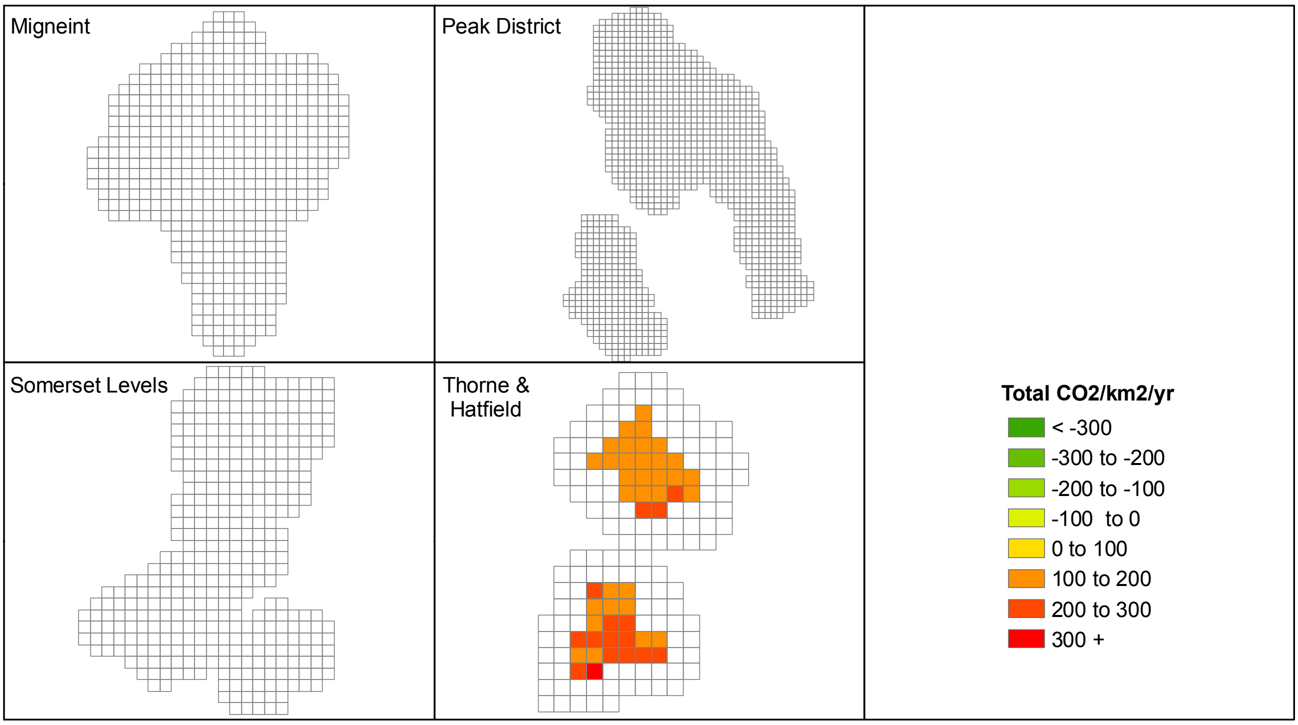
b) no drainage (gully/ditch blocking)



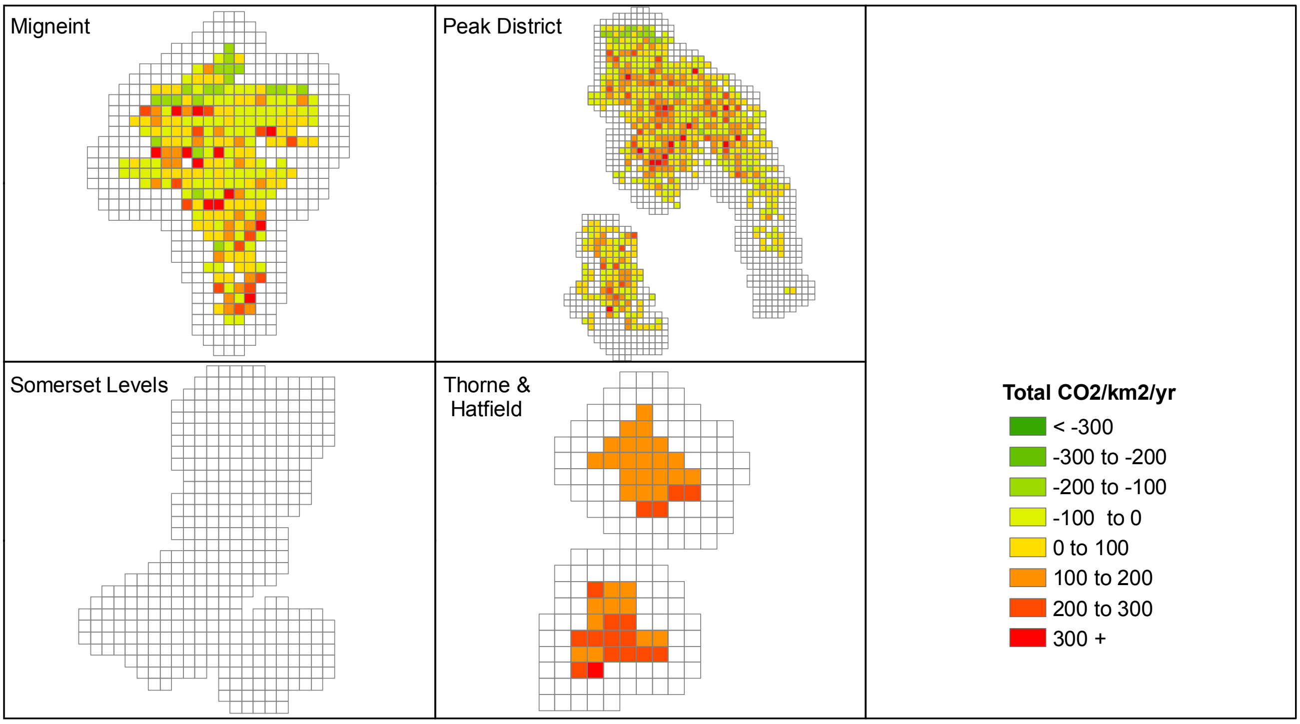
c) revegetation



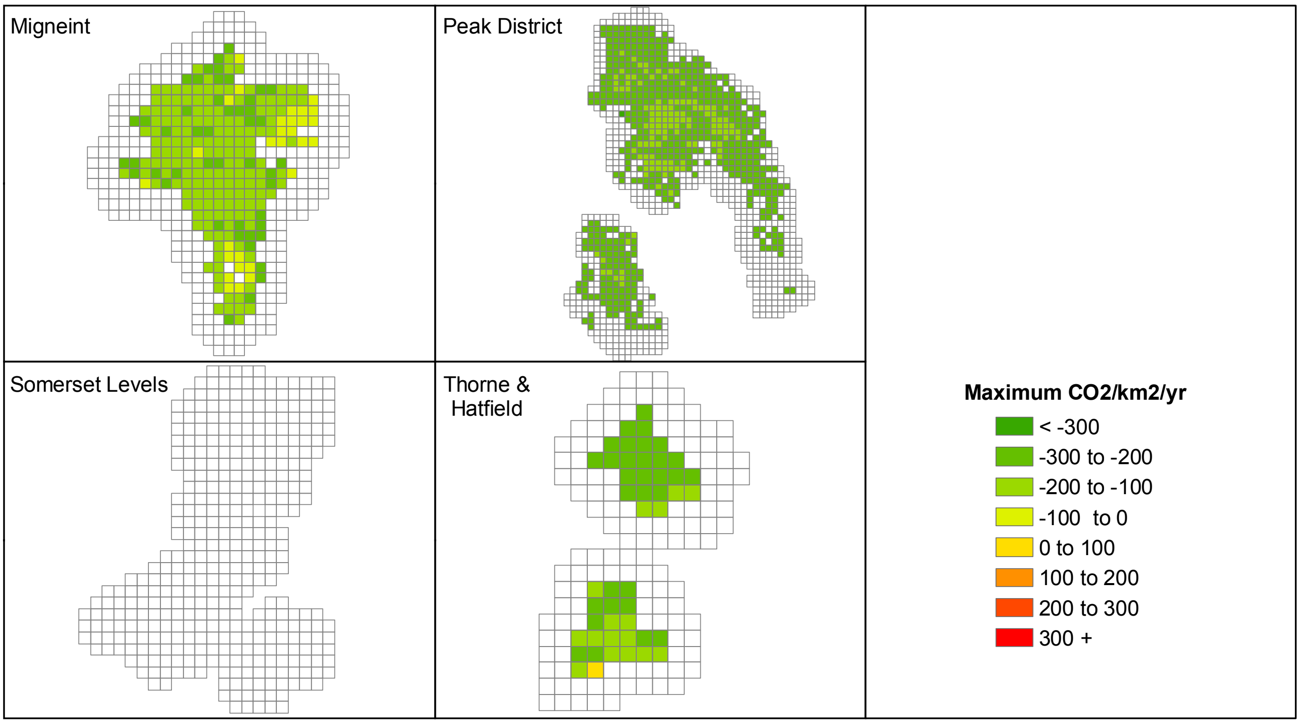
d) Conservation led rewilding (no drainage, revegetation, no grazing, no burning)



e) Food security (Thorne & Hatfield – convert to arable; not deemed feasible for uplands)



f) Economy (Grouse for uplands – increase burning; Lowlands – peat extraction)



g) Optimise for Carbon management

Figure 4.11a,g: Comparison of spatial distribution of equivalent CO_2 budgets carbon budgets for different scenarios across the Migneint, Peak District and Thorne and Hatfield Moors case studies. All units are in ktonnes eq.CO_2/yr). Somerset was not modelled. The graphs correspond to table 4.4. Scenarios include Business as usual (present), Restoration (gully/ditch blocking), Restoration (revegetation), Conservation led rewilding, Food security/Arable (scenario only deemed realistic for Thorne & Hatfield Moors), Economy (grouse moors for uplands with burning, peat extraction for lowlands) and Carbon economy (optimisation for soil carbon management).

Table 4.4: The total equivalent CO_2 budget and average equivalent CO_2 export for each study region and scenario.

	Peak District		**Migneint**		**Thorne & Hatfield**		**Somerset levels**
Scenario	Total budget (ktonnes eq.CO_2/yr)	Average export (ktonnes eq.CO_2/km^2/yr)	Total budget (ktonnes eq.CO_2/yr)	Average export(ktonnes eq.CO_2/km^2/yr)	Total budget(ktonnes eq.CO_2/yr)	Average export (ktonnes eq.CO_2/km^2/yr)	Average export (ktonnes eq.CO_2/km2/yr)
Business as usual	-62	-86	-26	-109	-7	-142	na
Restoration (no drains)	-63	-87	-26	-109	-7	-142	na
Restoration (re-vegetate)	-71	-98	-39	-164	-9	-183	na
Conservation-led rewilding	-117	-161	-38	-159	-9	-183	na
Food security/ Arable	na	na	na	na	+9	+183	+503
Economy	+32	+44	+9	12	+9	+183	N/A
Optimal carbon management	-160	-221	-40	-168	-9.3	-190	-414

4.2.1.7 Carbon budget on Somerset Levels and Moors

The net ecosystem exchange (NEE) of CO_2 was measured by the eddy correlation system at Tadham Moor in 2002 (Lloyd, 2006) and separated using a soil respiration model into the components of Gross Primary Production (GPP), the amount of CO_2 uptake by the vegetation during photosynthesis, and total respiration (R), the sum of autotrophic and heterotrophic respiration from the combined vegetation-soil surface. The result of this exercise is shown in Figure 4.12 together with the cumulative values for GPP and R over the year.

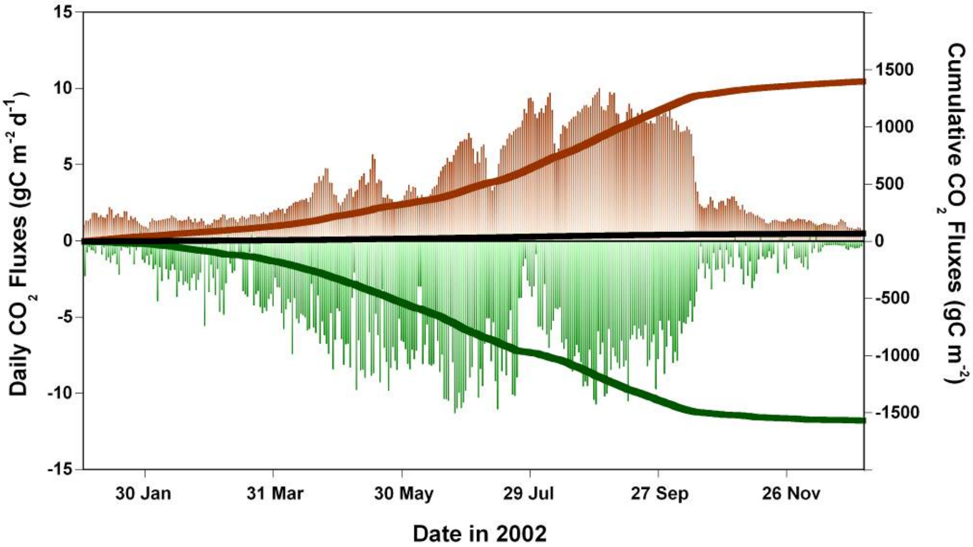


Figure 4.12: Carbon dioxide fluxes from Tadham Moor, Somerset, during 2002

The cumulative lines in the figure show that while 1568 gC m^{-2} were assimilated into the vegetation during 2002, only 1399 gC m^{-2} were respired from the combined vegetation and soil surface leaving an NEE balance of 169 gC m^{-2} making the site an apparent sink for carbon.

The eddy correlation measurements of NEE contain the assimilation of CO_2 into the meadow vegetation but not the loss of CO_2 that would have occurred if the vegetation had been left to senesce and decompose in the field. Instead, the hay was harvested and taken away, and some of the new meadow growth was consumed by cattle which also took away the vegetation in the form of increased body weight. From harvest yields and established relationships between cattle weight gain per kg of herbage eaten, it was estimated that 228 gC m^{-2} had been removed from the field. Subtracting this from the NEE above turned the field from a carbon sink to a carbon source losing 59 gC m^{-2} during the year.

It was further shown in a modelling exercise that had the water levels in the field been maintained to the prescribed water level management scheme, then respiration losses would have been reduced by 243 gCm^{-2} over the year. Such an exercise shows that, notwithstanding a certain degree of uncertainty in this result, it is probably valid to say that adhering to the water level management scheme could have reduced the carbon losses to such an extent as to make the field at least carbon neutral.

Although raising water levels may make wetlands CO_2 sinks, they may emit large amounts of methane (see Baird et al., 2009). Measurements of soil CH_4 fluxes were made at Tadham Moor during three hydrological phases being summer August low water table, winter November surface-flooding and spring March post-flooding events during August 2003 and 2004. Water tables were on average -80.6 , +1.75 and -23.2 cm above or below the soil surface for these three campaigns, respectively.

Mean CH_4 fluxes were -85 (±1 S.E. 22), +19 (±1 S.E. 16) and -19 (±1 S.E. 13) $\mu g\ m^{-2}\ hr^{-1}$ for the summer, winter and spring field campaigns respectively. Strong relationships were apparent between water table depth and average CH_4 flux for each campaign (R^2 = 0.79; $P < 0.01$) such that a reduced water table resulted in net CH_4 consumption rather than emission (Figure 4.13). The critical water table level at which this switch takes place is around 10 cm below the soil surface. Overall, due to the water tables generally being below 10 cm during this study period the Tadham moor peatland was a net sink for CH_4. When CH_4 fluxes were positive (winter) they were an order of magnitude less than measured fluxes from wetlands that have not had drainage management. Overall, the Tadham Moor results highlight the potential for soil water level management to control the soil CH_4 budget.

This analysis of methane fluxes could be interpreted as a negative ecosystem service, in that it shows a natural ecosystem process that may not be beneficial to humans because of the contribution to global warming of this greenhouse gas. It could be argued that this is only a problem because of high greenhouse gas levels created by other anthropogenic actions such as removal and burning of tropical rainforests.

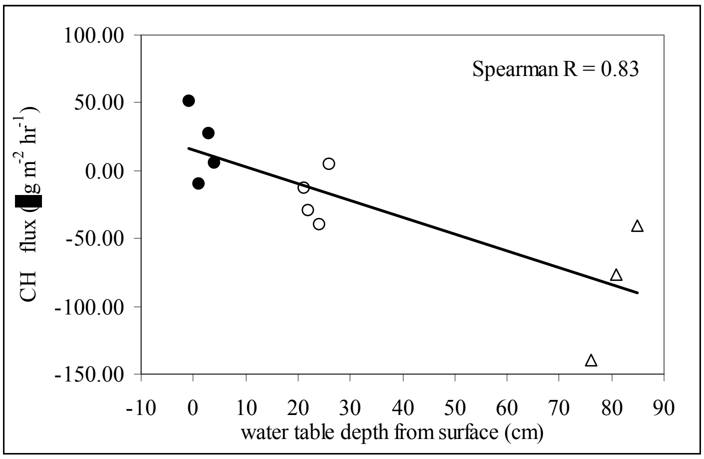


Figure 4.13: Water table control on methane flux at Tadham Moor, Somerset

4.2.2 Flood risk mitigation

4.2.2.1 Introduction

The peatland ecosystem services of climate regulation, enhancing raw water quality, and potentially attenuating storm flows are crucial to human well-being and fall into the *regulating services* subcategory (Haines-Young and Potschin, 2008). However, debate remains as to whether the UK's peatlands act to attenuate or exacerbate flooding (Holden *et al*., 2007a). Peat is capable of storing large quantities of water; saturated peat is commonly 90-98% water by mass (Holden, 2005a). This has led to the mistaken supposition that peatlands act as a sponge to soak up rainfall and prevent flooding, before gradually releasing water to maintain baseflow (Holden *et al*., 2007a). In reality, peat catchments exhibit a rapid response, with flashy hydrographs characterised by recessional limbs that return steeply to minimal baseflows (Evans *et al*., 1999; Holden and Burt, 2002; Holden and Burt, 2003c; Lane *et al*., 2004; Holden *et al*., 2007a). This poses two main problems; the rapid response to rainfall and snowmelt places downstream areas at risk from flooding, while utility companies are tasked with providing a consistent water supply despite poorly maintained baseflows (Holden 2005a). It is recognised that peatland hydrology interacts with vegetation communities, decomposition processes, carbon cycling, erosion, water quality and discolouration, and aquatic biodiversity through a variety of complex feedbacks (Holden *et al*., 2007b; Ramchunder *et al*., 2009). Nevertheless, despite a recognised need for a holistic approach to peatland management (Holden *et al*., 2007b; Ramchunder *et al*., 2009), recent initiatives have tended to focus on carbon and water quality issues. Future initiatives may seek to exploit certain ecosystem feedbacks to manage peatland hydrology for the benefit of downstream communities, primarily through flood mitigation but also through the continued provision of a quality water supply.

Saturation-excess overland flow is critical in facilitating peatlands' rapid response to rainfall (Holden and Burt 2003a, 2003b) yet it is only recently that work has been undertaken to determine the controls on overland flow velocity in these temperate systems (Holden *et al*., 2008). In neglecting the spatial complexity of peatland vegetation cover and its influence on the degree of connectivity of saturated areas to channels, a crucial mechanism by which vegetation management practices can be used to attenuate the flood hydrograph has been overlooked. The degradation of peatlands is commonly associated with a reduction in the cover of *Sphagnum* moss and an increase in the spatial extent of bare peat areas (Holden *et al*., 2007a; Ramchunder *et al*., 2009). This is of critical importance to upland management activities since recent evidence (Holden *et al*., 2008) demonstrates that *Sphagnum* offers greater hydraulic resistance to overland flow than other surface covers common in these fragile environments such as *Eriophorum* (cotton grasses), *Sphagnum*-*Eriophorum* mixes and degraded bare peat surfaces (Holden *et al*., 2008). Due to the dominance of saturation-excess overland flow (OLF) there is the potential for the rehabilitation of degraded peatlands to reduce downstream flood risk and mitigate low flows.

A lack of understanding of the catchment scale hydrological implications of vegetation management necessitates a research focus on the impacts of upland management practices on river flows. Overland flow velocities are crucial in determining hydrological response due to their impact on hillslope-channel connectivity. The recent development of an empirical overland flow velocity forecasting model determined by field observation has the potential to allow modelling of hydrological response at the catchment scale (Holden *et al*., 2008). Following stakeholder workshops it was determined that the two lowland study sites were not considered to be of interest in terms of downstream flooding. At Thorne and Hatfield Moors there was some very small scale localised flooding issues on one or two fields at the edges of the site. The Somerset Levels have some history of marine inundation on site, but were not considered to interact with the surrounding systems in terms of flood risk. This contrasts to the two upland blanket peat sites. Flooding in the Conwy Valley notably in Llanrwst,Trefriw, Dolwyddelan and Betws y Coed was common and in the Peak District there is a long flood history with significant flood events notably in the Glossop Brook catchment and the 2007 Sheffield Derby flood.

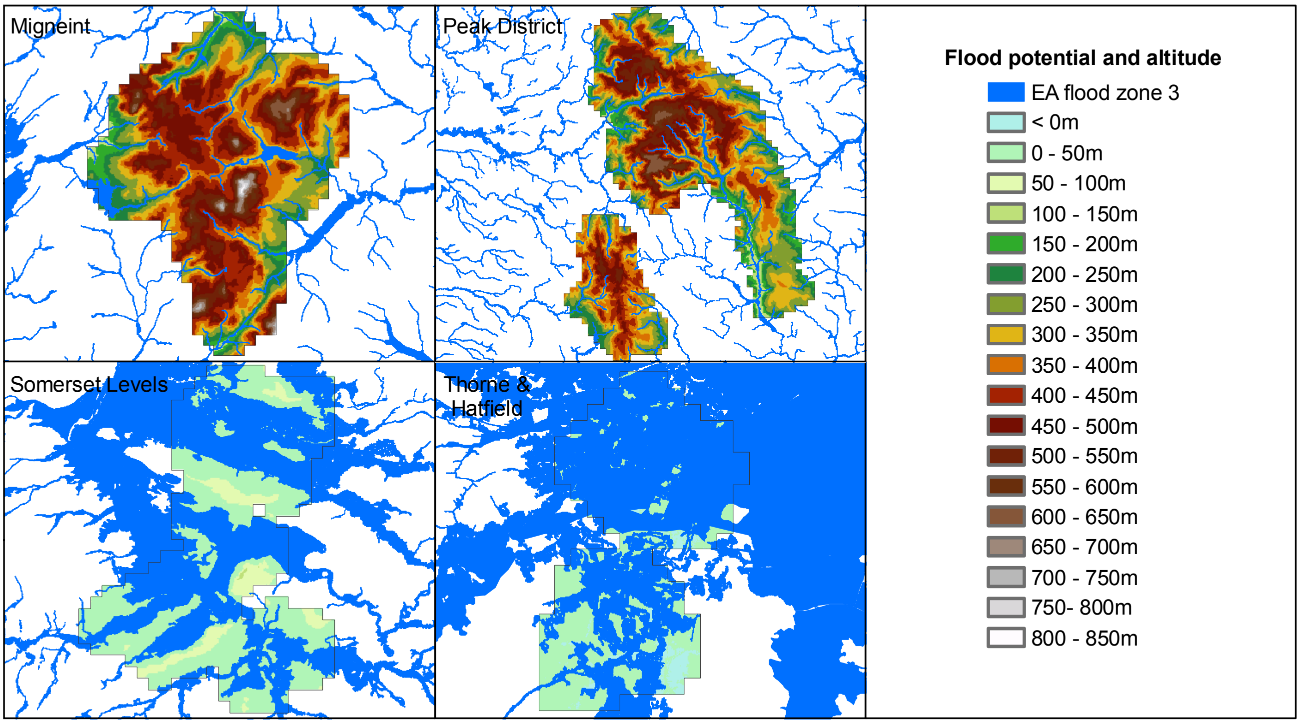


Fig 4.14: EA Flood risk maps overlayed on topography for case study areas. Flood Zone 3 shows areas with the highest probability of flooding, where the annual probability is greater than or equal to 1% for river flooding and greater than or equal to 0.5% for flooding from the sea.

The flood risk maps (Fig 4.14) demonstrate that the type of peatland and its topographical setting will be important determinants. While upland peatlands may contribute as sources of flooding, lowland peatlands may act as recipients of flooding and offer flood storage potential (see 4.2.2.5).
This therefore demonstrates that not all peatland types should be considered to offer the same services. The spatial extent of the two upland case study sites, however, necessitates careful consideration of the resolution of topographic data used in producing predictions at the scale of interest, which still reflect real-world hydrological functioning.

4.2.2.2 Methodology, data requirements and preparation issues

TOPMODEL

The well documented TOPMODEL concept (e.g. Beven and Kirkby, 1979; Beven, 1997), is one of the most widely applied distributed hydrological models. The model is simple and yet works on the basis of spatially distributed data (e.g. topography, roughness etc). Hence we are testing the model's use for the purpose of this scoping study in order to establish whether it is readily applicable to national roll out for ecosystem services of peat studies. Full details of the TOPMODEL methodology and data preparation are provided in Appendix 4 and only a very brief summary is provided here. The model has the advantages that it can be physically based since it is possible to directly measure the model parameters (Beven and Kirkby, 1979) and that outputs can be easily presented by mapping them back to a distributed raster grid (Wu *et al*., 2007).

The research required (see Appendix 4 for full details):

i) Elevation data pre-processing – selecting relevant resolution topographic data, resampling this data and removing 'topographic depressions' to enable model flow of surface water.
ii) Determination of the topographic wetness index.
iii) Collation of relevant precipitation data - as high temporal resolution as possible given the flashy nature of flow; it should be noted that such high temporal resolution upland records are sparse
iv) Collation of relevant discharge data – in this case 15-minute instantaneous discharge records were obtained for a number of EA gauges from the hydrology teams in the EA's North East, North West, Midlands and Wales operating areas.
v) Evapotranspiration estimation

A series of storms were identified for initial TOPMODEL calibration (see Appendix 4). However, disappointment in the ability to predict the observed hydrograph, despite calibration, led to the implementation of a version of TOPMODEL that partitions the catchment into two distinct areas, each with a different *m* value (Kirkby, 1997); see below.

Peat land cover identification

Land Cover Map 2000 (LCM2000) Level 2 vector data were obtained from the Centre for Ecology and Hydrology. The data are provided as ArcView shapefile polygons defining parcels of land with attributes that include categorisation of the parcel into one of 26 land cover subclasses. The vector data was converted to a 10 m resolution raster dataset. A 12.7 km^2 catchment of the Afon Gelyn, which drains to the EA gauge at Cynefail (SH84254205) was identified for preliminary analysis based on its favourable size, minimal anthropogenic disturbance with runoff rates affected by natural processes, and a responsive regime characteristic of upland peat catchments (CEH, 2009a). The catchment's land cover composition is described in Appendix 4 (Figure A4.2). Attempts were made to reclassify the LCM2000 Level 2 subclasses, in conjunction with aerial imagery, to rudimentarily delineate the peatland vegetation cover categories identified by Holden *et al*. (2008; Appendix Table A4.3). The LCM2000 Level 2 classifications of '101 Dwarf shrub heath' and '102 Dwarf shrub heath' pose the most problems since aerial imagery indicates that these categories are coincident with areas of heather in the catchment, a land cover not examined during the overland flow velocity experiments of Holden *et al*. (2008). Mean velocity in these areas was estimated to be in the order of 0.04 m s^{-1}, a value between that of the 'Bare' and '*Eriophorum*' land covers. A catchment average overland flow velocity of 0.02963 m s^{-1} was established for the Cynefail catchment based on weighting the mean overland velocities detailed in Table A4.5 by the aerial coverage of the reclassified land cover categories.

EA flow gauges are more frequent in the Peak District than in the Migneint where, beyond the gauge at Cynefail, the only other identified gauge is at the outflow of Llyn Celyn. The runoff here is affected by reservoir impoundment, water supply abstractions and hydro-electric regulation (CEH, 2009c). However, of the eight identified flow gauges whose catchment areas are coincident with the Peak District study site, only the gauges at Hollinsclough and Tunstead House have catchments with a natural regime, uninhibited by issues similar to those that render the Celyn outflow gauge unsuitable. A raster reclassification procedure was performed on the rasterized LCM2000 Level 2 vector data for each catchment to identify a catchment averaged overland flow velocity based on the observations of Holden *et al*. (2008). However, the Peak District catchments are more diverse than the Cynefail catchment in terms of LCM2000 subclasses and their reclassification into areas analogous with the land covers examined by Holden *et al*. (2008) is rudimentary. The catchment averaged overland flow velocities for the Hollinsclough and Tunstead House catchments are 0.03004 and 0.02655 m s^{-1} respectively.

Natural England data held for the Peak District delineates areas of peatland classified into categories including pristine, gullied, wooded, scrub, cultivated, burnt, afforested, restored. However, the data coverage in the Hollinsclough and Tunstead House catchments is sporadic. A decision was made to delineate areas analogous to the Holden *et al*. (2008) surfaces based on the reclassification of rasterized LCM2000 Level 2 vector data since the dataset's national coverage ensures entire catchment classification and aids inter-site transferability. However, information was extracted from another Natural England dataset which allowed the coverage of peat soils in the Peak District catchments to be quantified. 12.3% of the Hollinsclough catchment is composed of 'deep peaty soils', 65.6% is composed of 'shallow peaty soils', and 0.3% is composed 'soils with peaty pockets'. 25.3% of the Tunstead House catchment is composed of 'deep peaty soils' and 42.6% is composed of 'shallow peaty soils'.

Attempts were made to estimate overland flow velocities from standard engineering equations based on Manning's equation (Pitt *et al*., 2006) for the range of surface covers that occur within the study site boundaries; however, the calculated values were at least an order of magnitude higher than the overland flow velocity observations of Holden *et al*. (2008) so were discounted in favour of a reclassification based on the observed values.

Partitioned catchment approach

In the Cynefail catchment, a rapidly responding area, composed of 'Bare' and 'Heather' land covers, was delineated by raster reclassification of the LCM2000 Level 2 subclasses (Figure 4.15). Another area, exhibiting a more moderated response, was delineated from the '*Eriophorum*', '*Eriophorum-Sphagnum* mix' and '*Sphagnum*' land covers (Figure 4.15). In the Hollinsclough and Tunstead House catchments the same procedure was applied; however, the '*Eriophorum*' category was decomposed and all constituent groups deemed to exhibit a moderate response with the exception of '51 Improved grassland' which was deemed to respond rapidly. Different *m* model parameter values and time delays were applied to the partitioned catchment areas.

The elevation ranges of the catchments are not favourably comparable to the elevation of the respective gauges from which meteorological model inputs were sourced. In response, adjustments were made to the meteorological data to fine tune the catchments' response and improve their water balances. In particular the gradient of the recessional limbs were reduced by decreasing the rate of evapotranspiration. The meteorological data adjustment had an element of trial and error and is not a reflection of any quantified meteorological difference between gauge and catchment. Furthermore, in addition to the intensity differences the adjustments attempt to represent, there is likely to be an elevation related difference in the duration of rainfall events which is not reflected.

The adjusted meteorological inputs were used in TOPMODEL using the existing calibrated parameters. The performance of the calibrated parameter sets, both with and without the application of the meteorological data adjustment factors, in simulating the hydrograph of a test storm was assessed in each catchment. The test storms were chosen to include the highest discharges recorded in each catchment in the flow series data obtained from the EA (Cynefail, 01/08/2007 00:00 to 31/12/2008 23:00; Hollinsclough, 01/08/2007 00:00 to 31/12/2008 23:00; Tunstead House, 01/08/2007 00:00 to 28/02/2009 23:00). The Topographic Wetness Index (TWI, see Appendix 4) and LCM2000 datasets for each catchment were converted to ASCII files. Due to the non-normal distributions of the data Kruskal-Wallis tests were employed to test for significant differences between the TWI distributions associated with the different LCM2000 subclasses in each catchment.

Vegetation re-establishment and management scenarios

Seven scenarios were explored in each catchment (Table 4.5) to compare with business as usual (i.e. present land cover). These scenarios relate to vegetation cover as this links with the new hydrological modelling approach being tested in this scoping project. However, the vegetation cover scenarios are linked to realistic scenarios for the study sites. Hence more *Sphagnum* cover relates to vegetation and water table restoration scenarios in Table 4.1, enhanced heather cover relates to increased burning under the economy scenario in Table 4.1. Bare peat scenarios relate to the increase in grazing density under the food security scenario, although is an extreme case to indicate the level of change we might expect if damage was severe. It was not possible to relate the modelling to the exact scenarios developed in Table 4.1 because data is simply not available to support this and we know there is major gap in understanding how flood behaviour relates to different types of upland management. Hence our approach provides a novel step forward, but we are limited by experimental and data availability and this is something that should be pursued before Phase II can be rolled out for other peatlands.

Based on the scenarios in Table 4.5, catchment averaged overland flow velocities were calculated. For each scenario the ‘Internal subcatchment routing velocity’ in the SAGA *TOPMODEL* module was adjusted based on the calculated catchment averaged velocities; all other parameters were maintained. The proportion of the catchment exhibiting a rapid response to rainfall, used in the partitioned catchment approach, was also altered in reflection of the re-establishment and management scenarios. Again, the calibrated parameters were held constant. There is greater diversity of LCM2000 subclasses in the Peak District catchments. A decision was made to classify ‘51 Improved grassland’ as exhibiting a rapid response while ‘71 Calcareous grass’, ‘61 Neutral grass’ and ‘81 Acid grass’ were considered to exhibit a more moderate response. Therefore, in defining the proportion of the catchment exhibiting a rapid response under the scenarios described in Table 4.5, care was taken to maintain the proportional coverage of ‘51 improved grassland’ relative to other grass subclasses.

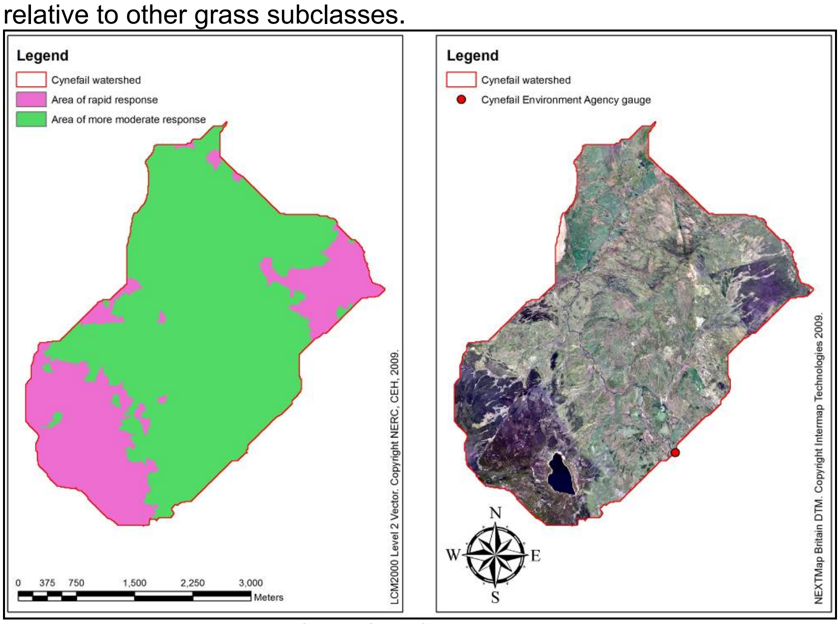


Figure 4.15: Partitioning of the Cynefail catchment into two distinct areas exhibiting different hydrological response based on vegetation cover. The rapidly responding area makes up 27.3 % of the catchment. An aerial image is included for comparison.

Table 4.5: The vegetation scenarios applied for hydrological modelling

Scenario	Description	
1	100% '*Sphagnum*' coverage	
2	100% 'Bare' coverage	
3	'Bare' revegetated to '*Sphagnum*'	↓ Cumulative ↓
4	50% '*Eriophorum-Sphagnum* mix' to '*Sphagnum*'	
5	50% '*Eriophorum*' to '*Eriophorum-Sphagnum* mix'	
6	50% 'Heather' to '*Eriophorum*'	
7	30% 'Heather' to '*Eriophorum*'	Alternative to Scenario 6

<u>Multi Criteria Evaluation (MCE)</u>
A MCE was undertaken, using the data available, to identify areas with the highest potential to generate rapid runoff. Table 4.6 details the rationale behind the four MCE factors created for the Peak District and Migneint study sites. An output with a resolution of 1 km is required to link with other ecosystem services and this is reflected here. 10 m DEMs were extracted for each study site and resampled to a resolution of 1 km.

Table 4.6: Rationale behind MCE factors

Factor	Rationale
Elevation	A reflection of the orographic rainfall effect.
Slope	A reflection of the topographic control on overland flow velocities and runoff generation.
Wetness Index	A reflection of high TWI values having a higher propensity to saturate.
Average OLF velocity	A reflection of the land cover control on overland flow velocities.

Due to the subjectivity of defining factor weights in such an elementary analysis the factors were equally weighted. Various scenarios of vegetation change from the present situation were explored. The average overland flow velocities, determined from LCM2000 data reclassification, were adjusted along the Bare-Heather-*Eriophorum*-*Eriophorum*/*Sphagnum* mix-*Sphagnum* spectrum. Scenarios that moved the average overland flow velocity 1 and 2 steps in either direction along the spectrum from the present situation were explored. For example, the scenario that shifts the average overland flow velocity 1 step towards the pristine bog end of the spectrum involves the reclassification of the average overland flow velocity MCE factor shown in Table 4.7. The thresholds used to classify the MCE grid created by weighted linear sumation of the elevation, slope, wetness index and present situation average overland flow velocity factors into 8 categories for display were recorded. The thresholds were used to similarly categorise the grids created for each of the 4 scenarios of vegetation change in each study area to facilitate comparison with the present situation.

Table 4.7: Generation of a reclassified average overland flow velocity MCE factor for the scenario that shift vegetation categories 1step towards the pristine bog end of the Bare-Heather-*Eriophorum*-*Eriophorum*/*Sphagnum* mix-*Sphagnum* spectrum.

Original category	Average OLF velocity (m s^{-1})	MCE factor value	Category if shifted 1 step towards pristine	New average OLF velocity (m s^{-1})	New MCE factor value
Bare	0.04959	255	Heather	0.04	184
Heather	0.04	184	*Eriophorum*	0.03376	138
Eriophorum	0.03376	138	*Eriophorum-Sphagnum* mix	0.01798	22
Eriophorum-Sphagnum mix	0.01798	22	*Sphagnum*	0.01490	0
Sphagnum	0.01490	0	*Sphagnum*	0.01490	0

4.2.2.3 Results

TOPMODEL catchment simulation
Results of hydrograph analysis and associated discussion are provided in Appendix 4.

Topographic Wetness Index (TWI) and land cover
The adjusted p-value for the Kruskal-Wallis test in the Cynefail, Hollinsclough and Tunstead House catchments is <0.001. A significant difference exists between the TWI medians of at least two of the LCM2000 subclasses in each of the catchments. Although a statistically significant difference has been identified, it is difficult to establish a pattern in the TWI values associated with various LCM2000 subclasses (Figures A4.17 to A4.19, Appendix 4). This is a reflection of the complex interactions between vegetation communities and topography, hydrology, temperature, decomposition process, soils and, perhaps most fundamentally, land use and management. Nevertheless, the occurrence of different LCM2000 subclasses with similar TWI ranges is encouraging from a peatland vegetation re-establishment and rehabilitation perspective; it suggests that it is likely that any constraint to the re-establishment of species associated with pristine blanket bog systems offered by hydro-topographic factors may be overcome through the application of sympathetic management practices.

Vegetation re-establishment and management scenarios
The modelled effects of the re-establishment and management scenarios on the peak discharge are presented in Figures 4.16a,b. The means by which the scenarios are defined, shifting proportions of current-situation vegetation categories toward the pristine end of the vegetation spectrum, ensures that the original catchment composition is influential in each catchment's response to a particular scenario. The biggest changes in peak discharge, simulated using the SAGA *TOPMODEL* module, occur at Scenario 5 where there is a shift from *Eriophorum* to *Eriophorum-Sphagnum* mix coverage. The greatest difference in average overland flow velocities between adjacent surface covers in the spectrum occurs here and this is where the majority of the gains in the SAGA simulations are seen. However, in more degraded catchments, where the present bare peat coverage is more extensive, the re-vegetation of bare surfaces (Scenario 3) would also see a more marked reduction in simulated peak discharge.

Nevertheless, only subtle differences are seen in the simulated hydrographs. The simulated hydrographs generated using the SAGA *TOPMODEL* module and partitioned catchment approach for each scenario in the Hollinsclough catchment are shown in Figures 4.17 and 4.18. With the exception of Scenario 2, and only when simulated using the partitioned catchment approach, there is minimal departure from the hydrograph that simulates the present situation. The impacts of vegetation change scenarios are greater in the Cynefail and Tunstead House catchments when simulated using the partitioned catchment approach since the scenarios result in a change in weighting of the partitioned TOPMODEL *m* and time delay parameters; in the SAGA modelling all parameters are held constant with the exception of the 'Internal subcatchment routing velocity'. In the Hollinsclough catchment, the marginally greater response evident using the SAGA module simulation is a reflection of the lower initial proportion of the catchment identified as exhibiting a rapid response in the partitioned catchment approach which limits the proportional gains that can be made. The lag times associated with the realistically achievable scenarios (Scenarios 3 to 7) are very close to those simulated for the present situation (Table 4.8). Nevertheless, small changes in lag time can be important in headwater catchments particularly if flood wave synchronicity is impact downstream so that two tributaries now peak at the same time instead of one peaking 30 minutes before the other.

Table 4.8: The impact of re-establishment and management scenarios on the lag times associated with the peak instantaneous discharge. Values quoted reflect the change in hours from the lag times modelled for the present situation. Positive values indicate an increased lag time; negative values, a decreased lag time.

	SAGA *TOPMODEL* module			Partitioned catchment approach		
Scenario	Cynefail	Hollinsclough	Tunstead House	Cynefail	Hollinsclough	Tunstead House
1	+8	+4	+7	+1	0	+3
2	0	-7	-3	0	-18	0
3	0	0	+1	0	0	0
4	0	-1	+1			
5	+1	+1	+2		0	0
6	+2	+1	+2	+1	0	0
7	+1	+1	+2	+1	0	0

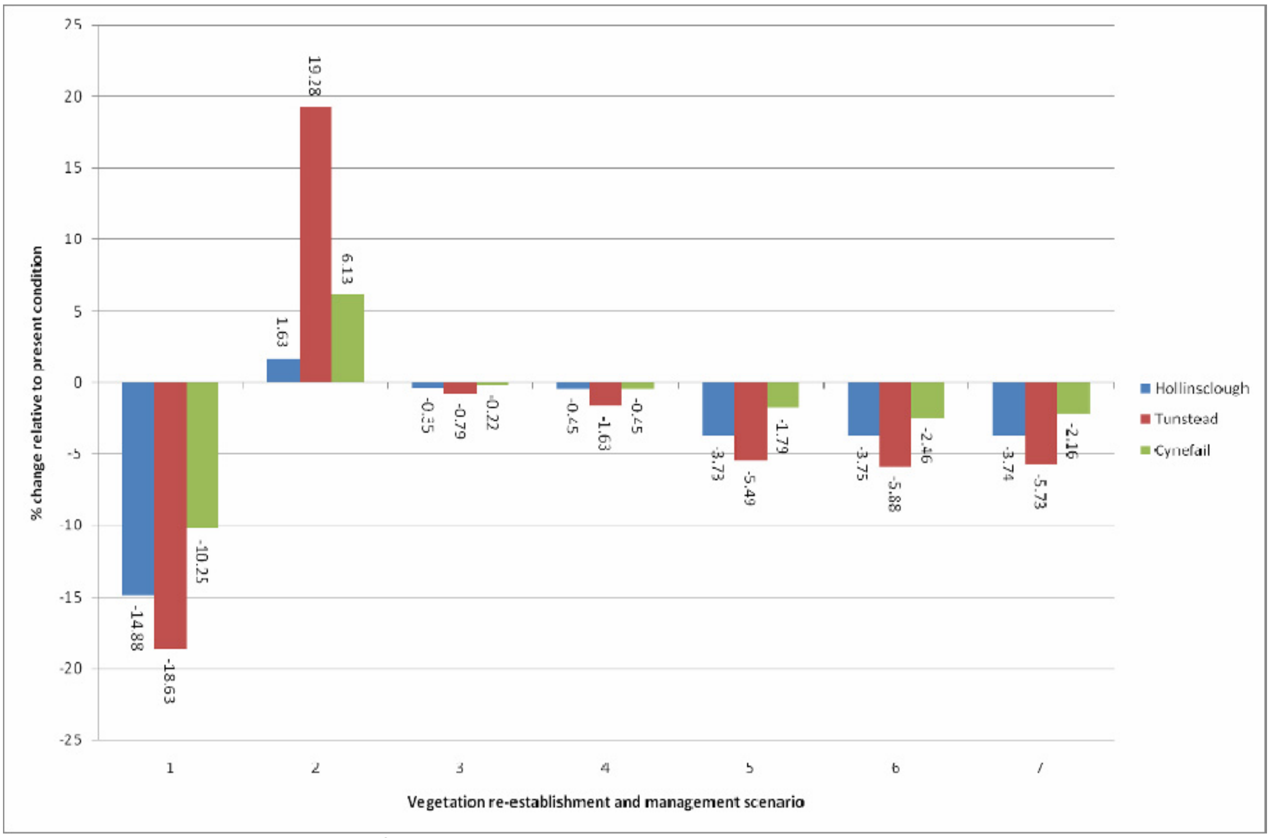


Figure 4.16a: The impact of vegetation re-establishment and management scenarios on the peak instantaneous discharge modelled using the SAGA *TOPMODEL* module.

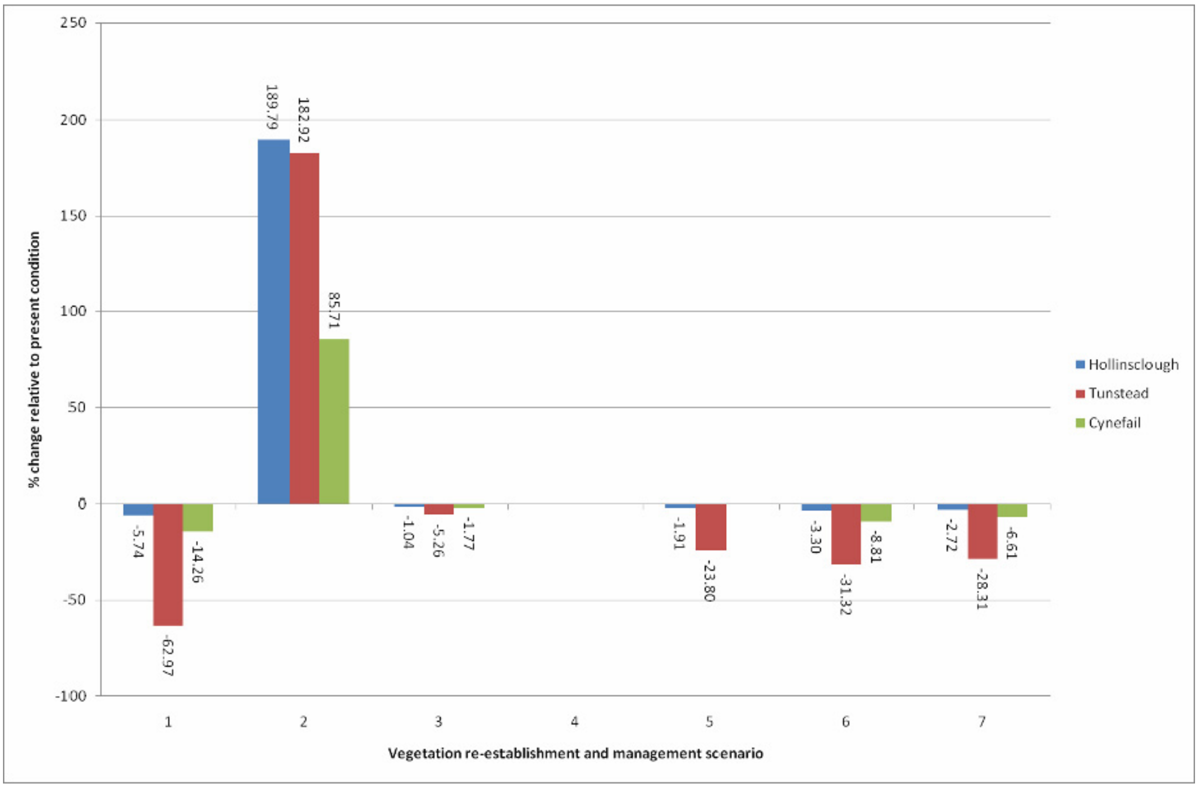


Figure 4.16b: The impact of re-establishment and management scenarios on the peak instantaneous discharge modelled using the partitioned catchment approach. In all catchments Scenario 4 is identical to Scenario 3 and in the Cynefail catchment Scenario 5 is also identical to Scenario 3 because of the method by which the proportion of the catchment that exhibits a rapid response is defined using reclassification of the LCM2000 data.

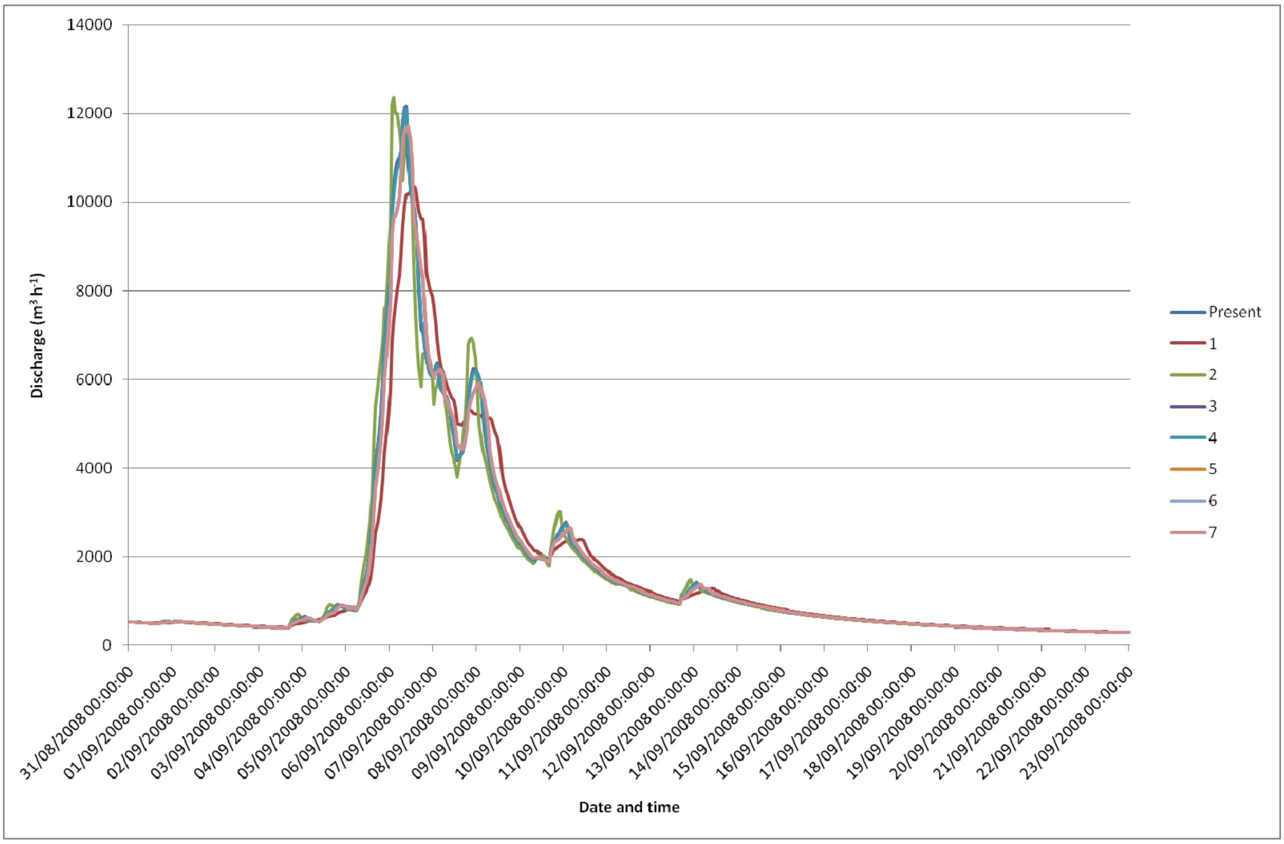


Figure 4.17: The simulated hydrographs generated using the SAGA TOPMODEL module for each vegetation re-establishment and management scenario in the Hollinsclough catchment.

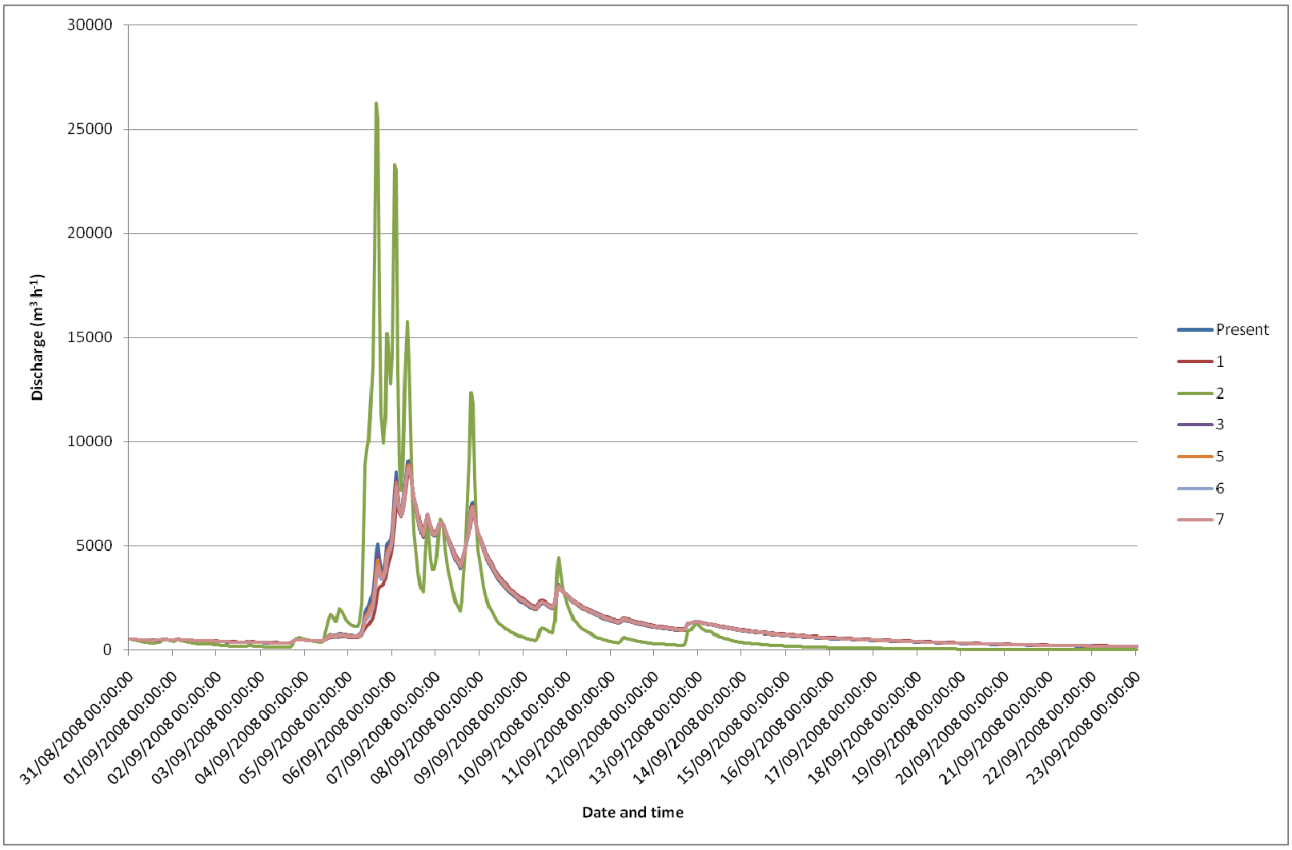


Figure 4.18: The simulated hydrographs generated using the partitioned catchment approach for each vegetation re-establishment and management scenario in the Hollinsclough catchment.

Multi Criteria Evaluation

The MCE analyses that identify areas likely to have the highest potential to rapidly produce runoff in the Migneint and Peak District are shown in Figure 4.19 The MCE analyses were designed so that those areas with a combination of high elevation, steep slope, high TWI and rapid average overland flow velocities were identified as having the highest potential to rapidly produce runoff. Clearly there are other factors that influence the rate of runoff such as soil structure, infiltration rates and interception; however, the focus of this study is on the impact of vegetation change on overland flow velocities and associated runoff attenuation. Indeed, TOPMODEL assumes homogeneous soil characteristics across the catchment (Kirkby, 1997) and this assumption has been extended to the MCE analyses performed here. The MCE exploration of the vegetation change scenarios in the Migneint and Peak District are presented in Figures 4.20 and 4.21 respectively. The present-day (business as usual) MCE modelled situation is included to aid comparison; the MCE analysis for each scenario has been presented in such a manner that the categories are directly comparable to those depicting the current situation. In both study sites changing the vegetation cover from the current situation in either direction along the degraded-pristine spectrum has significant effects on the classification relative to the current position. For example, a 2-step shift to the degraded end of the spectrum results in both study sites being dominated by areas with a potential to rapidly produce runoff equal to or greater than the highest current situation classification. Likewise, a 2-step shift to the pristine end of the spectrum results in the study site being dominated by areas with a potential to rapidly produce runoff equal to or lower than the lowest current situation classification.

a) b)

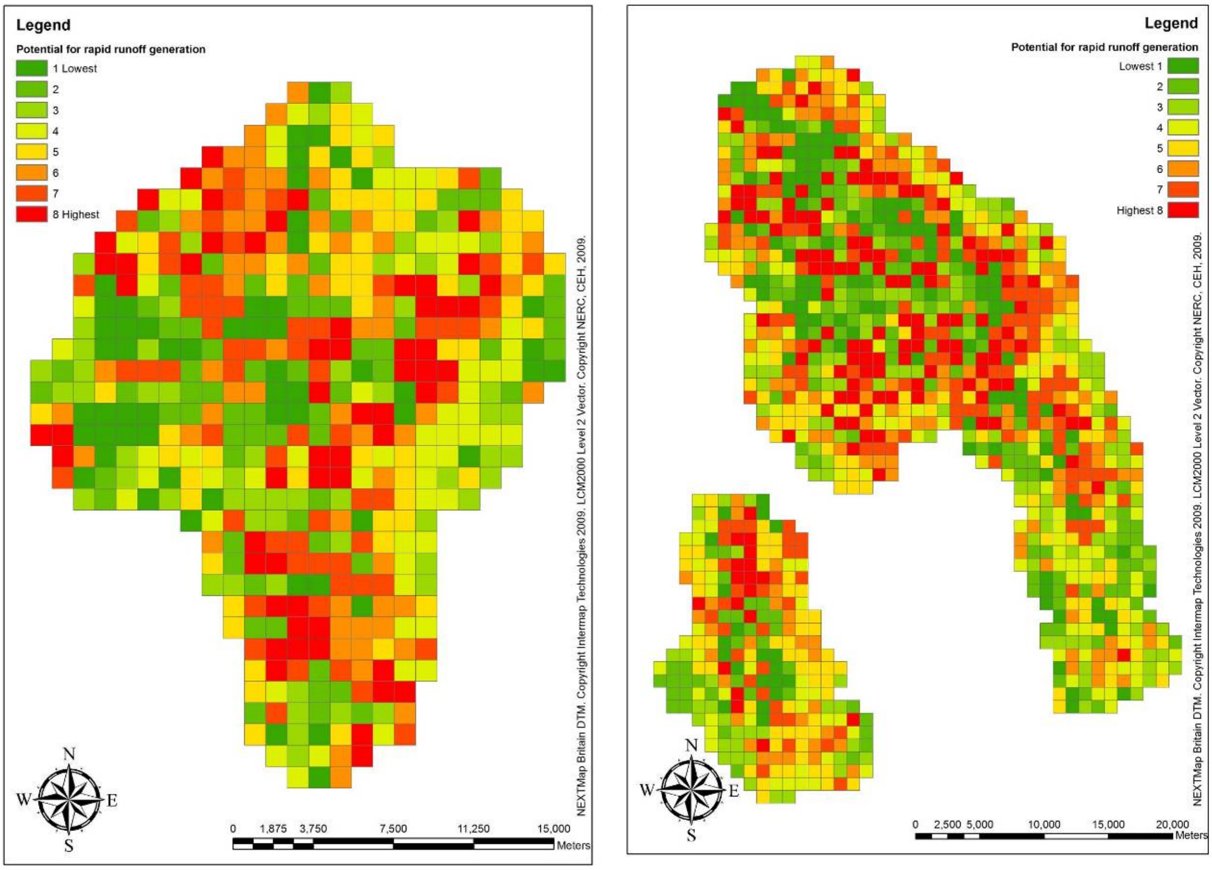


Figure 4.19a,b : A MCE analysis to identify the areas in the (a) Migneint and (b) Peak District with the highest potential to rapidly produce runoff. The analysis is based on the weighted linear summation of elevation, slope, TWI and average overland flow velocity MCE factors.

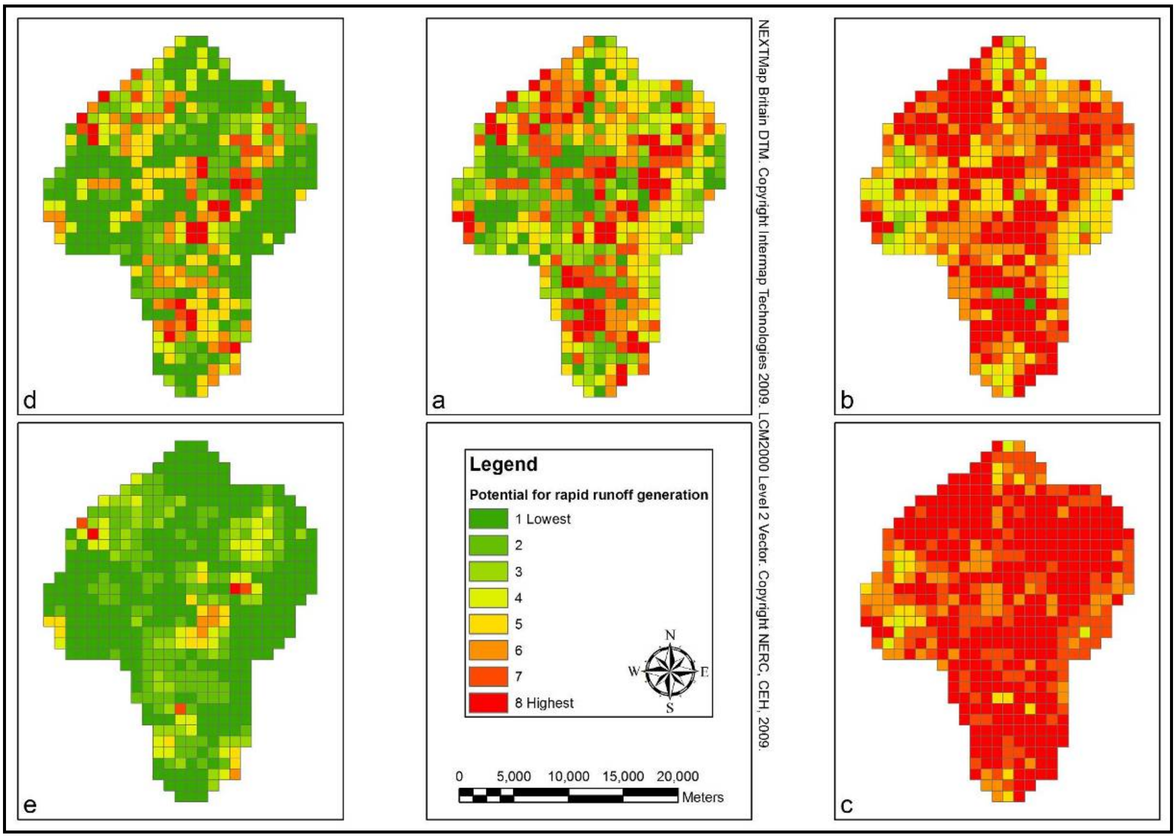


Figure 4.20: The impact of vegetation change on the potential of areas of the Migneint to rapidly produce runoff. The current situation is shown in (a). Shifts in vegetation coverage of 1 and 2 steps towards the degraded end of the Bare-Heather-*Eriophorum*-*Eriophorum*/*Sphagnum* mix-*Sphagnum* spectrum are shown in (b) and (c) respectively. Shifts of 1 and 2 steps towards the pristine end of the spectrum are shown in (d) and (e) respectively.

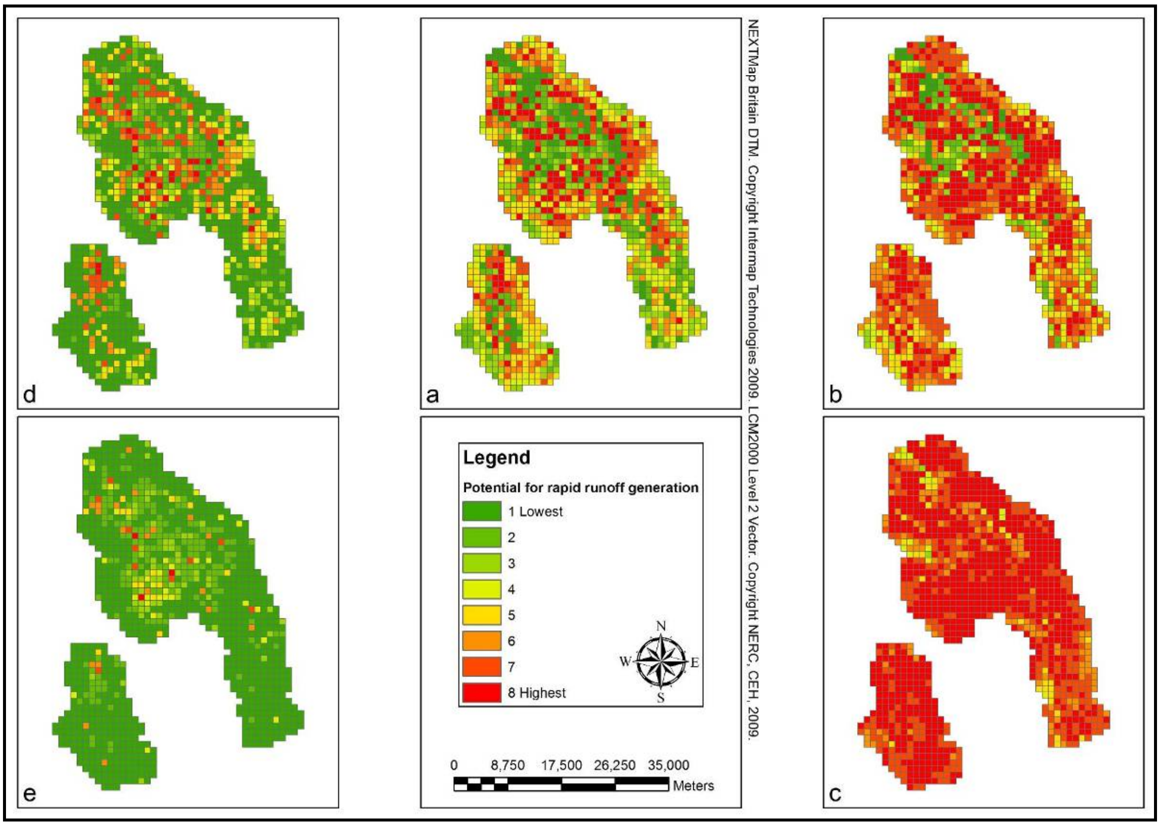


Figure 4.21: The impact of vegetation change on the potential of areas of the Peak District to rapidly produce runoff. See legend for Figure 4.20 above.

4.2.2.4 Summary

The hydrological methodology which has been scoped in this study has been shown to be a fruitful one that could be rolled out effectively to other blanket peatlands across the UK. The results above are indicative of the results that a larger more definitive study, employing careful experimental design to overcome the identified issues, may be able to achieve. A method that applies the same TOPMODEL *m* across the catchment, irrespective of changes in peatland vegetation, is advocated based on values of TOPMODEL *m* estimated for each surface by re-plotting the overland flow velocity observations of Holden *et al*. (2008). A modest simulated reduction in peak discharge is associated with those vegetation re-establishment and management scenarios that involve a significant return toward pristine blanket bog vegetation. However, modest changes in the hydrographs can mean large changes in flood peaks further downstream depending on flood wave synchronicity and connectivity of the river channel network. Hence a large scale flood modelling project is required that needs to be well funded and comprehensive to understand how small scale peatland service changes impact over larger scales when it comes to flood risk. However, **a clear conclusion from the work in this scoping study is that eliminating bare areas (i.e. by encouraging vegetation restoration) should be a priority and any return to a more pristine *Sphagnum* cover elsewhere would be beneficial in terms of delaying flow. In practice, this conclusion is emphasised by the partial association of bare areas with erosional features, so that re-vegetation and/or flow diversion/blocking around eroded channel ways should have high priority.**

However, the following improvements could be made:

a) Areas with better rainfall and flow data would more effectively enable model calibration - Relative comparisons between various scenario simulations were necessary since meteorological data short-comings within the case study catchments inhibited the development of suitably robust rainfall-runoff models able to provide confident predictions of absolute runoff.

b) We need more repeat overland flow velocity observations on a greater range of peatland vegetation types to provide comprehensive coverage and reduce the number of assumptions in reclassifying land cover maps to enable effective modelling. Indeed, the occurrence of land covers such as broad-leaved woodland, deciduous woodland and suburban/rural development within the small catchments identified for study highlight the problems of quantifying the ecosystem services offered specifically by peatlands.

4.2.2.5 Flood storage in lowland peatlands

It is widely recognised that the storage of floodwater on floodplain wetlands can reduce flood magnitude downstream. For example, the UK Flood Studies Report (Natural Environment Research Council, 1975) documented the attenuation of flood peaks on the River Wye by its floodplains. Acreman *et al.* (1993) undertook a modelling study of the River Cherwell in Oxfordshire and showed that separation of floodplains from the river by embankments increases the peak flows downstream by up to 150%. The US Corps of Engineers (1972) calculated that the flood reduction function of 3,800 hectares of floodplain storage on the Charles River, Massachusetts saved US$ 17 million worth of downstream flood damage each year. The Parrett catchment is the primary drainage unit of Somerset Levels and Moors. Because of the low-lying nature of the riparian land on which they are built, many towns and villages along the Parrett, such as Burrowbridge and Bridgwater are at risk of inundation. The Parrett Catchment Project (Forum for the Future, 2005) is seeking to store floodwater temporarily in designated storage areas on farmland in the upper and mid catchment wetlands until the peak flow of floodwater has passed. Currently, six pilot schemes are being developed to demonstrate the approach, learn what is required to implement and increase effective storage capacity by 392,000 m^3.

Acreman *et al*. (2006) calculated flood water storage volume available in soils and ditches of the North Drain catchment (26.5 km^2) of the Somerset Levels and Moors using a GIS. For this study, it was assumed that ditch water levels were at field level within the land parcels where owners had signed-up to high ditch water level agreements (currently 0.68 km^2) and low in the remainder of the catchment (25.8 km^2) as created by current operation of the pumping station at the outlet of the North Drain. The volume of storage available was estimated as 3.58 million m^3; this does not include above ground water storage. Using methods in the Flood Estimation Handbook (Robson and Reed, 1999) this equates to around 84% of the median annual maximum flood (V_{med}) for the catchment.

4.2.3 Water quality regulation
4.2.3.1. Overview

Peatlands, particularly blanket bogs, are significant water supply sources in the UK, notably in Northern England. This ecosystem service is related to high rainfall amount, low evapotranspiration and upland landscape position. Peat occurrence and condition do, however, impact on the quality of raw water supply via dissolved organic carbon (DOC) generation, and on reservoir storage capacity via particulate organic carbon (POC) generation. Water quality in peatland surface waters is also influenced by other environmental drivers, notably atmospheric deposition, with elevated runoff acidity and inorganic N concentrations affecting aquatic biodiversity and recreational fisheries. These impacts may be either mitigated or exacerbated by peatland condition. Finally, runoff from peat headwaters provides an ecosystem service as a source of relatively dilute water, reducing pollutant concentrations in downstream agricultural, urban and industrial areas. The following section summarises progress in the scoping study on quantifying and mapping these ecosystem services, and the effects of change scenarios. The study focused largely on the two upland case study regions (Peak District and Migneint), because their landscape position and aerial extent makes them important sources of water supply and aquatic habitat. At the Thorne and Hatfield, natural surface waters are not present within the site, and as drinking water abstraction is negligible this issue was not identified as important at the stakeholder workshop. Issues relating to water supply in the Somerset Levels are discussed in Section 4.1.4.

4.2.3.2 Volume of water supply
See Section 4.1.4

4.2.3.3 Upland water quality

<u>Current status, historic condition, and baseline scenario</u>
During the last century, the dominant driver of water quality change in the UK uplands has been atmospheric pollution. Generated remotely via fossil fuel burning and agriculture, this is effectively an externally imposed driver of change in peatlands. We therefore took the sequence of historic and projected future sulphur (S) and nitrogen (N) deposition as our baseline scenario, and used the MAGIC model (Cosby et al., 2001) to estimate water quality under pre-industrial reference conditions, and at three time points: 1970, 2005 and 2020. MAGIC simulations were obtained from a large set of model applications to surface waters across England and Wales for the Defra Critical Loads and Dynamic Modelling project (for details see Evans et al., 2007). The dataset used comprised 16 lakes and rivers on the Migneint, and 28 reservoirs and rivers in the Peak District. For each region, these model runs were used to derive a mean runoff chemistry at each time point for 100% peat and 0% peat catchment 'end members'. A simple mixing model was then used to generate simulated water quality for all streams within the moorland area at each time point and for each land-use scenario.

MAGIC simulations (Figures 4.22, 4.23) show current conditions, and modelled historic and future water quality changes. In both areas, peats generate runoff which is naturally more acid than that from adjacent mineral soils due to their lower base cation buffering capacity, and have been further acidified by atmospheric pollution. In the Peak District, very high pollutant inputs have led to highly ecologically damaging surface water quality, with mean Acid Neutralising Capacity (ANC) below zero. Impacts on water quality in the less polluted Migneint have been milder, but still sufficient to cause fisheries losses in lakes and rivers draining the peat areas.

While sensitive to acidification, functioning peats perform an important water quality buffering role by retaining atmospheric pollutants. Accumulating peats with high water tables can store deposited sulphate (SO_4), by reducing it to organic sulphur forms. This is evident in both regions, and has significantly reduced the degree of acidification in peats and peat runoff. However SO_4 leaching from the Peak District peats is comparatively high (> 100 μeq l^{-1} in 2005), and water table lowering, particularly associated with gully erosion, appears to have reduced peat capacity to retain deposited SO_4.

Most peatlands are also highly effective at retaining atmospheric N. As nutrient-poor systems, most or all incoming N is incorporated in plant and microbial biomass, and ultimately transferred to long-term storage in the peat. High water tables also favour NO_3 reduction to less mobile NH_4. In the Migneint these processes result in near-100% retention of incoming N, buffering the system against eutrophication and acidification. In the Peak District, however, this N retention service has been severely compromised, to the extent that NO_3 leaching from peats is close to that from mineral soils (Helliwell et al., 2007). The key driver of this breakdown in N retention appears to be the loss of *Sphagnum* and other bryophyte species, which have a key role in retaining nitrogen when it is first deposited (Curtis et al., 2005). The catastrophic loss of *Sphagnum* from the South Pennines peatlands during the 20th century was attributed to acute atmospheric SO_2 pollution (Fergusen and Lee, 1983), probably accentuated by moorland burning and erosion. Bare ground is generally also associated with elevated NO_3 leaching (e.g. Helliwell et al., 2007), while Cresser et al. (2004) found higher NO_3 concentrations streams draining recently burnt areas, compared to unburnt areas.

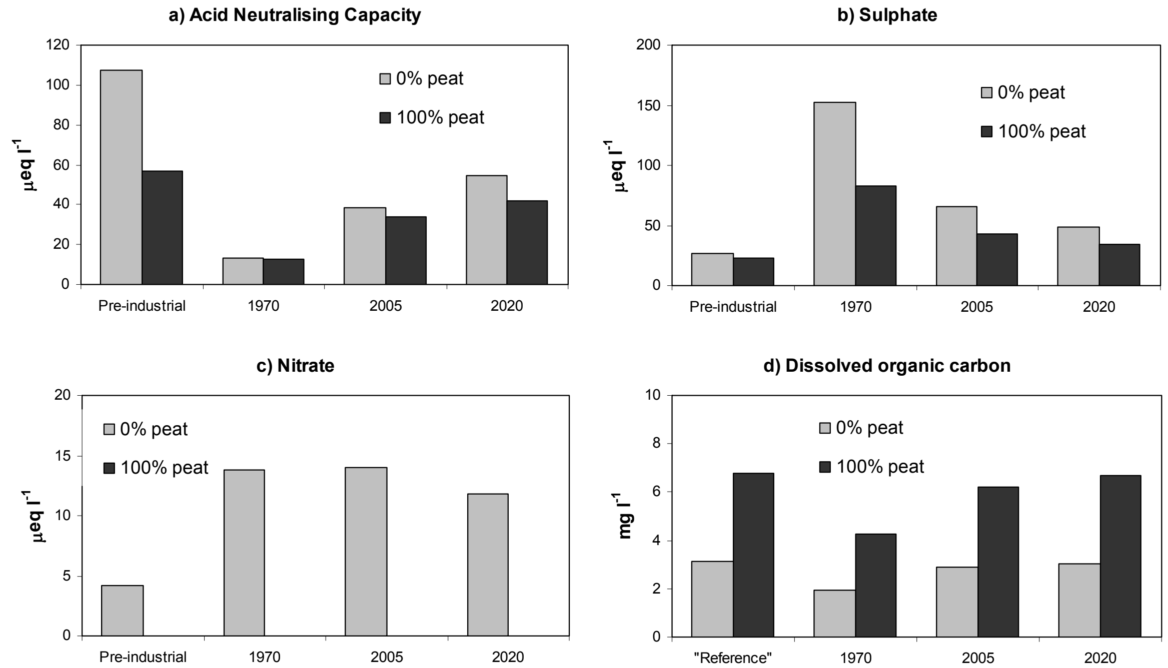


Figure 4.22: Modelled average water quality of runoff from peat and non-peat catchments in the Migneint, for pre-industrial (reference) conditions, 1970, 2005 and 2020, as a function of atmospheric S and N deposition.

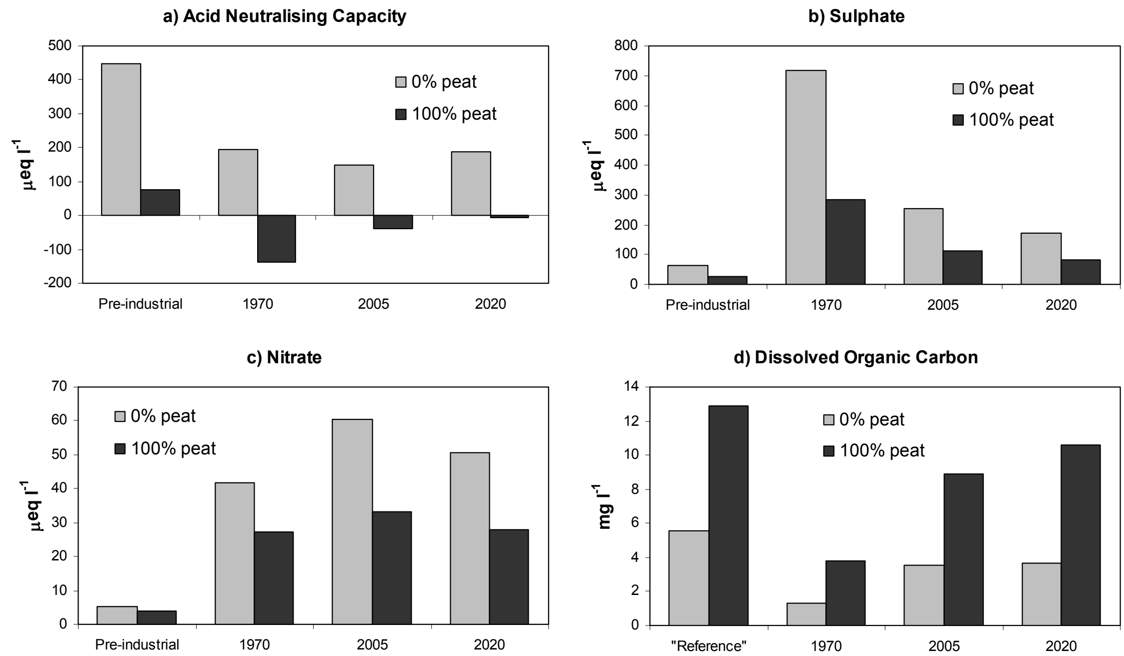


Figure 4.23: Modelled average water quality of runoff from peat and non-peat catchments in the Peak District, for pre-industrial (reference) conditions, 1970, 2005 and 2020, as a function of atmospheric S and N deposition.

Peats naturally produce large amounts of dissolved organic carbon (DOC), due to incomplete organic matter composition under waterlogged conditions. Because high-DOC water is problematic and expensive to treat, this can arguably be considered an ecosystem 'disservice', although DOC may impart some benefits to aquatic ecosystems (e.g. as an energy source and by providing aquatic invertebrates with protection against harmful ultraviolet radiation). DOC concentrations have increased markedly in recent decades, which has been interpreted as evidence of peat degradation. However, subsequent work suggests that decreasing acid deposition may have contributed to these increases. We therefore used an empirical relationship derived by Monteith et al. (2007) for 400 European and North American surface waters, which relates changes in DOC concentration to changes in atmospheric deposition. This was was to simulate changes in 'baseline' surface water DOC as a function of MAGIC-modelled SO_4 and base cation concentrations from 1970 to 2020. At the 1970 peak of S deposition, results suggest around 40% suppression of peat DOC loss in the Migneint, versus 70% suppression in the Peak District (Figures 4.22d, 4.23d). The model suggests a return to reference conditions in the Migneint by 2020, but still somewhat reduced DOC losses from the Peak District.

Assessment of future land-use scenarios for water quality

We evaluated each of the land-management scenarios (from Table 4.1), based on available literature and data on the impacts of each management option on water quality, as follows:

1. Business as usual: Maintenance of current management in each region, but taking into account reductions in atmospheric pollution by 2020.

2. Re-wetting: Restoration of a water table close to the surface by blocking of drainage ditches and (in the Peak District) erosion gullies. This is anticipated to lead to enhanced peat SO_4 retention. For the Peak District, it was estimated that water table restoration could generate a 50% reduction in SO_4 leaching, based on a comparison of gullied and intact catchments on Bleaklow by Daniels et al (2008). For the less impacted Migneint, it was assumed that the maximum achievable reduction in SO_4 through ditch-blocking would be to the lowest simulated 1850 SO_4 concentration of any individual modelled site within the region, equivalent to a 25% reduction relative to the baseline scenario. Based on the study by Wallage et al. (2006), ditch-blocking was estimated to lead to a 25% reduction in DOC could be achieved by ditch blocking. However it must be emphasised that there is great uncertainty in the magnitude and even the direction of this response, with other studies (e.g. Worrall et al., 2007) showing contrasting results.

3. Re-vegetation: Since there is little evidence of vegetation loss in the Migneint, this scenario was only appropriate to the Peak District. Here, this was considered to imply the restoration of a functioning *Sphagnum* cover, leading to the restoration of the N-retention function of the peatland. This was simulated by assuming that proportional retention of N deposition in the Peak District peats would increase to the levels observed in the Migneint. In addition, it was assumed that establishment of *Sphagnum* cover would require cessation of current moorland burning for grouse management. Yallop et al (2009) found a strong positive relationship between DOC and area of recent burn in a range of Pennine catchments. Taking their data for peat-dominated catchments only, downscaling observed relationships to measured long-term mean DOC concentrations for peats, and assuming (based on their data) an average of 16% recent burn area for the Peak District, it was estimated that cessation of this burning could lead to an average 40% reduction in surface water DOC concentrations. Again, it must be emphasised that this estimate is uncertain; few data on burning impacts on water quality are available, and other (experimental rather than correlational) studies have not shown the same DOC response to managed burning (Ward et al., 2007; Worrall and Adamson, 2007).

4. Conservation-led re-wilding: This scenario was considered to involve a combination of re-vegetation, re-wetting, and cessation of burning and grazing. Water quality impacts were calculated by taking a 'best case' combination of predicted responses to all individual scenarios.

5. Food security: At the upland case study sites, this scenario was considered likely involve an increase in (sheep) grazing density, but no fertiliser or lime application (as might occur in a lowland bog during conversion to arable production). Although it is possible that changes in grazing density might be expected to impact on water quality (for example via changes in vegetation and nutrient cycling), there is insufficient published evidence available to make clear predictions. Therefore, the only water quality impact modelled under this scenario was reduced DOC loss in the Peak District, due to cessation of grouse moor burning.

6. Grouse economy: In the Peak District, much of which is already managed for grouse, this scenario was considered to represent business as usual, which is why there is no difference to the present situation. In the Migneint, which is not currently managed for grouse, it was assumed that rates of burning would increase to current Peak District levels. Impacts on DOC concentrations were again calculated based on the relationships observed for peat catchments by Yallop et al (2009).

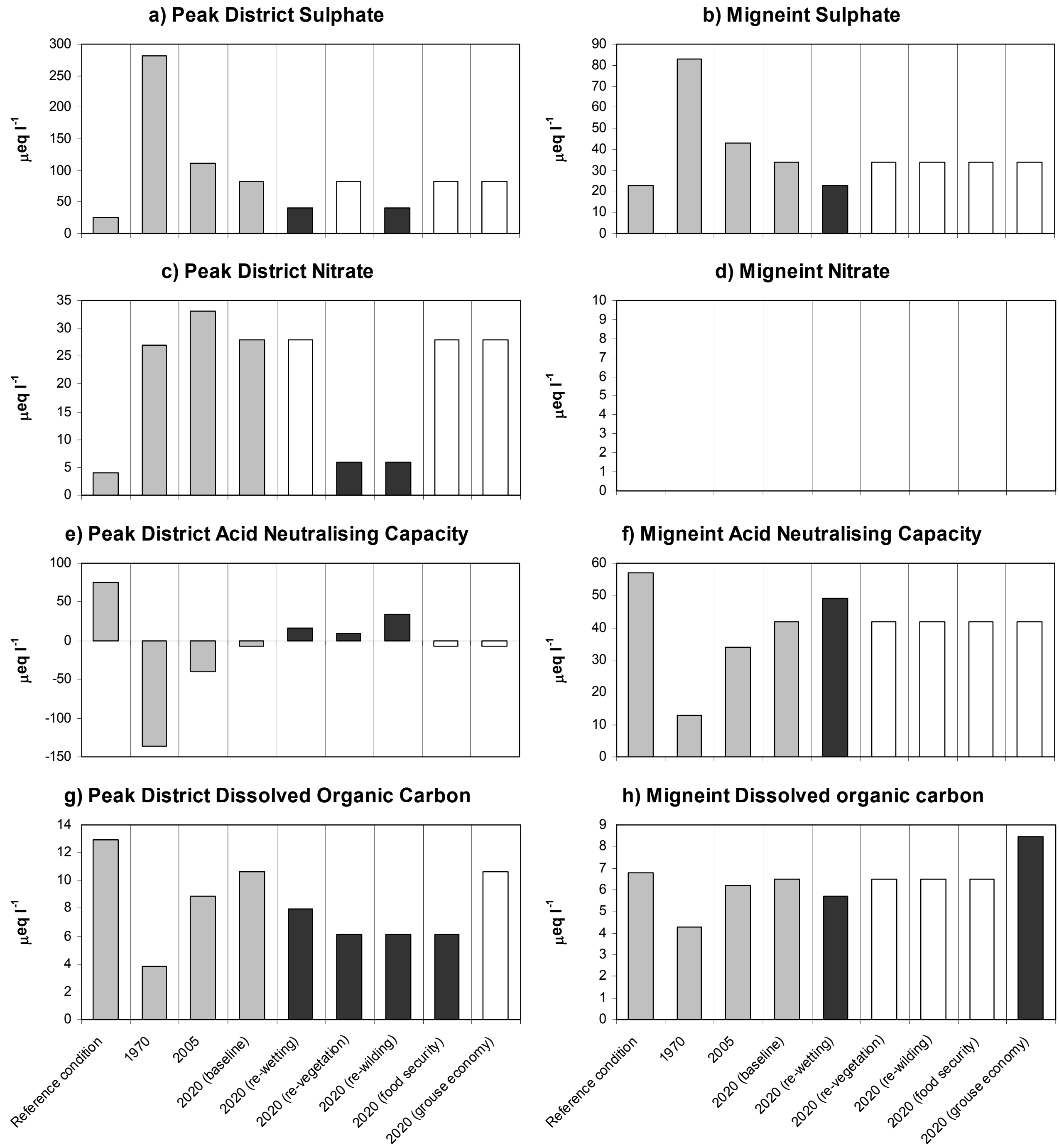


Figure 4.24: Modelled average water quality of runoff from peat catchments in the Peak District and Migneint, showing historic and baseline 2020 scenario (grey), and future land-use scenarios. Dark bars indicate a change associated with that scenario, white bars indicate no change relative to 2020 baseline.

In addition to estimated changes in individual solute concentrations, the combined effect of these changes on surface water acidity were modelled by using MAGIC to simulate ANC in 2020. In each case, this simulation was carried out based on a change in peatland management from 2010 onwards. Predicted water quality for 2020 was mapped, as for the baseline scenario, using a mixing model with simulated peat and non-peat end-members. The quality of the non-peat end-member was held constant, so that the specific impacts of changes in peat management could be evaluated. The following maps (Figures 4.25 to 4.32) show mapped predictions of water quality for: pre-industrial reference conditions; 1970; 2005; in 2020 under the baseline scenario; and in 2020 under management scenarios for which concentrations of the mapped water quality parameter differ from those under the baseline scenario.

In the case of surface water acidity, many water quality improvements have already been achieved through reductions in atmospheric pollution since the 1970s. However for the Peak District in particular it appears possible to achieve significant additional water quality benefits through peat restoration. The assessment indicates that restoration of a fully functioning *Sphagnum* cover (and associated cessation of burning) in the Peak District would have considerable positive impacts in terms of DOC, NO_3 and acidity levels in surface waters. Re-wetting would also have benefits in terms of DOC, SO_4 leaching and acidity, while ‘re-wilding’ would combine the benefits of these two scenarios, having the greatest positive impact on ANC (raising it above the UK’s 20 μeq l^{-1} critical acidity threshold for freshwaters). For the Migneint, a comparatively modest reduction in SO_4 and DOC, and increase in ANC, is predicted for the re-wetting scenario. Other restoration scenarios are less applicable to this region, reflecting lower levels of past landscape degradation. However, it is predicted that a return to land-management for grouse rearing (with associated burning) could increase DOC losses considerably, to levels above the natural reference condition.

Nitrate, Peak District

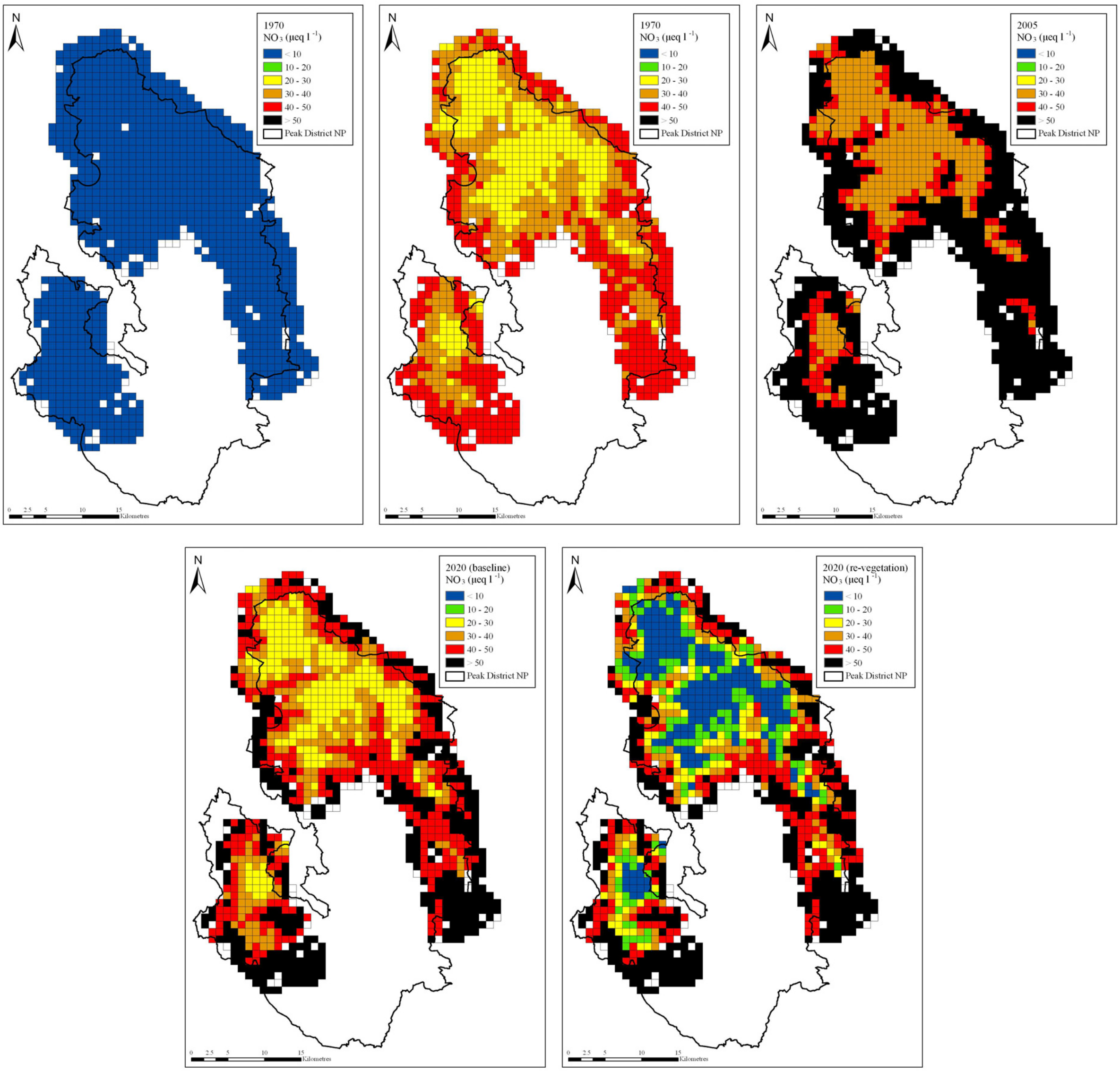


Figure 4.25: Modelled average nitrate concentrations in the Peak District, for pre-industrial (reference) conditions, 1970, 2005 and 2020 under different management scenarios.

Nitrate, Migneint

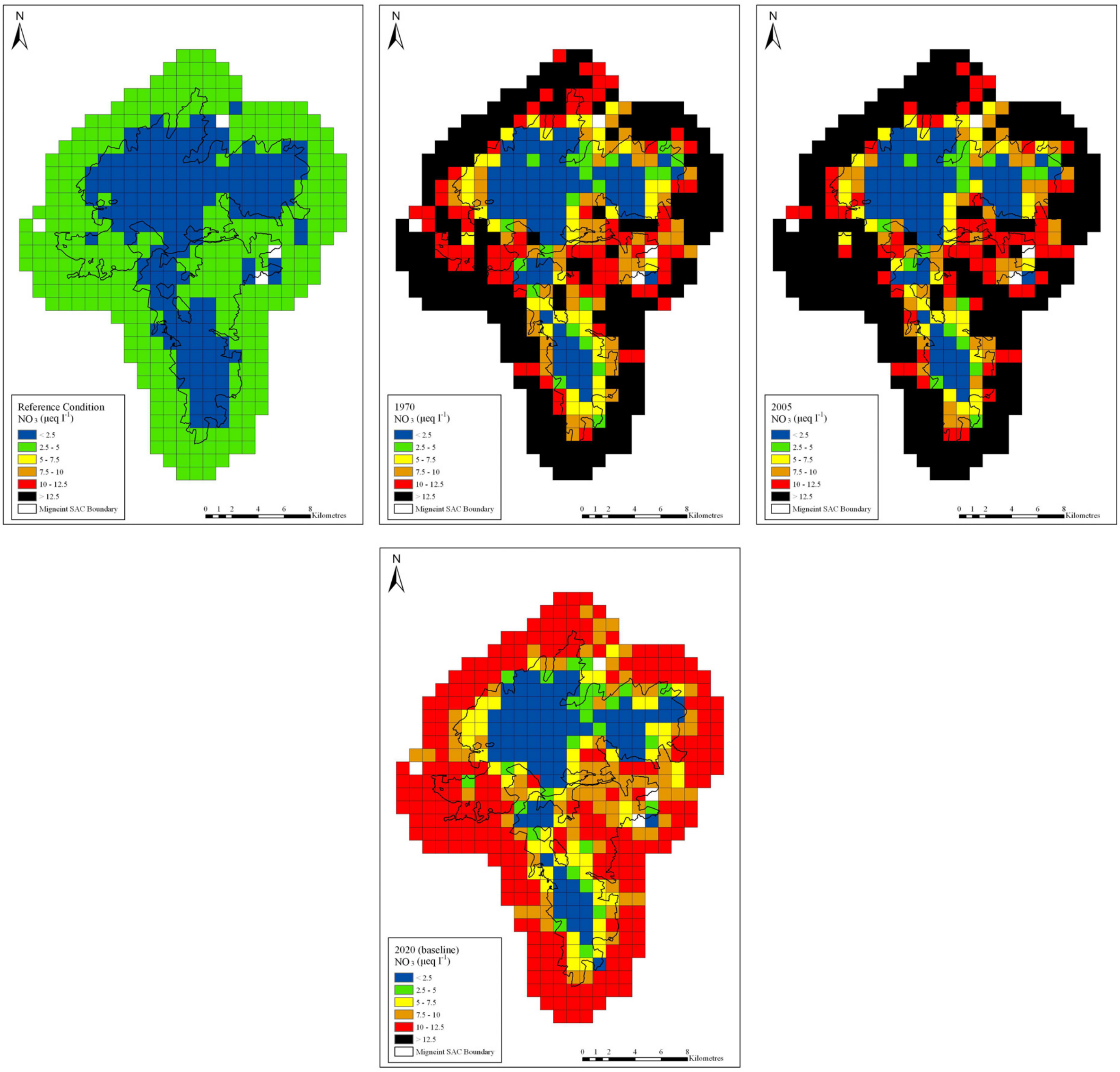


Figure 4.26: Modelled average nitrate concentrations in the Migneint, for pre-industrial (reference) conditions, 1970, 2005 and 2020 under different management scenarios.

Sulphate, Peak District

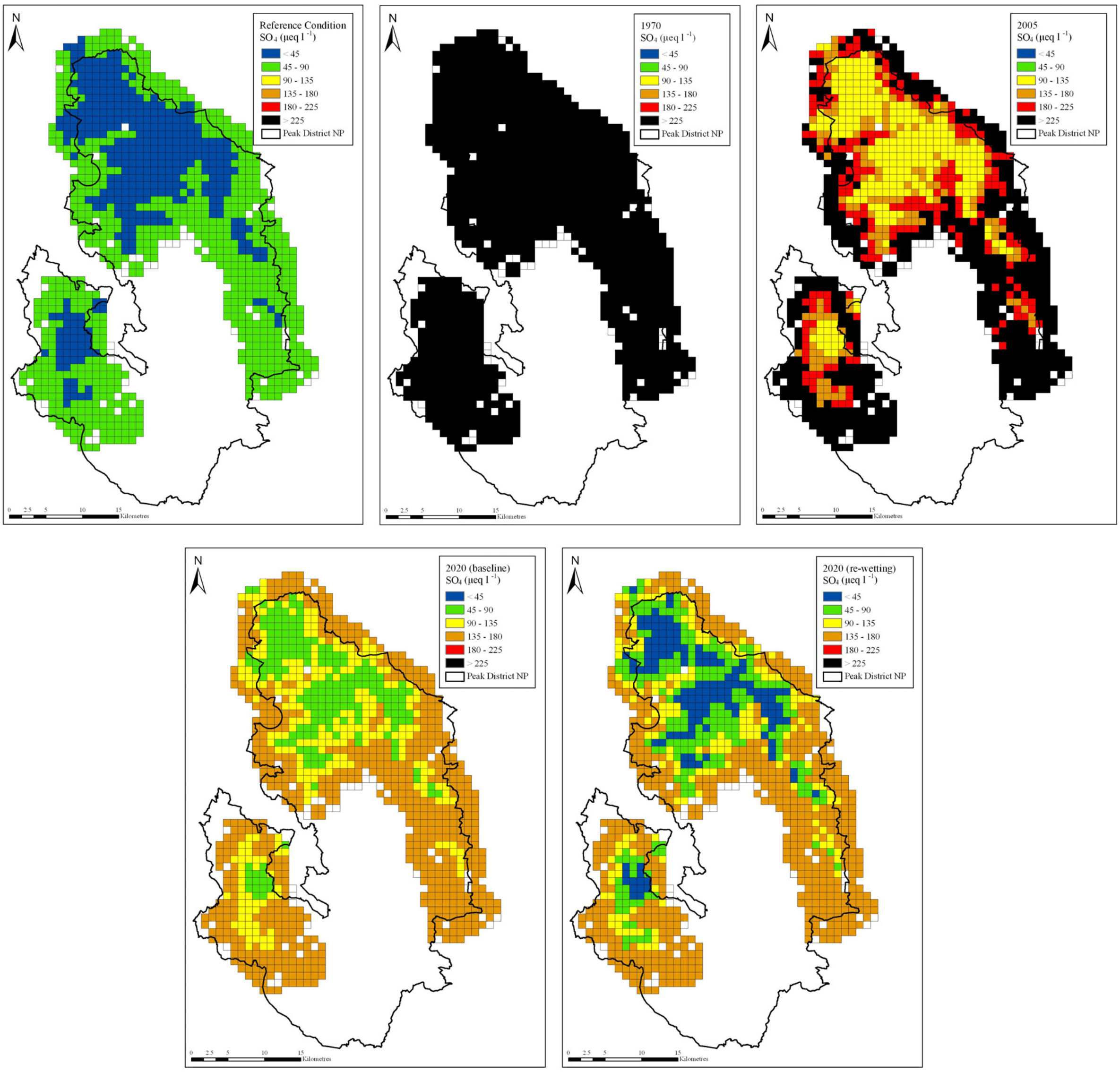


Figure 4.27: Modelled average sulphate concentrations in the Peak District, for pre-industrial (reference) conditions, 1970, 2005 and 2020 under different management scenarios.

Sulphate, Migneint

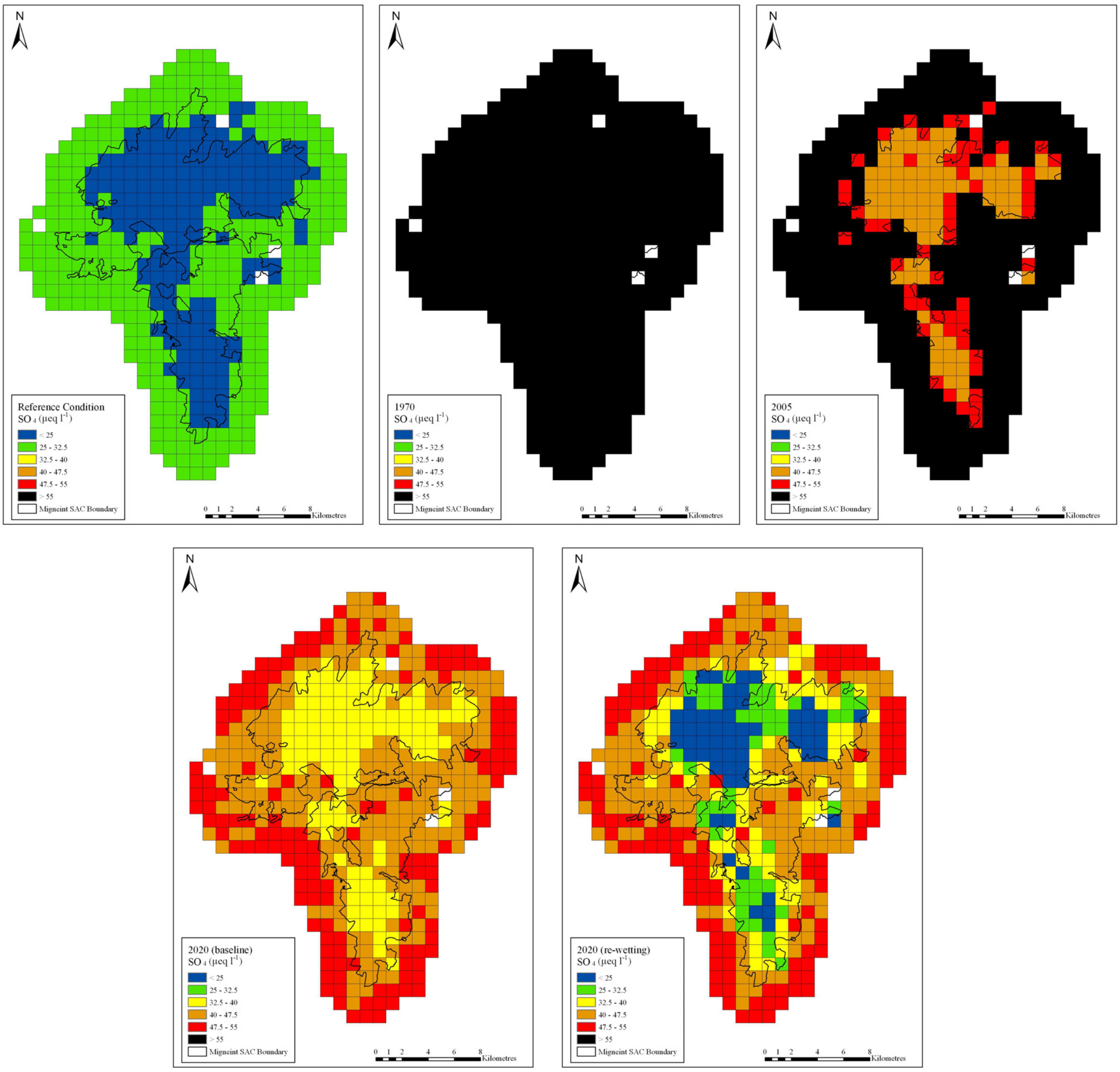


Figure 4.28: Modelled average sulphate concentrations in the Migneint, for pre-industrial (reference) conditions, 1970, 2005 and 2020 under different management scenarios.

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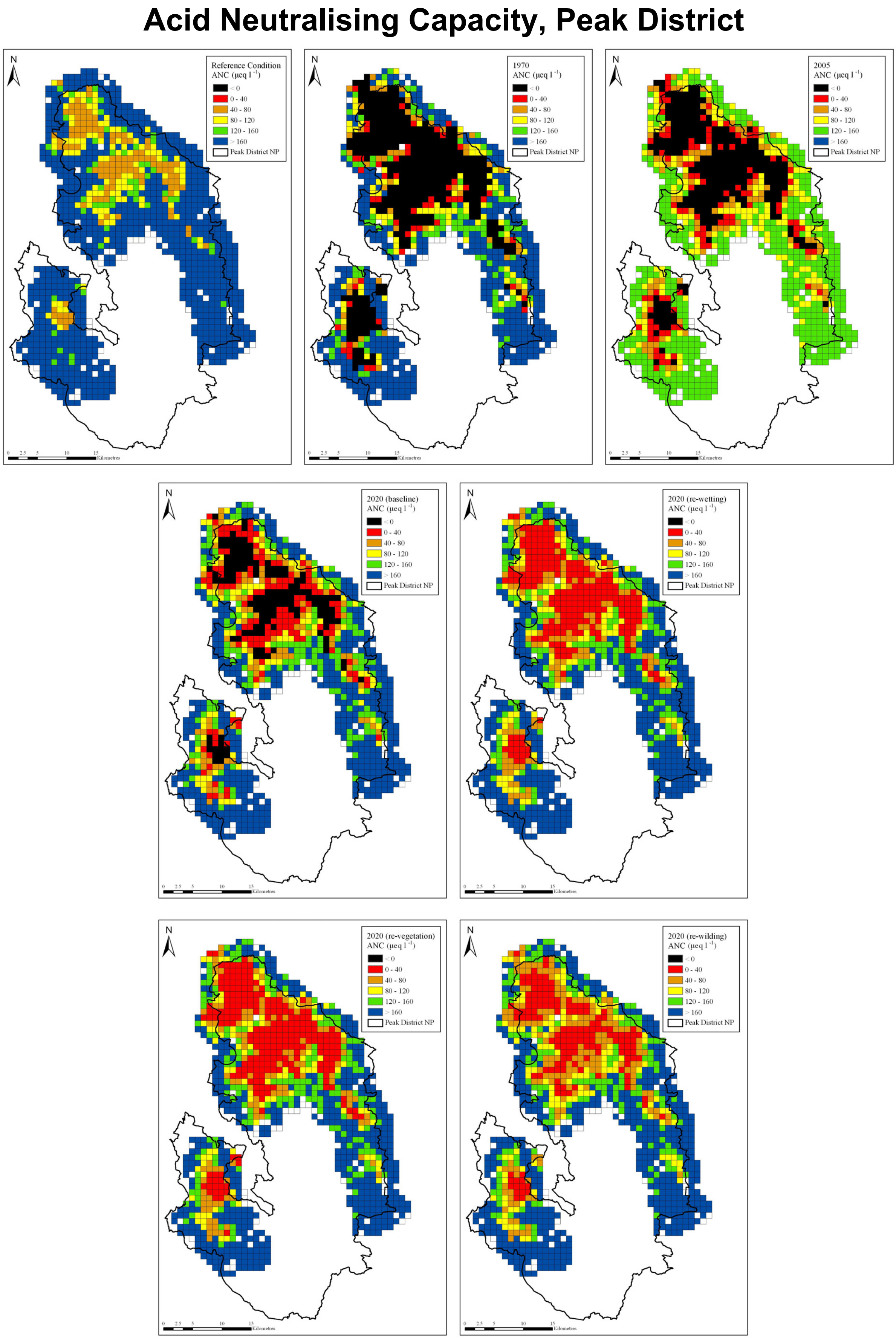


Figure 4.29: Modelled average Acid Neutralising Capacity in the Peak District, for pre-industrial (reference) conditions, 1970, 2005 and 2020 under different management scenarios.

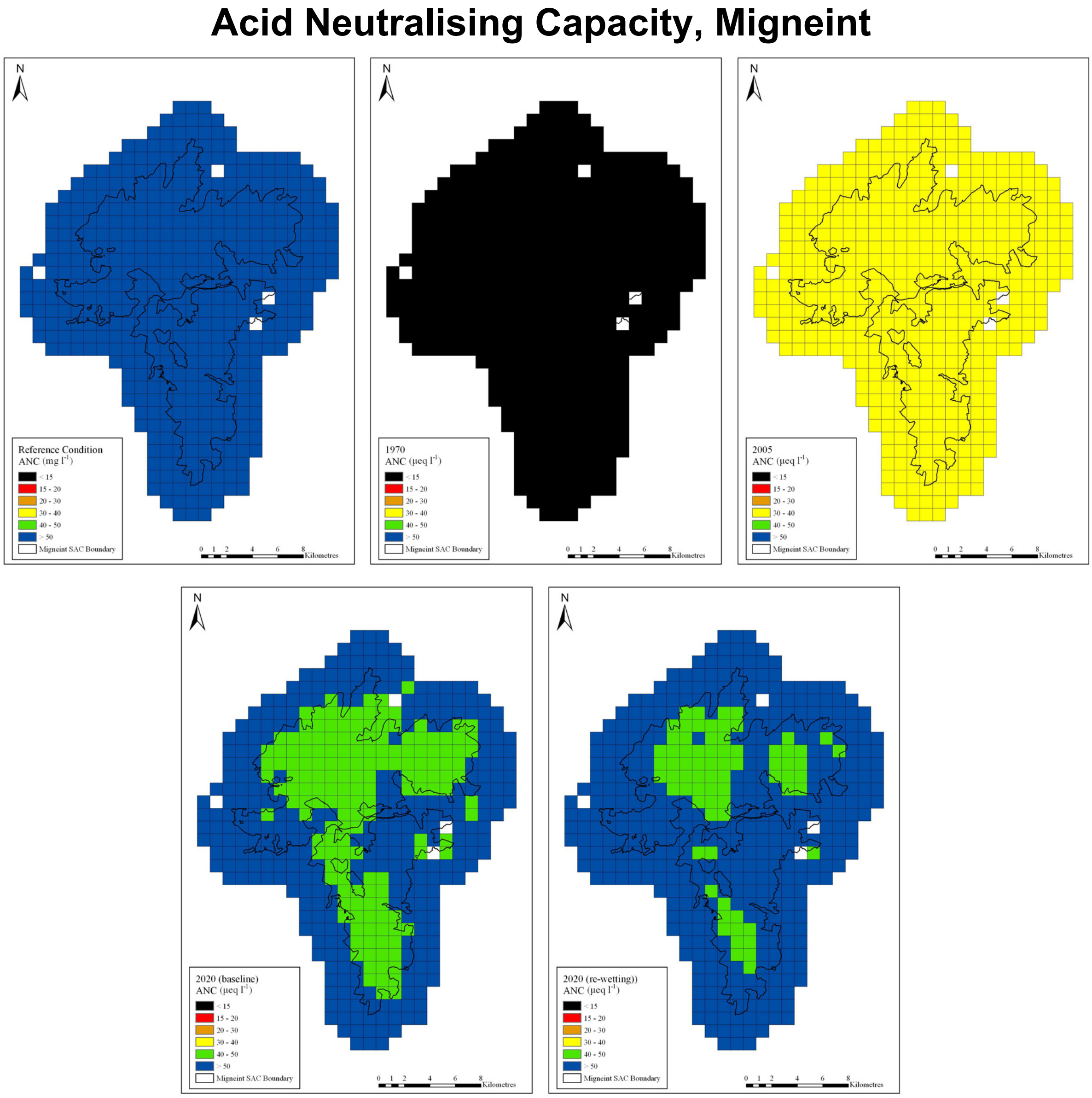


Figure 4.30: Modelled average Acid Neutralising Capacity in the Migneint, for pre-industrial (reference) conditions, 1970, 2005 and 2020 under different management scenarios.

Dissolved Organic Carbon, Peak District

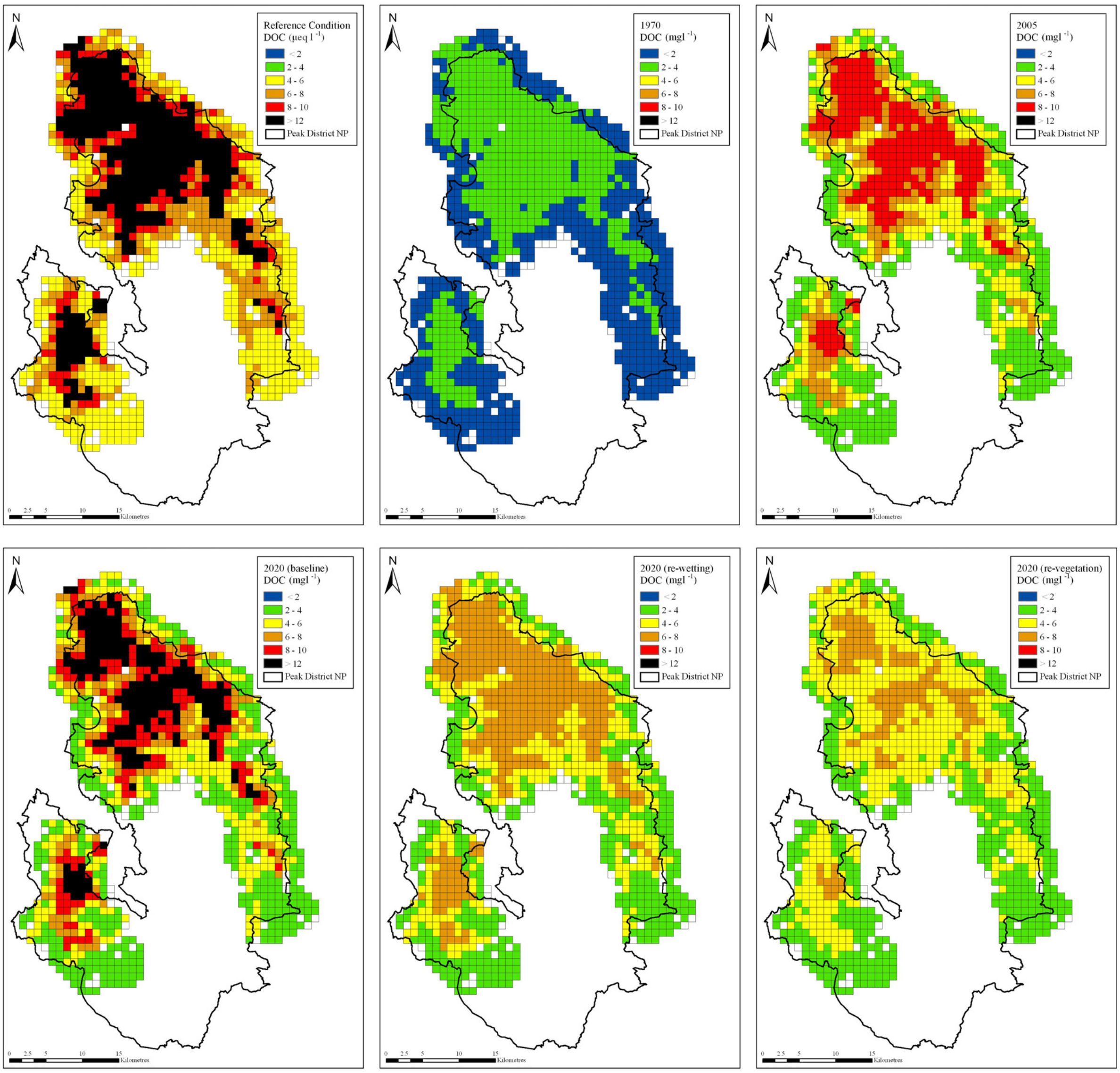


Figure 4.31: Modelled average Dissolved Organic Carbon concentration in the Peak District, for pre-industrial (reference) conditions, 1970, 2005 and 2020 under different management scenarios.

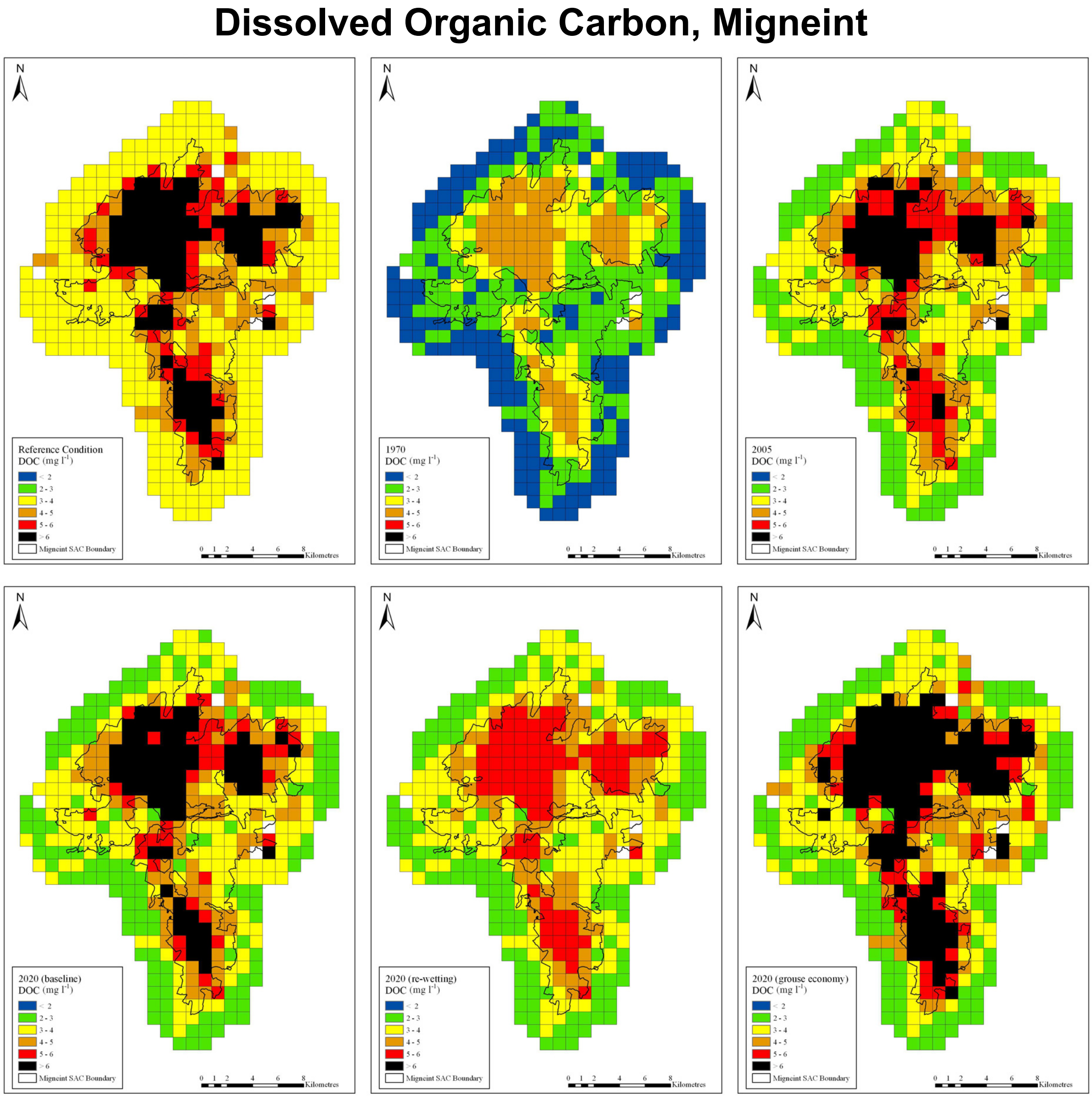


Figure 4.32: Modelled average Dissolved Organic Carbon concentration in the Migneint for pre-industrial (reference) conditions, 1970, 2005 and 2020 under different management scenarios.

Particulate organic carbon production

Many areas of upland blanket peat are degraded and actively eroding. Peat erosion has a number of negative environmental consequences ranging from degradation of the natural landscape through to impact on water quality due to release of heavy metals (Rothwell et al., 2005) and loss of water storage capacity in reservoirs due to deposition of aquatic transported particulate peat. The main causes of peatland erosion include changes in climate, atmospheric pollution (in particular sulphur and nitrogen deposition), over grazing by sheep, drainage and burning (see Holden et al., 2007a and b). However, quantifying the relative importance of each one of these factors is difficult and yet to be achieved. Direct monitoring of suspended sediment outputs from UK upland catchments have produced sediment yield estimates of <1 t km^{-2} a^{-1} in intact Scottish peatlands (Hope et al., 1997) to around 100 t km^{-2} a^{-1} in heavily eroded peatlands of the southern Pennines (Evans et al., 2006), whilst UK reservoir sedimentation studies have produced estimates of sediment yields ranging from 25 to around 200 t km^{-2} a^{-1} (Yeloff et al., 2005). The difference in estimates between the methods partially reflects the fact that the reservoir studies represent estimates of long-term average sediment yield over the life of the reservoir, and give no indication to the temporal variation in sediment flux occurring. In addition, sedimentation studies do not differentiate between the different potential sources of sediment. For example, recent work by Holliday et al. (2008) found that approximately 54% of the annual sediment yield of 33.3 t km^{-2} a^{-1} for Burnhope reservoir in the north Pennines came from stream inputs, while the rest originated from actively eroding reservoir shoreline. In addition, quantifying the amount of suspended sediment that originates from the hillslope is difficult. For example, Evans and Warburton (2005) showed that while gully erosion was high in the Rough Sike catchment in the North Pennies, poor connectivity between the hillslope and the stream channel minimised the impact of peat erosion in generating suspended sediment fluxes.

Very few studies quantifying sediment yield differentiate between the organic and inorganic fraction of the sediment which would help to identify the proportion of sediment originating from blanket peat. In those that have, the organic sediment yield was found to represent anywhere between 15 and 73% of the total sediment yield (Table 4.8).

Table 4.8: Estimates of sediment yield for catchment containing areas of upland peat

Author	**Catchment**	**Sediment yield ($t\ km^{-2}\ a^{-1}$)**	**Organic fraction ($t\ km^{-2}\ a^{-1}$)**
Labadz et al (1991)	Wessenden Valley Reservoirs, south Pennines	204	39
Hutchinson (1995)	Howden Reservoir, Derbyshire	127	31
Holliday et al (2008)	Burnhope Reservoir, North Pennines	33	5
Yeloff et al (2005)	March Haigh Reservoir, south Pennines	27.8 (1976-1984) 9.6 (1984-2000)	8.1 (1976-1984) 1.8 (1984-2000)
Evans et al (2006)	Upper North Grain, south Pennines Rough Sike, north Pennines	267 44	195 31

Given that the sediment within a reservoir originates from a variety of sources including peat erosion from gullies, stream/river bank erosion and reservoir bank erosion and the paucity of data that quantify the impact of different peatland management regimes on organic sediment production and transport we were unable provide any quantitative information on sedimentation rates for reservoirs within the case study sites. However, Evans et al. (2005) have highlighted that the degree of vegetation or re-vegetation of a peatland is important in controlling the suspended sediment flux either through its role in limiting sediment production on intact surfaces or in reducing slope-channel linkage in eroding but re-vegetating systems while Holden et al. (2007c) showed that blocking drains in blanket peatland could reduce suspended sediment (and hence POC) loss, with at least 50 times more sediment coming from open drains than from blocked drains. However, more studies are needed across a range of blanket peatland sites to provide a more general picture of how ditch blocking and re-vegetation affects sediment and POC losses at both the hillslope and catchment scale. Once organic suspended sediment enters a reservoir it may be deposited and end up in long-term sedimentary storage where it may reside for decades or centuries or it may be oxidised in the fluvial system and then lost to the atmosphere as CO_2.

4.2.3.4 Downstream water quality

For the scoping study, we have focused on the impacts of peat management on upland water quality. However, water draining from peatland (and other upland) areas is generally of a higher quality than that from downstream agricultural and industrial areas. As a source of clean water, peatlands thus deliver a remote ecosystem service through the dilution of diffuse and point-source pollution inputs in the lower reaches of rivers with peatland headwaters. At Thorne and Hatfield Moors, where there are no surface waters within the sites themselves, this provision of clean water to rivers draining surrounding arable land may be particularly important. To fully evaluate this would require the integrated modelling of upland and lowland water quality, which is beyond the scope of the current project. However, estimates of the proportion of flow in rivers draining the study areas (e.g. Figure 4.33) partially illustrates the spatial extent over which this ecosystem service is likely to operate.

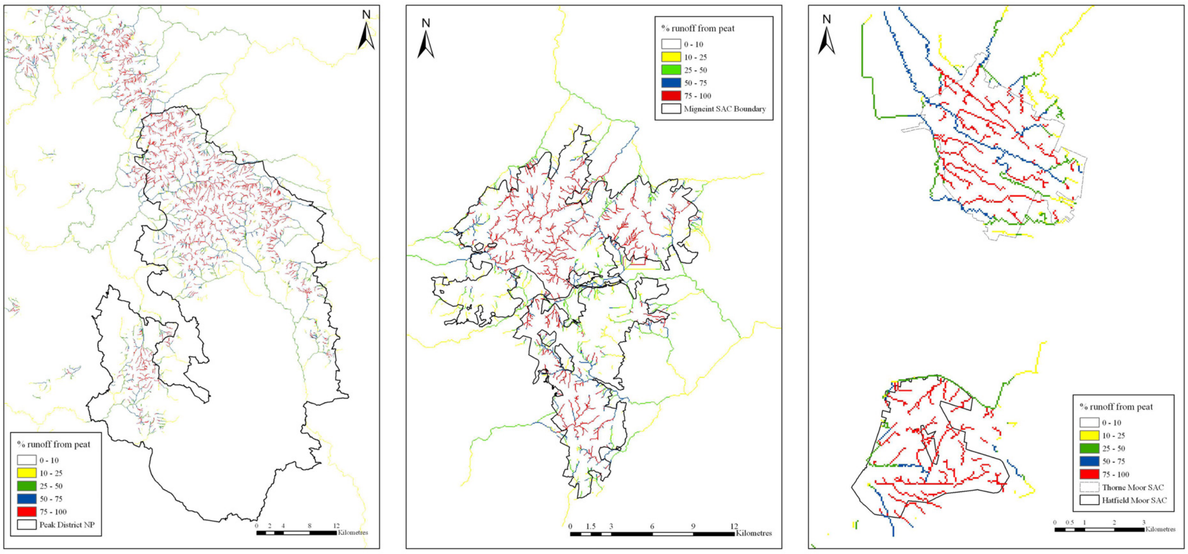


Figure 4.33: Average percentage of streamflow derived from peat areas in rivers within and downstream of the Peak District, Migneint and Thorne & Hatfield study areas, indicative of the potential of peat runoff to dilute downstream pollutant inputs..

4.2.3.5 Summary and research gaps

In some respects (e.g. drinking water provision, pollutant retention and dilution) peats provide a clear and quantifiable ecosystem service. In others (notably DOC production) the presence of peat is arguably detrimental to water quality, at least in relation to drinking water treatment. Many of the water quality changes that have occurred in peatlands have been externally imposed, primarily through atmospheric deposition. However **peat condition and management can influence runoff water quality in a number of respects, including POC loss, N and S retention, and DOC production.** The Migneint, although affected by extensive ditching and atmospheric deposition, appears to retain important functions of S and N retention, and there is little evidence that DOC loss has been substantially increased by management. In the Peak District, on the other hand, severe acidification has been exacerbated by the loss of S and N retention functions. DOC loss may have been increased by burning, but also appears to have been suppressed by past acidification, with a part of the recent increases therefore linked to subsequent ecosystem recovery rather than degradation. There is also some evidence that peat gullying could have suppressed DOC loss.

This assessment is necessarily preliminary, since the quantitative understanding and process models required to fully evaluate the water quality implications of all management scenarios and combinations remain incomplete. **The overall impact of gullying and ditch blocking on DOC, N, S and acidity remains uncertain, as does the impact of water table on N retention**. Other peat ecosystem services relating to the retention and release of heavy metal and persistent organic pollutants could not be evaluated on the timescale of the scoping study, but merit future attention. Finally, **further work is required to quantify the impact of peat condition on the quantity and timing of runoff in relation to water supply, and to the dilution of diffuse and point-source pollution**. This last ecosystem service, delivered downstream of the peat itself, appears likely to be of high economic value, but to date has received relatively little attention.

4.3 Cultural Services

Cultural services encompass a range of services, that are traditionally valued as 'public goods', such as opportunities for recreation and enjoyment in nature as well as spiritual, religious, aesthetic and educational services. Furthermore, peatlands may offer a sense of place and have high cultural heritage value by preserving the historic environment and often being associated with traditional low intensity land management. We class opportunities for field sports as recreational service, as this serves more for recreational enjoyment rather than primarily food provision through game.

Cultural Services may have associated considerable economies, such as tourism and field sports, but are very much mediated through cultural values and preferences in society (Curry 2009), and may be perceived differently by different sectors in society (Suckall 2009). It is notable, that the Millennium Assessment (Fig 1.1) assigned only low potential for mediation through socio-economic factors, but moreover, only weak links between cultural services and human well-being. Nevertheless, the majority of (upland) peatlands in England and Wales have received national and international landscape and biodiversity designations, and it was the strong Access Movement, culminating in the Kinder Mass Trespass in the Peak District, that led to the Countryside and Wildlife Act in 1949 and creation of National Parks, now sixty years ago. This cultural driver has in effect safeguarded many of the other ecosystem services of peatlands through protection from development and other drivers.

In the following section, we focus on recreation as main service given in the Defra brief, and only briefly describe some of the others. There is an extensive area of work on landscape aesthetics and landscape character, which is now a major policy driver for planning through the European Landscape Convention (Council of Europe, 2000) that came into force in the UK in 2007 (see also the recent Natural England report on Cultural Services, Natural England 2009c). The conservation of historic environment is also a crucial service of peat environments, but for this scoping study this is only reviewed briefly.

4.3.1 Provision of recreation services

4.3.1.1 Mapping approach

The value of the ecosystem service provided through recreation is difficult to measure and as such we have chosen to model the service in three different ways. The first methods looks at the availability of recreation opportunities on peatlands (supply), the second assesses the accessibility of peatlands as a measure of its recreational opportunity (supply), and the last expert survey assesses realised demand by observed actual visitor numbers who use the peatland environment.

There is insufficient data on previous and future anticipated recreational use of the landscape, and recreational use does not seem to be significantly influenced by the chosen management scenarios, as explained below. Therefore, we only provide maps of the present opportunities within the landscape (Tab 4.9, Fig 4.34a,d).

4.3.1.2 Recreational opportunity mapping (supply)

The previous model focused on the actual use of the four study sites whereas opportunity mapping looks at the availability of infrastructure so that individuals can effectively (and with ease) use the four peatland systems for recreational activities. Therefore, the model looks at the provision of facilities required for recreation and maps their density. The model does not consider biodiversity or site condition as a metric for recreational preferences because there is no proof indicating that this is the case. The Moors for the Future visitor survey (Davies 2007) indicated that only <10% people show a preference for habitat condition or wildlife when visiting a site.

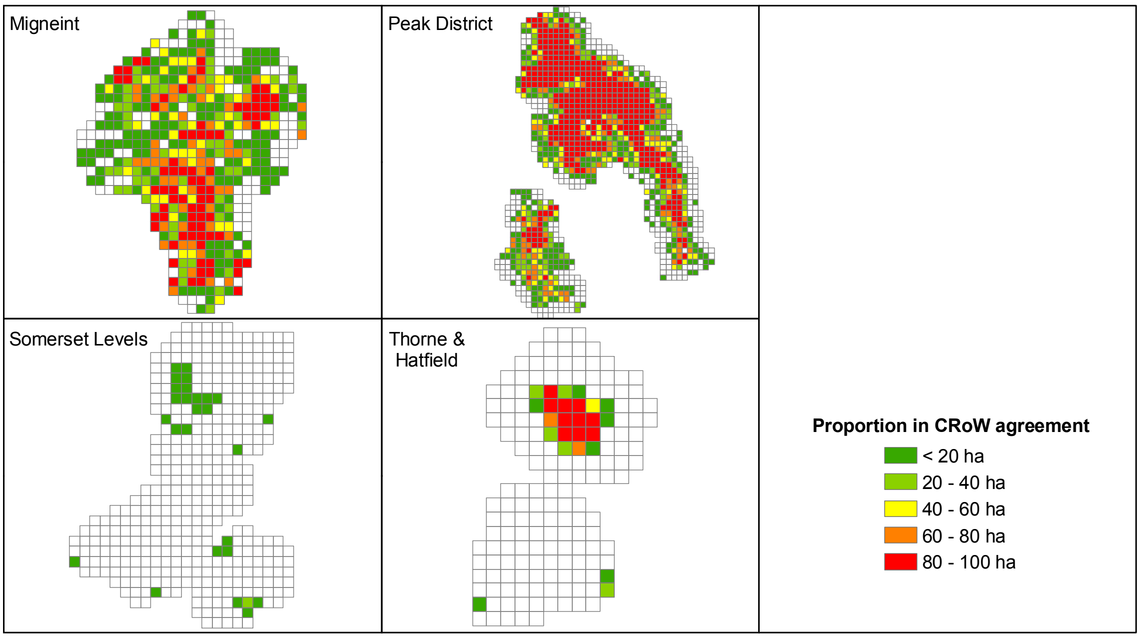
Consequently the model looked at four different classes of infrastructure within each 1km cell.

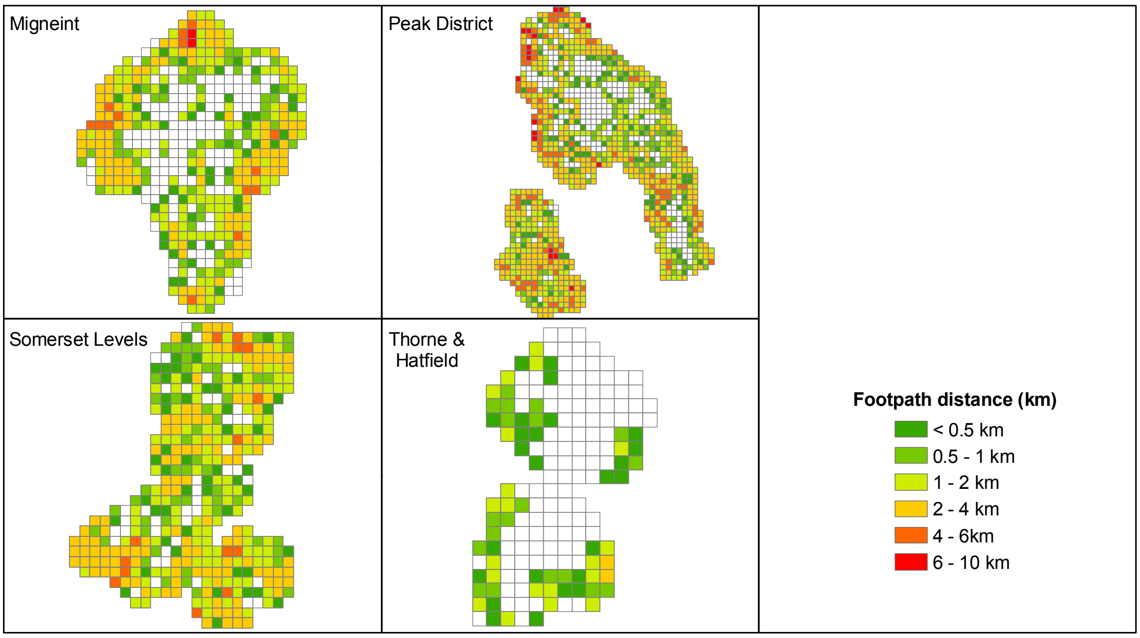
- *Footpath density:* Throughout England and Wales there are vast networks of public footpaths, bridleways and national trails that provide opportunities for recreation and research indicates that approximately 95% (MFF ranger survey) of people stick to designated footpaths. As such a layer on footpath density was constructed from Public Rights of Way (PRoW) dataset obtained from Natural England and the Countryside Council for Wales. These datasets differ from the Ordnance Survey Mastermap path layer because they offer a more complete coverage although there are still sections where the Ordnance Survey Mastermap path layer offers greater coverage but overall the PRoW dataset has by far the most representative coverage in the peatland environment. In addition to the PRoW dataset the national trail datasets were also included and these were obtained from Natural England and the Countryside Council for Wales. The four datasets were merged in ArcView 9.3.1 before being intersected with each 1km cell, after linking each stretch of footpath the total distance per square was calculated and this represents the footpath density calculated in km per 1km cell.

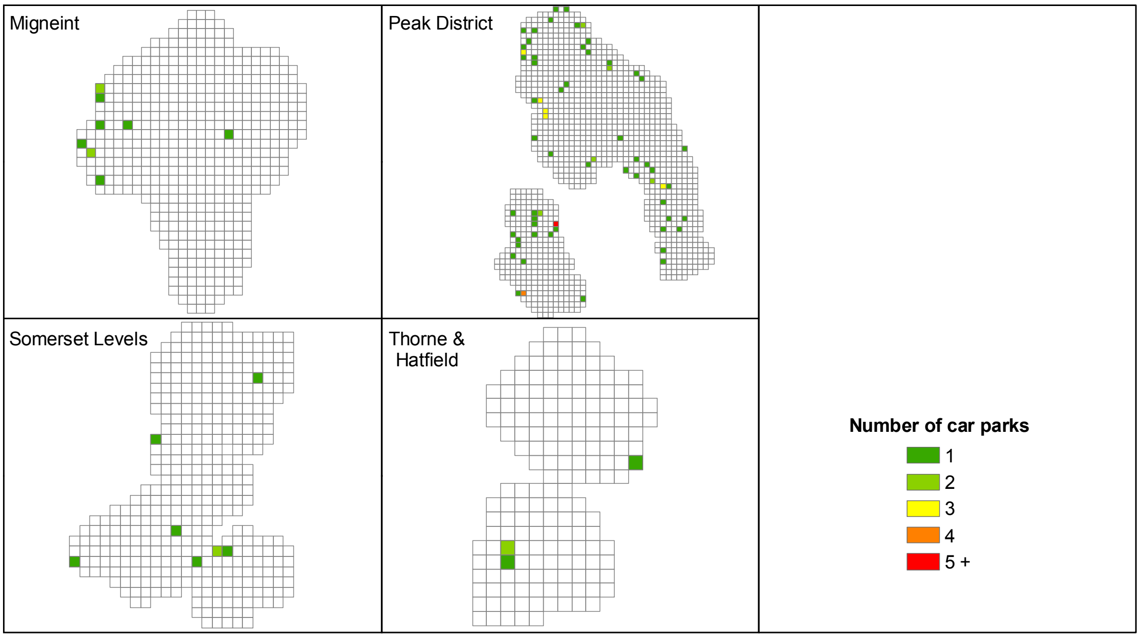
- *Road density:* The accessibility of an environment may be a strong indicator of the likelihood that it is used; hence road density is considered as a parameter that may influence recreational use. Road density was based on the Ordnance Survey Mastermap Integrated Transport Network, where all classification of roads that fall with the database were included, including M,A, B, minor and tracks. The road network was intersected (in ArcView 9.3.1) with the 1km grid cells and then the total distance (and therefore density) in km for each grid cell was calculated.
- *Car park density:* The provision of car parks was also seen as a predictor of recreational activity, especially since the four study sites are not home to any large conurbations and so visitors are likely to be there for recreation rather than functional visits. The car park information was derived from the Transport Direct car park database, which contains the most complete record of car parks in the UK. However, this does not provide complete coverage because not all car parks have been submitted, but it is still the most up-to-date and superior to the data that can be obtained through the Ordnance Survey raster maps, where data can only be obtained by visually verifying all car park locations identified by a blue marker. In addition it must be noted that this database does not contain any information relating to the actual number of spaces available at each car park. Intersecting the car park locations in ArcView 9.3.1 with the 1km grid cells created the car park density map.
- *Public transport density:* The final predictive variable for visitor use is provision of public transport, it could be disputed that this is more significant for the local public but this was taken as a possible metric for use and is therefore included. Data on the location of public transport infrastructure was obtained from the National Public Transport Access database (NaPTAN), which is contains the spatial location of access point to public transport in the UK and is managed by the Department for Transport. An alternative database, the National Public Transport Data Repository (NPTDR), which is also managed by the Department for Transport was not accessible for this project. The preferred database would have been the NPTDR because this provides information on the frequency and days at which each stop is serviced whereas NaPTAN only contains the spatial location. However, NaPTAN does still provide a comprehensive coverage of public transport access points in the UK. The NaPTAN dataset was intersected with the each 1km grid cell in ArcView 9.3.1 to provide a value of the density of public transport access point within each 1km cell.

Table 4.9: Provision of Public Rights of Way (PROW) and open access (CROW) land in case study areas.

Location	PROW footpath length [km]	Designated Open Country [km^2]
Migneint	592	168
Peak District	2071	534
Somerset Levels	607	1
Thorne & Hatfield	52	14


Migneint
Peak District
Somerset Levels
Thorne &
Hatfield
Proportion in CRoW agreement
< 20 ha
20 - 40 ha
40 - 60 ha
60 - 80 ha
80 - 100 ha


Migneint
Peak District
Somerset Levels
Thorne &
Hatfield
Footpath distance (km)
< 0.5 km
0.5 - 1 km
1 - 2 km
2 - 4 km
4 - 6km
6 - 10 km


Migneint
Peak District
Somerset Levels
Thorne &
Hatfield
Number of car parks
1
2
3
4
5 +

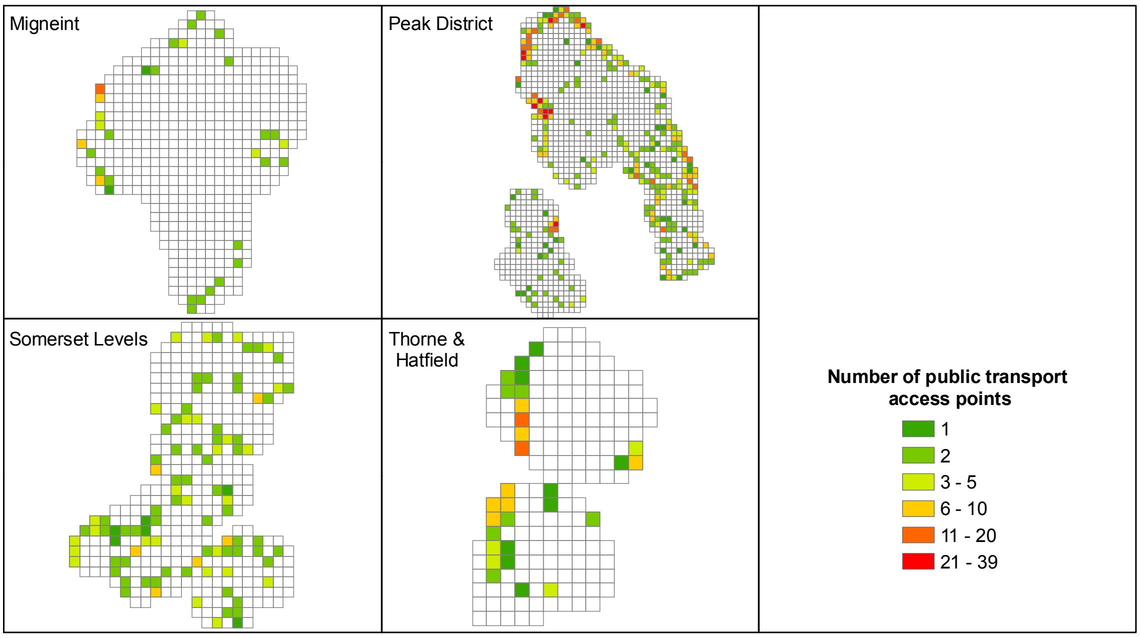


Figure 4.34a-d: Supply of access opportunities to enjoy recreation in the study sites. The figures show a) CROW land, b) Footpath density, c) car park density and d) public transport access points.

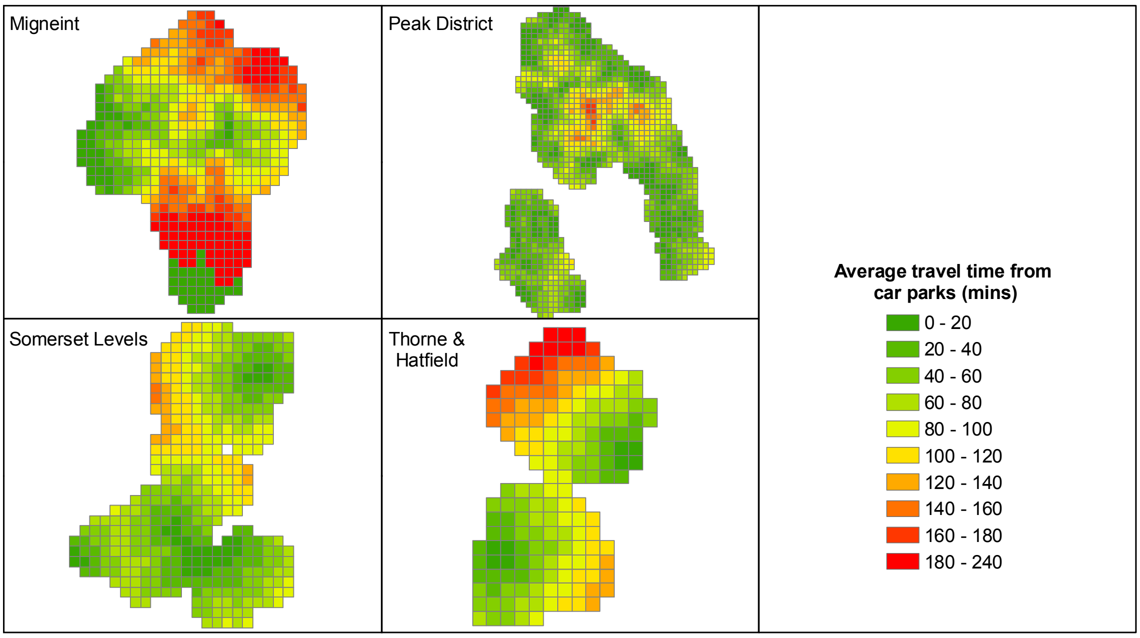
4.3.1.3 Accessibility of peatlands (supply)

The final model looks at the theoretical accessibility of peatlands as a metric of use, because inaccessible areas are likely not to be visited and as such will offer a limited amount of service for recreation. In order to assess this, the study has employed a cost surface model (CSM) to measure the accessibility of the landscape, based on geographic parameters (Figure 4.35). The model is based on that created by Brent Frakes (2008) to look at travel costs associated with accessing national parks and allows the travel cost to a particular pixel to be calculated and as such is used in this instance to measure accessibility. The accessibility model is based on eight parameters, which represent landscape features that would be encountered whilst walking through a rural landscape, which are described below.

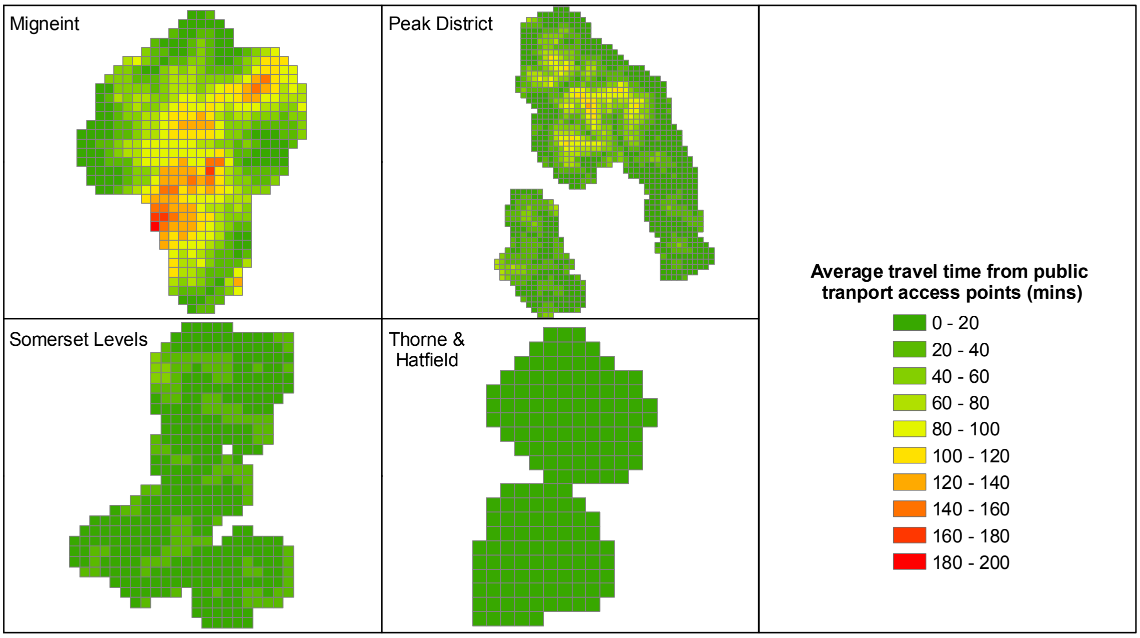
- *Rivers:* The rivers dataset is based on the Environment Agency Detailed River Network, which is a polyline map of all of the rivers in the UK and provides a better representation to that provided by the Ordnance Survey Mastermap topography layer. The rivers layer can be modelled with a cost associated with crossing it, but since this data is not compatible with this it has been decided to classify all streams as passable and therefore attach a travel coefficient of 100.
- *Lakes:* The Lakes dataset was derived from the Ordnance Survey Mastermap topography layer, where all inland water polygons were selected and then enclosed water bodies were separated from rivers and their tributaries. All lakes were given a travel coefficient of 0, which means that they are impassable.
- *Footpaths:* The footpaths dataset was constructed from the Public Rights of Way (PRoW) dataset and National trails dataset obtained from Natural England and the Countryside Council for Wales. These datasets differ from the Ordnance Survey Mastermap path layer because they offer a more complete coverage although there are still sections where the Ordnance Survey Mastermap path layer offers greater coverage but overall the PRoW dataset has by far the most representative coverage in the peatland environment. As no additional information relating to the quality of footpaths was available (apart from partial coverage in the Peak District), it was not possible to attach a range of travel coefficients; consequently, all footpaths were given a coefficient of 100.
- *Land cover:* The landcover dataset employed in this analysis was the CEH landcovermap 2000, which represents the most up to date available map of comprehensive habitat classification within the UK. There was a detailed Phase 1 habitat map available for all of Wales but as we aimed to compare the accessibility between the sites it was deemed appropriate to use landcovermap 2000, because it represented one common temporal snapshot and was at an appropriate resolution (25m). Other potential sources of data would have been the Ordnance Survey Mastermap “Natural Environment” descriptive group but this does not go into as much detail as landcovermap 2000. The land cover data was then intersected in ArcView 9.3.1 with the 1km grid cells and habitats were identified as falling within the study area. These habitat types were then given to a range of specialists who work in peatland ecology and they were asked to grade each

habitat according to its ease of passage and from this a median for the travel coefficient was calculated for each habitat type (see Appendix 5).

- *Roads:* The roads data was based on the Ordnance Survey Mastermap Integrated Transport Network, where all classification of roads that fall with the database were included, including M, A, B, minor and tracks. Each road was given a travel coefficient of 100.
- *Maximum travel time* This is the maximum travel time that can be achieved and in this instance it has been set to 600minutes in a bid to measure the travel time to all points within the four study sites.
- *Digital elevation model:* The Digital Elevation Model (DEM) is required so that the travel cost coefficient can be dependent on the slope, where potential ground speed on a slope is calculated with the formula (insert formula). The DEM is based on the Ordnance Survey DEM at 5m, but resampled to a 25m resolution to match that of landcovermap2000.
- *Start point:* Once all of the parameters have been set then the start locations have to be established and for this we are using two different start points, one based on public transport access points and one based on car parks (private transport). In relation to private transport we did not have a database of instances where people may park on a verge side so only designated car parks are used as access routes to the peatlands.



a)



b)

Figure 4.35 a,b: Modelled accessibility from a) car parks and b) public transport (see text).

Data on the location of public transport infrastructure was obtained from the National Public Transport Access database (NaPTAN), which is contains the spatial location of access point to public transport in the UK and is managed by the Department for Transport. An alternative database, the National Public Transport Data Repository (NPTDR), which is also managed by the Department for Transport was not accessible for this project. The preferred database would have been the NPTDR because this provides information on the frequency and days at which each stop is serviced whereas NaPTAN only contains the spatial location. However, NaPTAN does still provide a comprehensive coverage of public transport access points in the UK

The car park information was derived from the Transport Direct car park database, which contains the most complete record of car parks in the UK. However, this does not provide complete coverage because not all car parks have been submitted, but it is still the most up-to-date and superior to the data that can be obtained through the Ordnance Survey raster maps, where data can only be obtained by visually verifying all car park locations identified by a blue marker.

The model depicting the service provision in relation to recreation within the four study sites has drawn on national datasets exclusively. Improvements could be made in future work to the model at a local scale, especially if Phase I data or more detailed car park data is available but in this way the model is completely transferable to other sites in England and Wales.

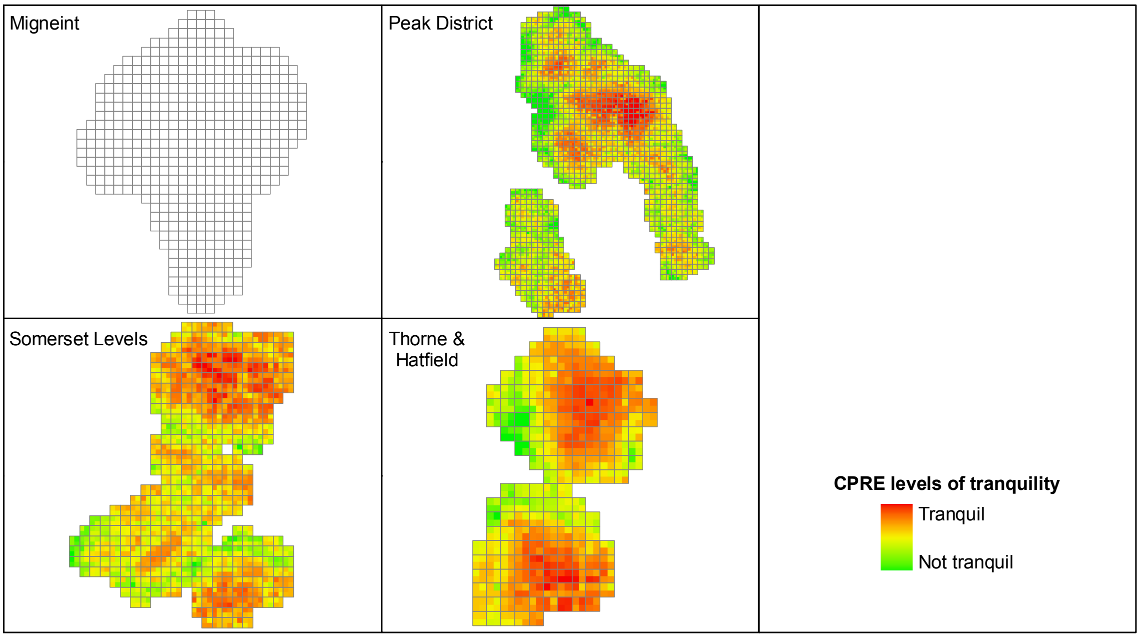


Figure 4.36: CPRE tranquillity maps for case study sites (CPRE 2006, England only)

Tranquillity
Peatlands, and especially their more inaccessible parts provide areas of high tranquillity, as some of UK's largest unfragmented habitats, especially in the uplands. The CPRE tranquillity maps (CPRE 2006, Figure 4.36) were produced by researchers from Northumbria and Newcastle University to try and establish the level of tranquillity in each 250m * 250m square of England. The study was based on the premise that tranquil areas were those areas "which are sufficiently far away from the visual or noise intrusion of development or traffic to be considered unspoilt by urban influences". The model was based on public perception to define the parameters but was modelled in a GIS, drawing on nationally available datasets such as proximity, to roads, railways, conurbations and the openness of the landscape (visibility analysis).

However, while tranquillity is an important reason visitors cite for visiting, relative tranquillity to home may be more important than absolute values to people, as more people visit for example Peak District upland peatlands, than for example North Pennine peatlands, which provide greater tranquillity in comparison (see national maps for England, CPRE 2006). Furthermore, as discussed below, access is an important if not overriding predictor for realised recreation demand. Assuming a shorter travel distance as important factor for visiting, the vicinity of the Peak District to large conurbations also increase the steepness of gradient of tranquillity from home to peatlands. This may explain in part why more people visit the Peak District than e.g. the Migneint. Indeed, analyses of postcode data for the Peak District show that a large proportion of visitors come from urban areas (43% of all postcodes are situated in urban areas, see also Fig. 6.5) This value was obtained by intersecting the postcode region centroids of all visitors with the OS Strategi layer to see which postcodes fell within the large urban areas polygons.

4.3.1.4 Observed recreational use patterns (demand)
The supply of recreation opportunity is abundant, but as the modelled use shows(see above), access varies across the peatland areas. However, real data of actual recreational use of peatlands is only available in a sparse and temporally broad format for the four study sites. Information from the English Leisure Visits Survey (Natural England, 2006) was too sparse to be useful. The main data sources identified as part of this project were that obtained from pedestrian counters located at bottlenecks, and information on car park revenues taken from car parks that involved payment. As such this provides an insufficient representation of the landscape, as it only looks at a small number of locations and does not indicate where people go after passing through this recording point (but see Davies 2007 and visitor feedback maps in unpubl. work by Cavan, McMorrow and Lindley, Manchester University)

In order to address the deficiency in data relating to recreational use we collected new data for the Peak District National Park, Thorne and Hatfield Moors and The Migneint from local experts. The local experts were local rangers or site specialists who regularly patrolled the sites and could therefore estimate usage for their particular area. The study was based around a questionnaire linked to a map depicting each ranger's area that they patrolled, where the area was split up into 1km cells that corresponded to the 1km cells used in the rest of the ecosystems service assessment (see Appendix 6 for sample map and instruction sheet). Each ranger was asked to state the average number of people that they would expect to be taking part in recreation on a typical peak day in summer (Saturday in June). In addition, rangers were asked to map areas used for certain recreational activities, such as climbing and cycling, using codes supplied on an instruction sheet. After the first seven maps had been returned, the data were used to create cohorts in order to assist estimating numbers. This was particularly useful in the PDNPA where visitor numbers are very high. Data for each 1km grid square were recorded in an Excel spreadsheet and maps showing estimations of daily visitor numbers produced using ArcMap. Draft maps of each area were returned to area rangers for them to assess the overall patterns and provide feedback.

Eleven rangers provided visitor number estimates for their areas within the PDNPA, four in the Migneint, and one in Thorne & Hatfield Moors. Some rangers used guidance from ranger records and pedestrian counters to inform their estimates. Several rangers completed the maps on their own, but others who found estimates difficult and benefitted from the presence of a facilitator to help them start and to talk them through the process. Estimation of visitor numbers is a difficult task, and concerns were raised about the overall accuracy of estimations, and differences in observer estimates between rangers. Therefore, final maps were discussed with the area team managers who have a good overview of the whole area. While it was emphasised, that individual grid cells may have a certain error margin, it was unanimously agreed that the overall patterns reveals a very accurate picture of the study areas, which could not have been achieved in any other format with limited spatial information from visitor surveys or pedestrian counters.

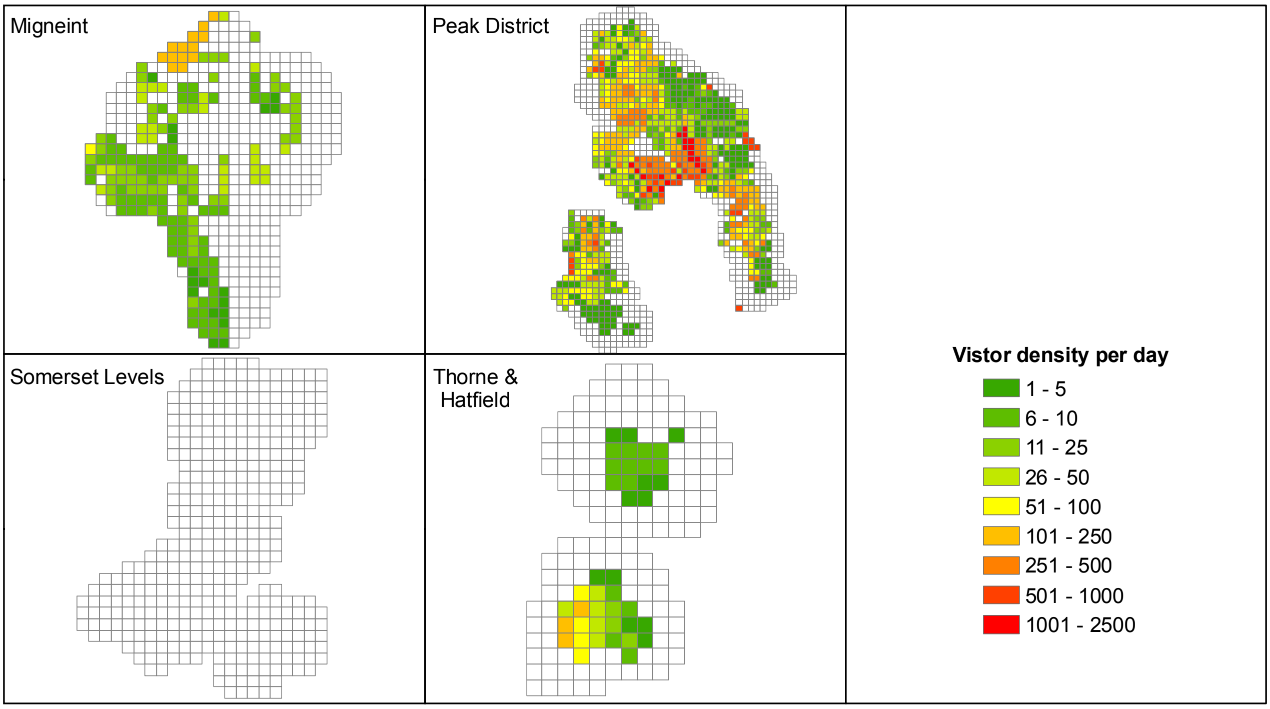


Figure 4.37: Realised recreational patterns of use. Visitor density on a peak day (Saturday in July) as assessed by expert survey through area rangers and wardens (no data for Somerset Levels, buffer zones of study sites not assessed)

As depicted in Figure 4.37, realised recreation demand as assessed by the expert survey is especially high in the Peak District, much higher than in the other case study areas. Especially popular are areas around reservoirs, iconic places, such as Kinder Scout, as well as famous routes, such as the Pennine Way. Woodland areas are also popular both in the Peak District and Migneint. Some areas with lower visitor densities in the Peak District were not Open Access pre CROW Act in the past. The most striking predictor for visitor usage, however, seems to be accessibility. Indeed, the cost surface models (Fig 4.35) for accessibility from car parks matches the pattern of realised recreation use (Fig 4.37). Over 90% of people use cars to travel to the Peak District (Davies 2007) and do not walk far from car parks. Using the estimated travel times of the cost surface model, the most visited grid cells are accessible within 50min walking. As Fig 4.38 shows for cumulative visitor usage, 50% of all visitors access places walk 42min or less in one direction, and only 10% of all visitors walk to places that require a walking time of 90 min and more, whereas only very few people walk to areas that require more than 2h walk in one direction.

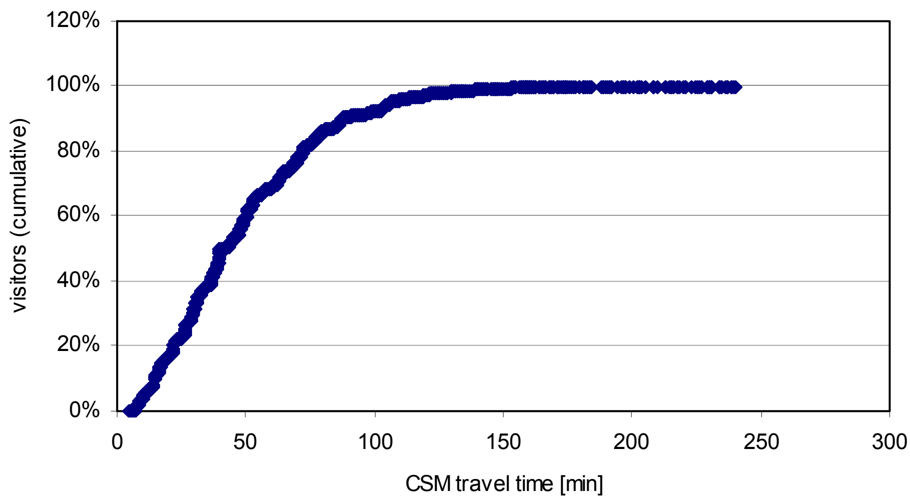


Figure 4.38: Cumulative visitor numbers versus estimated walking time from car parks using the cost surface model (see text and Fig 4.35).

4.3.1.5 Recreation in Somerset Levels and Moors

Tourism within Somerset County attracts 2.5 million staying visits each year and the total annual average spend by day visits is £86 million whilst the total spent by staying visitors is £300 million (Environment Agency, 2008). The main proportion of visitors tends to be concentrated in West Somerset, Sedgemoor and the coast. In rural areas numbers are much lower. Despite 17 separately identifiable tourist attractions, Mills *et al*. (2000) described the Somerset Levels and Moors as "underdeveloped and recognition of the area as a tourist destination is low". The report finds that provision of footpath and bridleways is poor for historic reasons and it estimates that the total visitor spend within the study area is only £2 million per annum. Sedgemoor District Council states that the area tends to attract visitors with specialist interests in walking, cycling, fishing or nature conservation. It is assumed here that these include appreciation of the landscape, including traditional practices of livestock rearing and dairy farming.

South Somerset District Council and partners have initiated an 80 km walking route along the River Parrett designed to be a sustainable tourism route. Route 3 of the National Cycle Network (Lands End to Bristol) already passes through the SLM, using for example the disused railway track between Glastonbury and Highbridge. This cycle path is used by hundreds of locals and visitors each year. Much of the attraction of the route is the low-lying open wetland landscape that offers wide views.

Bird-watching is a further major recreational activity in the Somerset Levels and Moors. Some 6-10 millions of starlings roost among the reed beds at Ham Wall every night during the winter. Thousands of people from all over the UK and beyond have flocked to the site, at the heart of the Brue Valley. Fishing in the area is primarily a recreational activity, although some species such as trout and pike are eaten. The Freshwater Fish Directive (78/659/EEC) requires certain designated stretches of water (rivers, lakes or reservoirs) to meet quality standards that should help fish to live and breed. The Directive score for the coarse fishery on the River Parrett varies to well above average for Chub, Roach and Pike at Thorney Moor, to only minor populations of fish species and poor habitat at South Petherton. The survey of the River Tone shows that Eel, Chub and Brown Trout feature significantly, although other species were also found such as Dace and Salmon Par. Roach is the predominant species within the River Yeo, most originating from Sherborne Lake in the headwaters. The River Isle has populations of Chub, Dace and Common Bream, but only in minor numbers due to the predominantly low water levels (Environment Agency, 2008). No figures were available for the Somerset Levels and Moors itself, but in England and Wales 2.6 million people over 12 years old went fishing in freshwater in 2005, spending £2.7 billion and supporting 20,000 jobs (EA, 2006).

4.3.1.6 Barriers to Recreation

As discussed above supply of recreation is not restricted. However, the demand may have shifted, as over 40% of people do not visit the countryside (Natural England 2006, Curry 2009) and there may be barriers for people's to enjoyment of such these opportunities (PDNPA/SHEBEEN 2004, Suckall et al 2009):

- ***Physical:*** physical disability (too difficult terrain); lack of appropriate equipment/clothing;
- ***Social/psychological:*** fear of going independently; anticipation of racism for black and ethnic minorities, fear of open space, wariness of bad weather;
- ***Culturally/educationally*** map-reading is a complex skill with few practical opportunities given to inspire and support young people in becoming familiar with maps and finding their way around strange places
- ***Practical/economic:*** where to go; how to get there; how to afford to get there; where to go on arrival; how to find way around

Pro-active outreach can address these issues, but peatland restoration and management activities as in the chosen scenarios will not imply any change in visitor behaviour for these groups.

4.3.1.7 Conclusions

While population maps and travel time are useful to understand the leisure services offered by peatlands such as the Peak District (large surrounding population with 16 M people living in 1h drive and 10M day visits per year) and the Migneint (sparse surrounding population and few visitor numbers) this may not be always a transferable and reliable indicator. For example, 5 million people live within an hour's drive of Thorne and Hatfield and yet this site receives very few visitors. Active recreation management through provision of visitor facilities (interpretation, visitor centres, etc) and transport opportunities (car parks, roads, public transport) plays a major role in visitor attraction.

Furthermore the sense of place is much stronger developed in the Peak District, with a long history of Access and indeed as a political place of the Access movement, that people are attracted to visit and go walking (J Waller, A Farmer, PDNPA Ranger Service, pers. communication). In contrast, Thorne & Hatfield Moors have until recently been industrial sites of peat extraction with no access and little recreation interest, so that people from surrounding areas have (yet) a less strong connection to these peatlands.

Moreover, as Curry (2009) argues, recreation is a culturally mediated service and as the maps for PROW footpaths and CROW Access land depict, there is clearly no shortage in supply of recreation opportunities. Demand has indeed decreased over the past decades (ELVS 2007), and while it was mainly working class people demanding access at the Kinderscout Mass trespass over 70 years ago, visitor now come from a predominantly white middle class background. It is unlikely, demand is linked primarily to the economic background of visitors, as countryside recreation is one of the inexpensive recreation options (average day visitor spend £14.97 in Peak District, Davies 2007), but the availability of home based entertainment and a consumer oriented recreation is more likely to influence choices and life styles (Curry 2009).

Regarding demand, the good correlation of the observed visitor usage pattern and this study's cost surface mode, using travel and access as the main predictor, suggests that access is the main predictor for recreation. Scenic beauty and tranquillity relative to home are important factor for demand, too, as stated in visitor surveys (Davies 2007). Therefore, it is likely that peatland restoration and management actions, as selected in this study will have little effect on change in visitor patterns. While bare peat re-vegetation may improve walkers experience through stabilised surfaces, and rewetting through grip blocking might possibly have slightly opposite effects, these impacts will be minimal and not likely to be expressed in a noticeable change of overall visitor usage. Active recreation management, through access improvement with footpaths, board walks, bird hives, visitor centres etc as mentioned, above will have much stronger effects, and so might development of built infrastructure such as wind parks or other changes in the built environment, such as changes in traditional farmhouse settings and thereby landscape character. We therefore have not produced change scenarios for recreation for the study scenarios.

4.3.2 Field sports

Opportunities for field sports and game management are essentially a cultural service, as shooting in the UK takes place for recreational purposes and not primarily for food provision. Therefore, this management is also essentially mediated through preferences by society or individuals for field sports. And there are high private investments in establishing and maintaining peatlands for field sports (PACEC 2006).

Moorland management for grouse has shaped upland peatlands since at least 150 years and has maintained open moorland – landscapes which are enjoyed by million of visitors each year (Natural England 2009a). It is a major land use on 14% of English uplands and in the Peak District 65% of the moorlands are owned by grouse moor estates (Sotherton et al 2009a). However, burning is not practiced across all the area, but only part of the estates, as depicted in Fig 4.39 below. Grouse moor management has less importance for the Migneint.

The associated managed burning and predator control creates heather mosaics, which favour game birds such as red grouse but also other ground nesting birds such as golden plover (Sotherton et al. 2009a, b). Other species are negatively associated with grouse moors, such as dunlin (for a review of effects of management on upland birds see Pearce-Higgins et al 2009) or hen harriers. The Heather and Grass Burning Code and Regulation (Defra 2007) sets out guidelines for best practice, and burning varies across different moors. Redpath and Thirgood (2009) propose various ways in which red grouse - hen harrier conflicts could be resolved to allow hen harriers to co-exist more easily on grouse moors. However, worries exist, that a reduction in grouse moor management intensity may lead to abandonment of grouse moors and loss of game keepers and subsequent effects on wildlife and landscape (Sotherton et al 2009b).

There needs to be a clear distinction between burning on dwarf shrub heath on shallow peat soils (Dry and Wet heath) and blanket bog on deep peats. On deep peat high burning intensity can negatively impact on peat forming species, such as Sphagnum, carbon flux, run-off potential and water quality (see 4.2. and scenario results for grouse economy scenario).

Yallop et al (2006, 2009) identified an increase in burning intensity across English uplands using aerial photos. In the Peak District grouse shooting activity has risen from 80 potential shooting days/year and 10 game keepers employed in 2000 to 128 potential shooting days/year and 32 game keepers employed in 2009 (data from the Moorland Association, published in Natural England 2009a). Overall, an estimated 47,000 people in the UK take part in grouse shooting (Natural England 2009a).

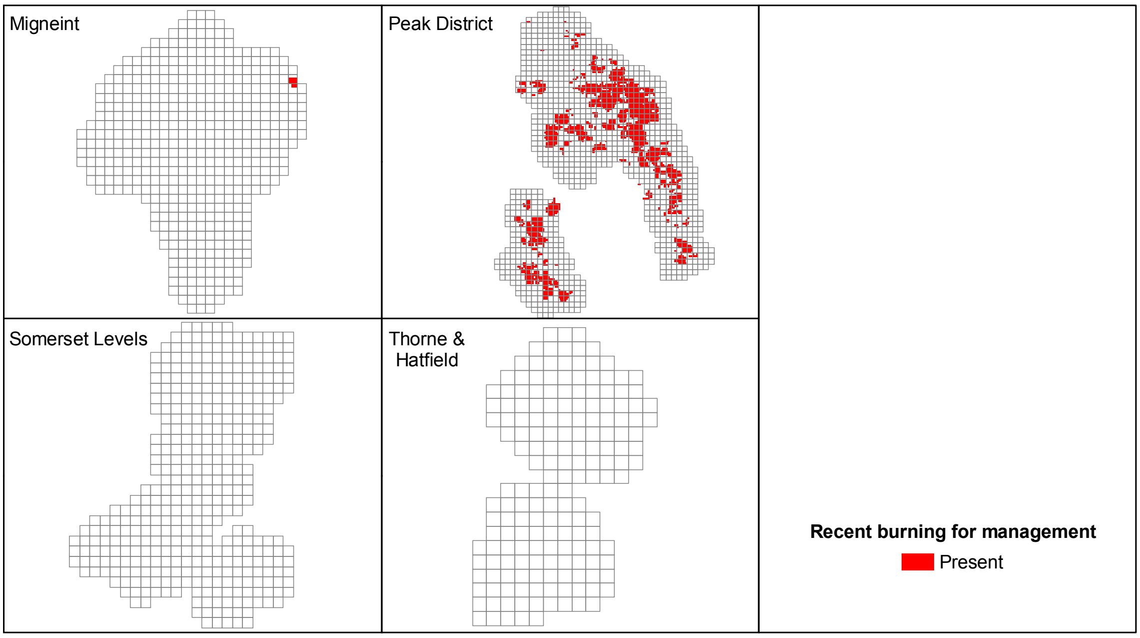


Figure 4.39 : Spatial distribution of managed burns for grouse moor management assessed from aerial photographs (aerial imagery licensed to: "Defra" for PGA through Next Perspectives ™)

Other important field sports include fishing. This is a relatively significant recreational activity on the Migneint. It is less pronounced on Peak District peatland areas, probably due to habitat degradation through acidification of the rivers, but has importance downstream in the White Peak Dales, with larger river sections and higher pH ranges.

Deer shooting is less pronounced in the case study sites, although there are some areas on the Eastern Moors in the Peak District where deer numbers are becoming an issue with regards to biodiversity conservation. On Thorne and Hatfield there are large numbers of Roe deer on both sites and a herd of about 50 or so Red deer on Thorne Moor. The red deer are a nuisance for adjacent farmers because they damage root crops, and they have also been causing damage to willow trees on some parts of the Moor that is being managed for nightingale. In addition, a number of animals have been born with birth defects, which may be a result of the original population being very small (~5 animals). As a result Natural England instituted a culling program in 2007, aimed at trying to increase the genetic mixing in the red herd. However, while deer may be seen as game, Natural England does not make any commercial gain from these activities, which are driven solely by nature conservation and animal welfare consideration. In addition, Natural England had tried to arrange a wider deer management policy across the area with local farmers. However, some locals are now either shooting themselves, or have leased out the shooting to commercial interests (on their own land), and as a result Natural England have stopped shooting while they re-assess the state of the herd.

4.3.3 Education Opportunities

Peatlands offer substantial opportunities to learn about the natural world and cultural heritage for the general public, professionals and scientists. Peatlands offer the largest remaining unfragmented landscapes with a rich biodiversity and in part natural processes, and due to the peat conservation potential as well as little development due to poor soils, they offer a rich view into the past (see 4.3.4).

Active promotion of learning opportunities through visitor centres, boardwalks, hides and viewing platforms enable groups to experience the wonders of the natural environment at close quarters. Guided walks programmes and school group visits are available through National Park programmes (e.g.

Education service, Ranger service) and NGO activities (National Trust, RSPB, Wildlife Trusts etc). Interpretation materials, such as interpretation panels on site, audio-trails as un-intrusive onsite guidance, newsletters, publications and websites offer opportunities for individual learning. Importantly, education opportunities encompass both the natural and cultural heritage of the moorlands, with e.g. an emphasis on the former in the Moorland Centre in Edale (Peak District) and a focus on the latter in the Peat Moors visitors centre (Somerset Levels) with three full size reconstructions of Iron Age roundhouses have been created to give an insight into living conditions the unique Glastonbury Lake Village.

These opportunities (visitor centres, bird hives, interpretation panels, location of guided walks) can be mapped. Figure 4.40 below just provides just one example for mapping education provision for school group visits through Losehill Hall and the Moorland Discovery Centre in the Peak District.

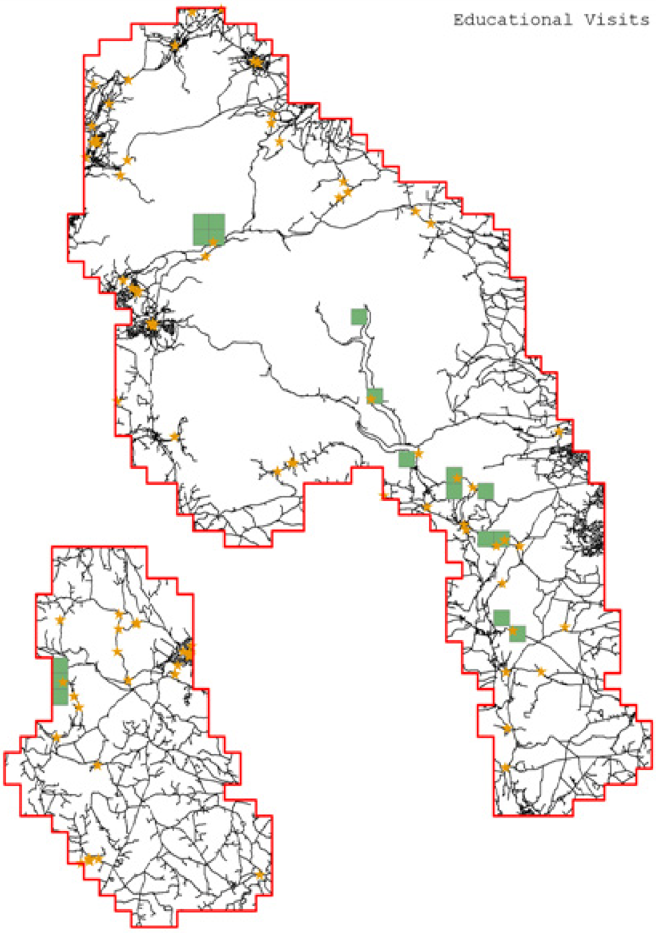


Figure 4.40: Location of educational visits on the Peak District peatlands overlaid on road network. (Green 1km grid cells – education activity hotspots; yellow stars – car parks**)**

Even stronger than for recreation, it becomes apparent that one of the main driving factors for location of education visits is the easy accessibility of sites and their vicinity to roads, car parks and even public toilets. In the uplands the educational service does therefore conflict little with other services, especially as guided walks and visits can carefully manage access and disturbance. In lowlands, board walks and bird hives can also serve to both facilitate and guide access to minimise disturbance.

However, due to the special nature of peatlands and their statutory protection, some scientific investigations and experiments may be spatially or temporally restricted to allow for minimal disturbance of wildlife or sensitive habitats.

4.3.4 Historic Environment: Archaeology & Palaeoecology

Peatlands are of considerable archaeological importance, as peat can preserve irreplaceable records of environment, climate, and land use over the last 10,000 years (Natural England, undated, Olivier and Van der Noort 2002, Simmons 2003). Peat also preserves organic archaeological material, which is lost from most dry-land sites. Peat deposits are composed of organic matter that is preserved by entering a waterlogged environment which excludes virtually all oxygen and thus slows down the normal rates of decay to extremely low levels. Thus, even very fragile material such as beetle wing cases or autumn leaves can be preserved for thousands of years. Peat deposits constitute the main repository of information about how the landscape of Britain has changed and the effects, which natural drivers and human activity have had on it (Brunning 2001).The records of our past environment and past culture therefore give us a fascinating insight into climatic change and sea level change, how peatlands developed and changed over time and how human activity and natural or human induced fire regimes impacted on them, and how this combination of processes led to the peatlands of today (Blackford et al 2006, Yelloff et al 2007).

Within the Humberhead peatlands, which Thorne and Hatfield Moors are a component, over 100 archaeological sites from 8,500 years ago to the Roman period have been uncovered. The oldest plank boats in the world, outside Egypt, were found in peat deposits near Thorne, and a rare Bronze Age pathway was unearthed by archaeologists in the 1970s, laid through Thorne Forest about three thousand years ago, when water levels were rising and the ground was becoming too boggy to walk upon. On 7 October 2004 a wooden structure was unearthed in the peat on Hatfield Moor that has been interpreted as a wooden platform & track way dating from the Neolithic period. It has immense international significance (Eversham 1991, Gaunt 1987).

In dryland sites, archaeological remains consist primarily of fragments of pottery, stones and corroded metal, since organic material rapidly decomposes. In wetlands, anaerobic conditions lead to the preservation of organic remains such as structural timbers, axe shafts, nets and fishing lines. Excavations on the Somerset Levels and Moors have revealed many structures and other finds providing fairly detailed knowledge of human activity from the Neolithic (9500 BC) to the end of Iron Age (1000 BC). The most notable discovery was the Sweet Track, in 1970. This was a raised walkway, built around 3800 BC to cross nearly 2 km of reed swamp that lay between dry land and a mid-marsh island (Coles, 1990). Its single plank walkway was held about 40 cm above the soft ground by pairs and groups of obliquely crossed pegs retained by a ground-level rail. The Sweet Track has undergone more decay where recent drainage has occurred and so water level management has actively been performed to reduce archaeological decay. The Glastonbury Lake Village is the best-preserved prehistoric village in the UK and was at one time inhabited by around 200 people living in 14 roundhouses.

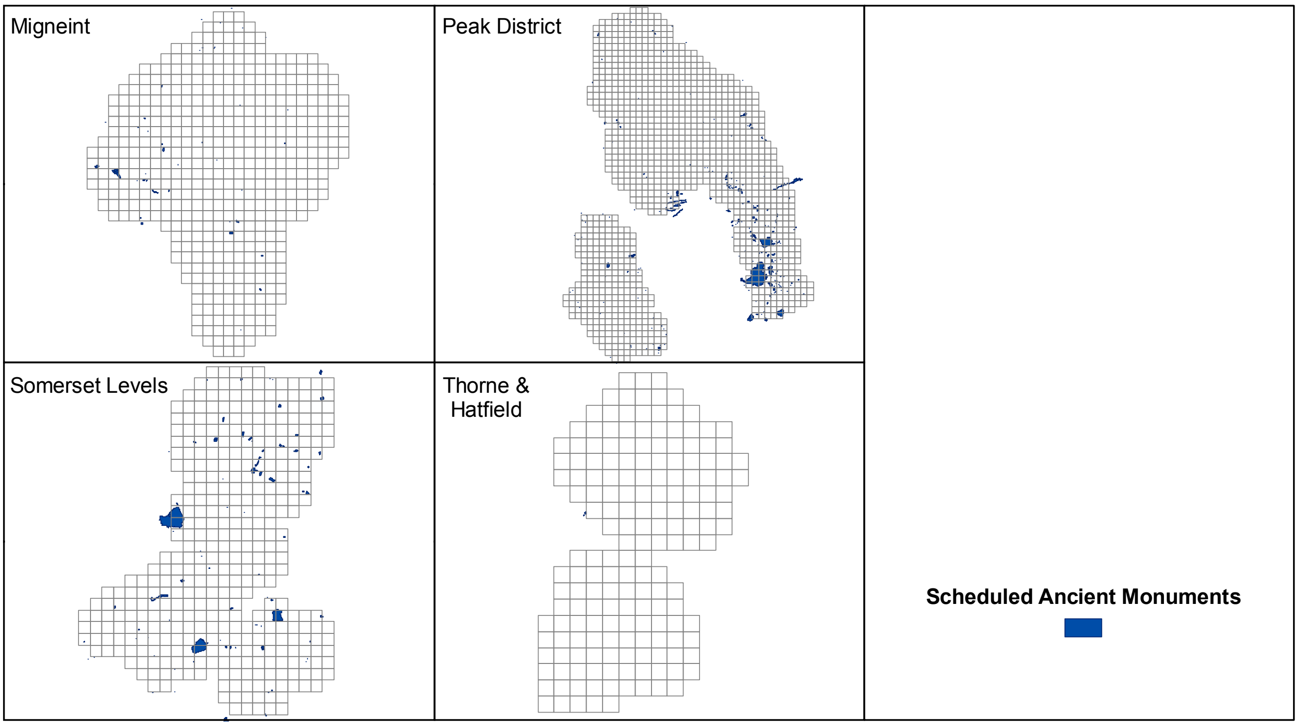


Figure 4.41: Distribution of Scheduled Ancient Monuments.

The distribution of Scheduled Ancient Monuments (SAM) is shown in Figure 4.41, with 46 SAM in the Migneint, 327 SAM in the Peak District, 112 in Somerset Levels and 1 in Thorne & Hatfield Moors.. While there are many more known locations of features of historic environment in the case study sites (e.g. Eversham 1991, Brunning et al 2008, Chapman and Geary 2009, Bevan 2009 and others), they are not always mapped consistently and have not been collated in a national database accessible for mapping in this study.

The archaeological record is at risk from any activity, which disturbs the peat strata in which they were laid down, such as peat extraction. Threats to the peatland archaeological record identified by Huckerby et al (2009) comprised drainage, climate, pollution, farming, forestry, recreation, fire, peat cutting, masts & wind farm development - of these dessication was the key concern overall although other factors, such as fire & visitor numbers, were locally significant. Lowering of water tables through grips and drains can threaten and destroy archaeological records by encouraging erosion and wasting of the peat (Brunning et al 2008). A landscape approach to water management is needed for both lowland and upland peatlands. Another key factor in the conservation of the upland historic environment is the maintenance of a vegetation cover, especially on bare peat, to prevent damaging erosion. In some cases, however, vegetation development might also harm the historic environment through either physical damage, reduction in the visibility of the historic landscape or damage resulting from an enhanced wildfire risk (ADAS and Oxford Archaeology North 2009). Dialogue between archaeologists and ecologists can facilitate best management.

4.4 Biodiversity

4.4.1 Biodiversity definitions

Biodiversity is not defined as an Ecosystem Service in the Millennium and National Ecosystem Assessments, but is seen as closely related to the concept of the ecosystem, and thus as underpinning the rest of the services (MA 2005; UKNEA 2009).

The Habitats Directive of the EU (EEC 1992) aims to maintain biodiversity by requiring signatories to monitor the conservation status of certain natural habitats, listed in Annexe I to the directive, and certain species, listed in Annexe II. For habitats, conservation status is defined as the sum of the influences that may affect the long-term natural distribution, structure and functions of the habitat as well as survival of typical species.

Species are the focus of another international initiative to protect biodiversity, the Red List of threatened species maintained by the International Union for the Conservation of Nature. Of the 555 Red List species listed for the UK, 116 occur in “Bogs, Marshes, Swamps, Fens or Peatlands”, of which 115 are animals and one is a plant.

Biodiversity protection legislation in the UK is also guided by the international Convention on Biological Diversity. This has been implemented via the UK Biodiversity Action Plan (UKBAP, 2007), which includes habitat, species and local action plans. There are currently BAPs for 1150 species across all UK taxa. Habitat BAPs most relevant for peatlands are those for Blanket Bog, Lowland Fens, Lowland Raised Bog, Upland Flushes, Fens and Swamps, and Upland Heathland.

Habitat structure and function are not easily defined without reference to species. The occurrence and abundance of particular species are key aspects of conservation status, and feature strongly in habitat definitions such as those in the habitat BAPs.

4.4.2 Biodiversity monitoring

Methods used for monitoring and assessing biodiversity provide a starting point for defining habitat quality metrics. Simple metrics of biodiversity can be derived from data on species presence and abundance, such as richness (number of species) or indices of evenness. However, the number of typical species in particular taxa can be small in certain habitats (e.g. vascular plants in Atlantic heathlands). Hence biodiversity metrics that weight species according to criteria such as typicality or rarity are more likely to reflect societal definitions of biodiversity. Several initiatives have attempted to establish quantitative indicators of biodiversity for use in monitoring (e.g. Hockley et al., 2009).

In the UK, the implementation of the EU Habitats Directive includes a standard procedure for site assessment known as Common Standards Monitoring (CSM) guidance (JNCC, 2006), which lists indicators of favourable condition for all Annexe I habitats. These include structural indicators such as the cover proportion of dwarf shrubs, and for many habitats lists of indicator species – those which are typical, and those which are untypical and invasive. Many site features are also cross-referenced to National Vegetation Classification (NVC) communities and so to quantifications of species occurrence.

4.4.3 Predicting changes to biodiversity

Models are available that predict impacts of environmental drivers on many aspects of biodiversity change, including habitat structure (e.g. Terry et al. 2004), and occurrence of individual threatened species based on habitat preference or population. Ecosystem models vary greatly in their detail and complexity, and hence in the number of parameters required to set up the model for a particular site. A pragmatic choice has to be made between models which reproduce many processes and may more accurately predict key aspects of environmental change, and models which can be run using the data available. In general, models predicting changes to habitat structure and population-based models require more parameters than models based on habitat preference i.e. niche space.

Capacity to predict the responses of multiple species in the UK has increased greatly with the development of the GBMOVE niche models for 1130 UK plant species in relation to abiotic factors i.e. soil, climate and vegetation (Smart et al., submitted). By coupling niche models to dynamic models predicting changes to these factors, effects of changes to environmental drivers can be propagated through to predict effects on the suitability of the habitat for individual species (de Vries et al., in press) (de Vries et al., in press) (Figure 4.42).

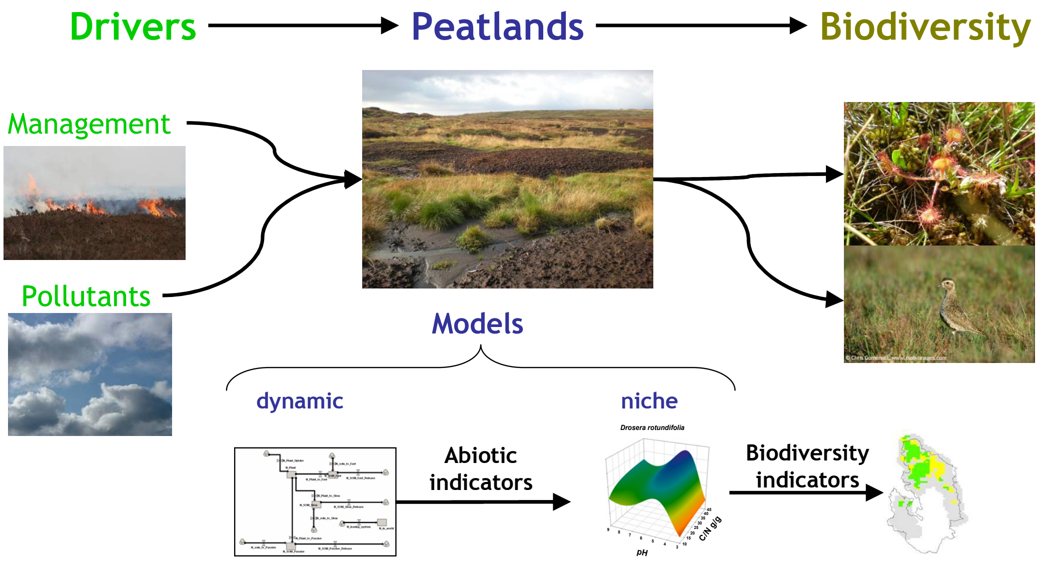


Figure 4.42: Schema for predicting biodiversity change in peatlands in response to environmental drivers

Translating changes in environmental suitability for a set of species into an overall metric or index of biodiversity requires an evaluation of which species are desirable and which undesirable on a site. This necessarily involves subjective choices, although objective criteria such as the rarity of species can be used to support such choices. In particular, major differences in the conservation objectives for particular habitats make it difficult to compare the biodiversity value of one habitat with that of another. Once a target habitat has been defined it is usually possible to obtain lists of desirable species based on expert judgment, and sometimes (as in the CSM guidance) also of undesirable species.

4.4.4 Current status

Traditional management of peatlands in the UK resulted in the development of open mire and heath vegetation of international conservation importance (Thompson et al., 1995). The study sites have all received considerable attention from naturalists, and have extensive records of occurrence of birds, vascular plants, bryophytes, mammals, invertebrates and other taxa. These records are extremely valuable as a baseline for assessing change. Wider biodiversity monitoring activities that include peatlands, such as the Breeding Birds Survey, Countryside Survey, UK Butterfly Monitoring Scheme, and BSBI's Plant Atlas and Threatened Plants projects, also provide relevant data, although these are unlikely to be available for particular sites. Overall biodiversity has recently been assessed across all UK habitats on a 10 x 10 km grid, using the criterion of presence of BAP species (Anderson et al. 2009).

Prediction of change in species occurrence / abundance is only currently possible for taxa for which niche models have been developed, such as plants (Smart et al., submitted) and certain bird species (Pearce-Higgins and Grant, 2006). The current study explores effects of management scenarios on plant species occurrence.

The baseline scenario used in the current study was obtained from national-scale modelling of effects of nitrogen and sulphur pollution on acidity and nitrogen accumulation in peats, as used for the UK Critical Loads submission to the UNECE (Hettelingh et al., 2008). This uses the VSD soil chemistry model (Posch and Reinds, 2009) to predict the effects of pollutant load as simulated by the FRAME deposition model (Dore et al., 2006). For three of the study sites, each 1 km^2 gridcell where > 0.01 ha of bog or heath habitat was recorded in the Land Cover Map 2000 was simulated. The main inputs for VSD, soil parameters describing cation exchange and carbon and nitrogen contents, were obtained from a national survey of acid-sensitive UK soils (Evans et al., 2004). VSD parameters for lowland fen peats and wetter mires are not yet available, so the Somerset Levels were not simulated in the current study. More detailed hydrological models may be required to simulate environmental suitability for habitats and species in such systems (e.g. Acreman et al. 2009).

4.4.5 Assessment of future land-use scenarios for biodiversity

Six different land use scenarios were quantified as effects on the inputs for the GBMOVE models (Table 4.10): business-as-usual (BAU); rewetting (Wet) i.e. blocking drains; conservation-led rewilding (CLR) i.e. blocking drains and removing grazing; food security (Food) (two scenarios, with and without liming and fertilisation) in which drainage is improved and grazing increased; and grouse economy (Grouse) i.e.

intensifying heather burning). Climate inputs to GBMOVE (maximum July temperature, minimum January temperature and precipitation) were not varied in the current study.

Table 4.10: Inputs for the GBMOVE plant species niche models, under different land use scenarios

Scenario	Soil carbon %	Soil nitrogen %	Soil pH	Soil water %	Canopy height m
Business-as-usual	50.7[1]	Modelled from atmospheric deposition	Modelled from atmospheric deposition	87[2]	0.3[5]
Re-wetting	50.7[1]	Modelled from atmospheric deposition	Modelled from atmospheric deposition	95[3]	0.3[5]
Conservation-led rewilding	50.7[1]	Modelled from atmospheric deposition	Modelled from atmospheric deposition	95[3]	0.6[6]
Food security	50.7[1]	Modelled from atmospheric deposition	Modelled from atmospheric deposition	74[4]	0.2[7]
Grouse economy	50.7[1]	Modelled from atmospheric deposition	Modelled from atmospheric deposition	87[2]	0.2[7]

[1]mean % C in peat cores (0-15 cm) from Countryside Survey, n = 107. [2]mean; [3]maximum; [4]minimum % water in peat cores from Countryside Survey, n = 107. Canopy height estimates: [5]current; [6]extensified; [7]intensified management.

There was some debate around the degree of intensification implied by the food security scenario. To support an increased stocking rate it is possible that farmers will need to increase plant productivity by adding lime and fertiliser. Thus an additional food security scenario was included, in which it was assumed that, as well as changes to grazing and drainage, the peat was limed to maintain a pH of 5.5 and additions of nitrogen fertiliser resulted in retention of 30 kg N / ha / y.

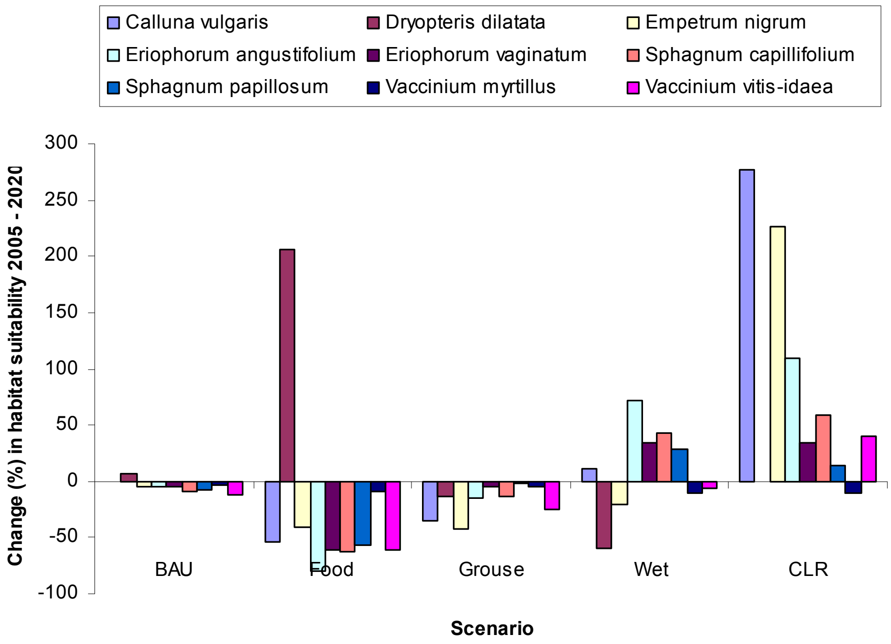
The naming of the “Conservation-Led Rewilding” scenario was issue for debate. The use of the term rewilding is unwelcome to many people with interests in management, whether for production or conservation aims. The idea that relaxation of management is beneficial for biodiversity conservation is controversial, with valid arguments in both directions. Much biodiversity has been lost due to the intensification of grazing, and semi-natural woodland and scrub are uncommon in the upland landscape even though very little of England and Wales is above the tree line. On the other hand, around half of the UK flora is typical of open habitats, including many scarce species, and such species are likely to be lost with succession to more wooded habitats. The use of the term conservation-led rewilding does not imply any pre-judgement that this minimal management scenario is better or worse for biodiversity conservation.

Predictions of habitat suitability for all species generated by GBMOVE were used to derive a habitat-specific Habitat Quality (HQ) index, defined as the mean suitability for positive CSM species for the habitat minus the mean suitability for negative CSM indicators (Rowe, in press). Habitat suitability, and hence HQ, is defined on a scale of -100 % to +100%. Using the entire set of indicator species reduces the danger of bias towards well-studied and charismatic species (Sitas et al., 2009). HQ indices were calculated for blanket bog and for upland wet heath.

4.4.6 Results

Changes in soil and vegetation under the different land use scenarios had differential effects on different species (Figure 4.43). The habitat suitability for one positive blanket bog indicator species, *Dryopteris dilatata*, increased with the decreased sward height and soil moisture content in the Food Security scenario, but in general negative indicator species showed a greater increase in habitat suitability under this scenario. Habitat suitability for positive indicator species did not change appreciably under the business-as-usual scenario, but increased considerably under the re-wetting and CLR scenarios.

a) Positive CSM indicator species



b) Negative CSM indicator species

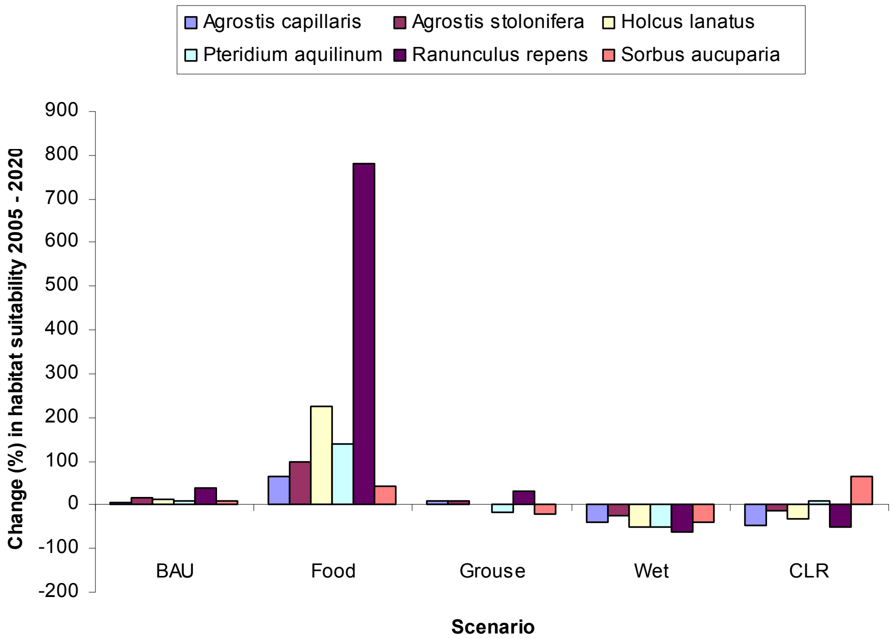
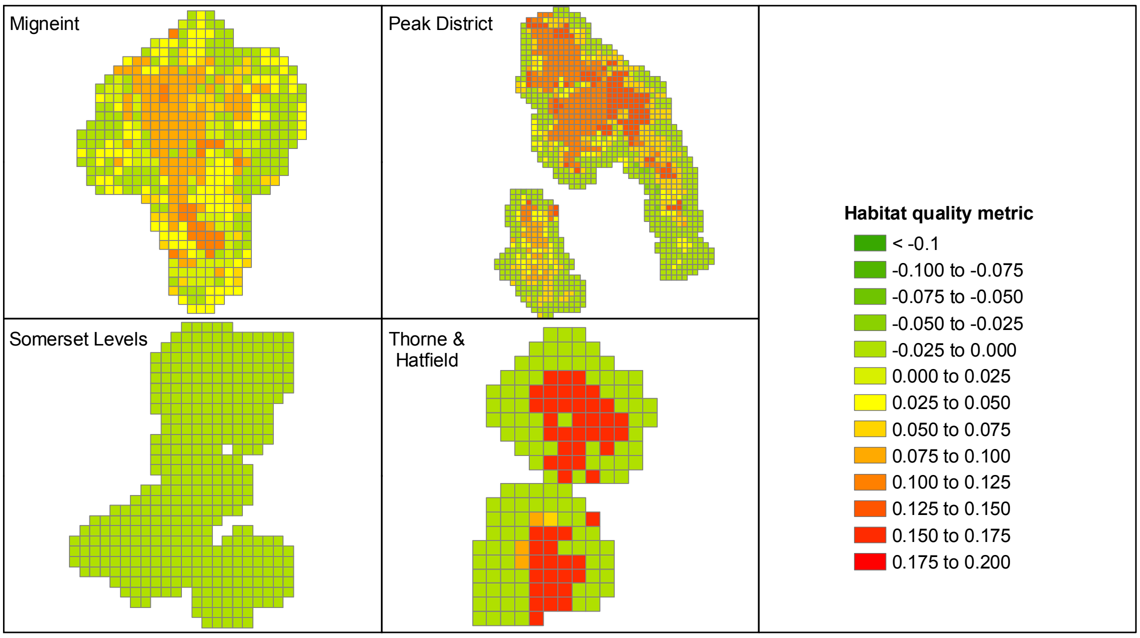
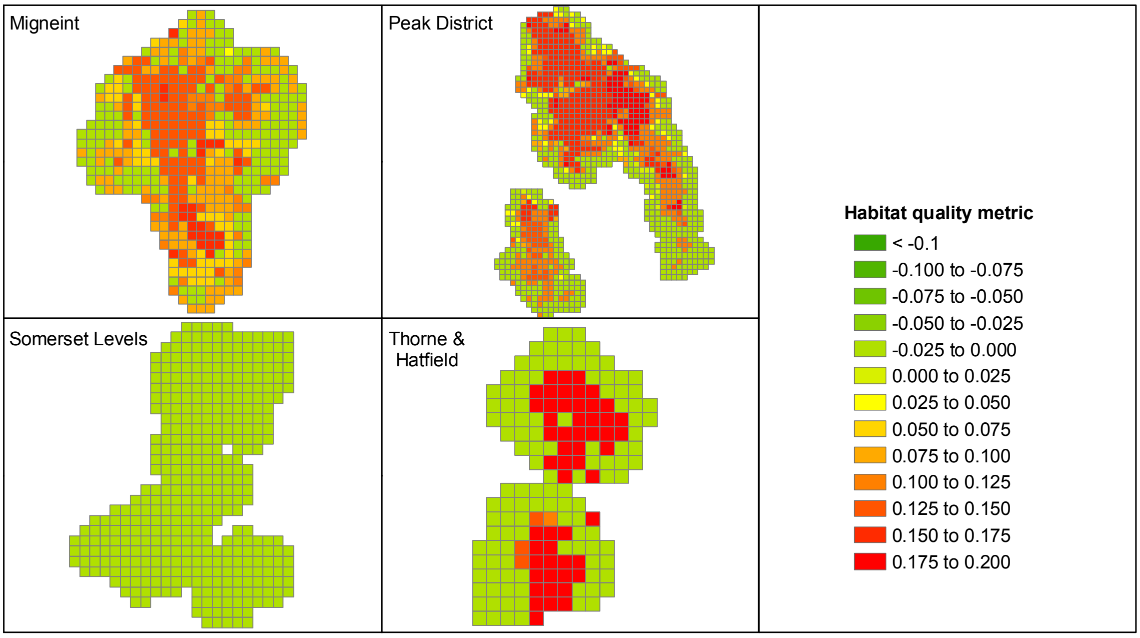


Figure 4.43: Changes in suitability for selected positive (a) and negative (b) indictor species as defined in the Common Standards Monitoring guidance for blanket bog, 2005-2020, under different land management scenarios: BAU = business-as-usual; Food = food security; Grouse = grouse economy; Wet = re-wetting; Wild = Conservation led re-wilding. Mean changes across three peatland SACs: Migneint, Peak District, and Thorne and Hatfield Moors.

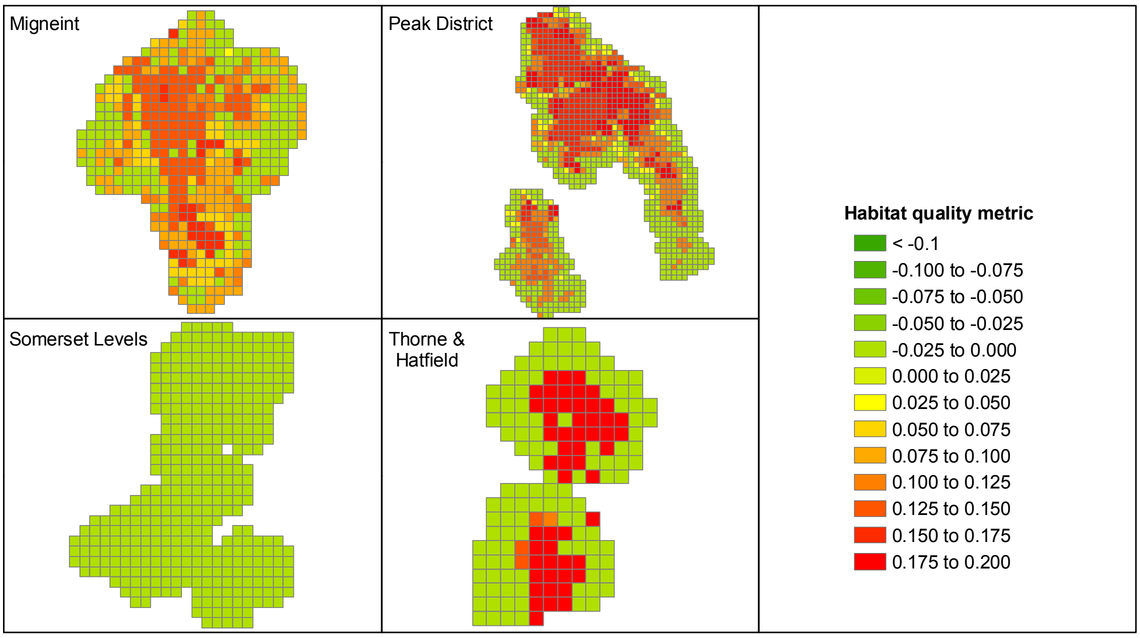
Effects on positive and negative CSM indicator species were summarised into a habitat quality metric, HQ. The predicted distribution of HQ for blanket bog across three of the study sites under five land use scenarios is illustrated in Figure 4.44 a-e. Coverage is limited to 1 km squares with bog habitats; wet heath was present on more of the 1 km squares in the study sites (map not shown). For the Ecosystem Service valuation exercise, an overall HQ was calculated for each square, defined as the maximum HQ for either habitat.



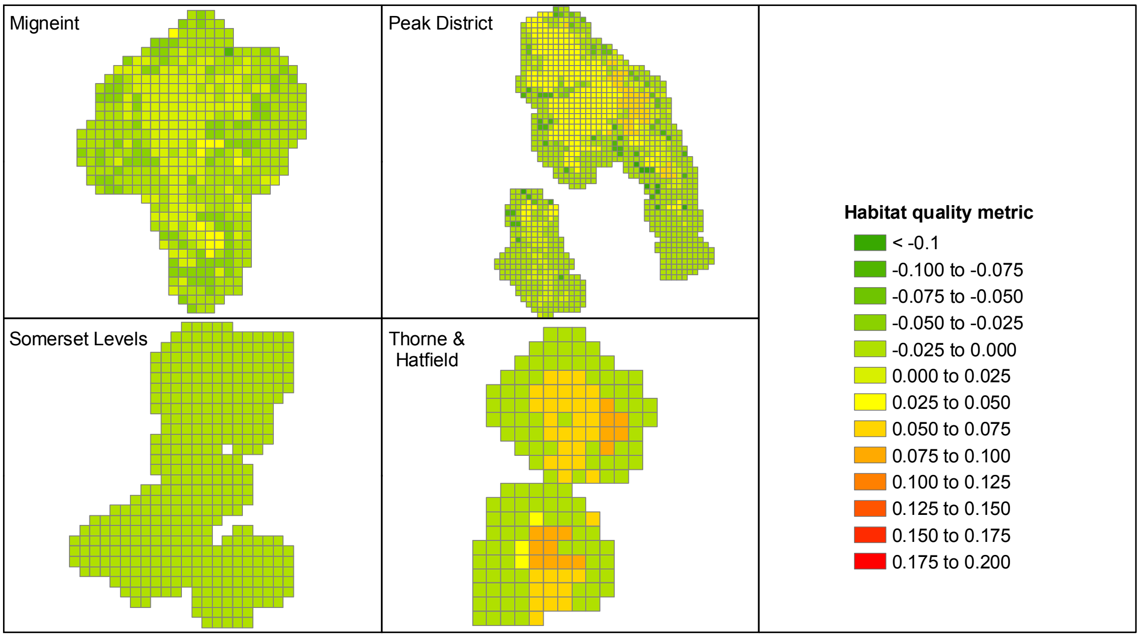
a) present situation - business as usual



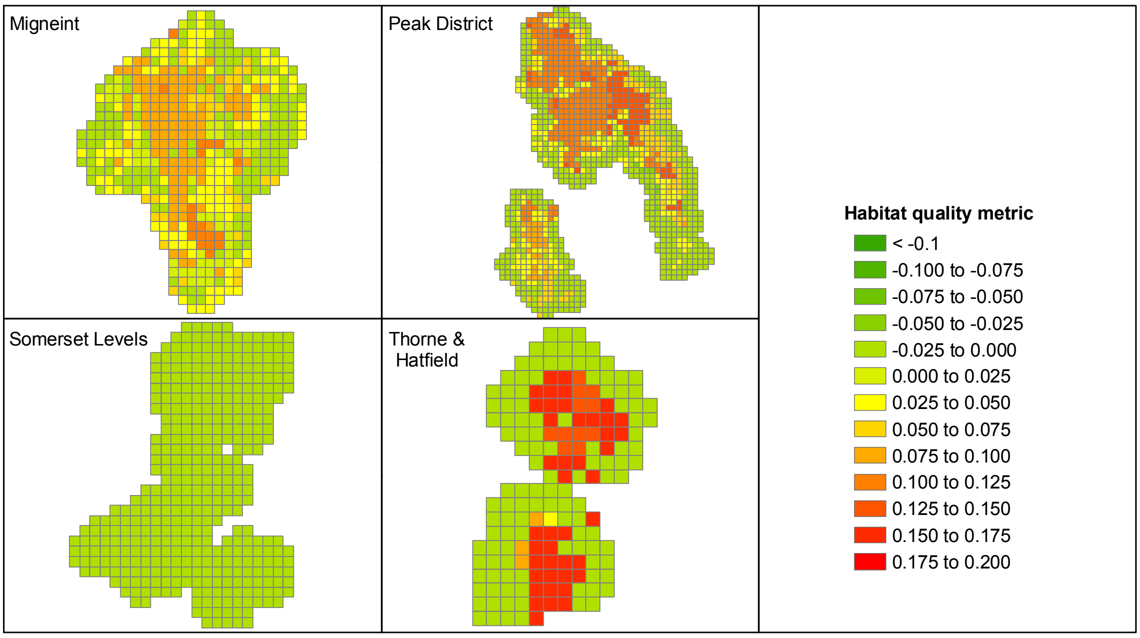
b) no drainage - rewetting



c) Conservation led rewilding



d) Food security (increase in grazing)



e) Grouse Economy (increased burning in uplands)

Figure 4.44 a-e : Distribution of a biodiversity metric based on suitability for blanket bog indicator species across three peatland SACs, under different land use scenarios. High scores indicate greater biodiversity value, i.e. high environmental suitability for positive indicator species for blanket bog and/or low suitability for negative indicator species.

The mean change 2005-2020 in predicted maximum HQ per square under the different scenarios, across all three sites, is shown in Figure 4.45. There was a small decline under the business-as-usual and grouse economy scenarios, which can be attributed to a combination of increasing pH (due to recovery from sulphur pollution) with a continuing increase in nitrogen saturation. Changing land management had much greater effects, with a substantial increase in maximum HQ under re-wetting and CLR scenarios, and a substantial decrease under the food production scenario, due largely to the assumed increase in drainage. This decrease was greater still when increased grazing and drainage were combined with lime and nitrogen additions.

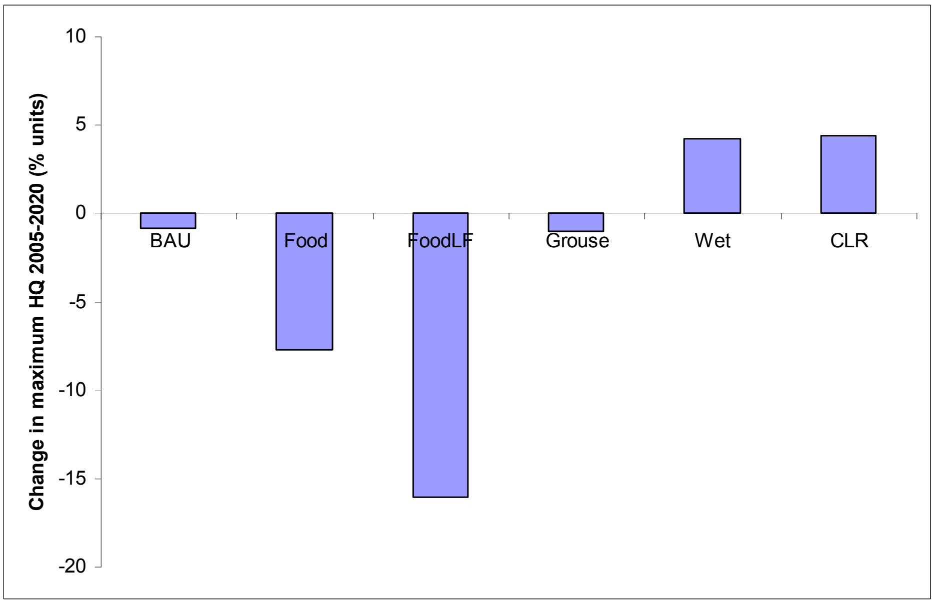


Figure 4.45: Mean absolute change 2005-2020 in habitat quality (as measured on a scale of +100% to -100%; maximum for blanket bog and wet heath in each 1 km2), across three peatland SACs: Migneint, Peak District, and Thorne and Hatfield Moors, under different land management scenarios: BAU = business-as-usual; Food = food security; FoodLF = intensified food security scenario with lime and N fertiliser; Grouse = grouse economy; Wet = re-wetting; Wild = Conservation-Led Rewilding.

4.4.7 Discussion

The habitat quality index provides a useful summary of effects on multiple plant species. For wet heath and blanket bog habitats, the index appeared to be most sensitive to changes in water content; changes in canopy height between the scenarios had relatively little effect. Thus the largest decline in habitat quality was observed under the Food Security scenario, and there was little difference between Business-as-usual and Grouse Economy, and between Re-wetting and Conservation-Led Rewilding scenarios. The habitat quality index was also highly sensitive to changes to soil pH and N contents; the more intensive food production scenario with lime and fertiliser additions resulted in a considerable decrease in habitat quality. A full sensitivity analysis would be required to determine the key drivers of change in different habitats. Parameters used to represent differences among scenarios would also need to be based on more empirical data to have full confidence in the results.

Key aspects of the approach, however, are the weighting attached to positive and negative indicator species, and the choice of habitat used to define these indicator species. There is in principle no reason why peatlands should not be evaluated for their suitability for other habitats, such as acid grassland or woodland, so there is an element of subjectivity in the choice of blanket bog and wet heath. However, these habitats are undoubtedly typical of peatlands under traditional management.

If the desired habitat(s) can be agreed upon, the choice of weightings to be applied to different species remains. The approach presented, weighting positive CSM indicator species at +1 and negative CSM indicator species at -1, is one of many possible weightings. Weighting based on scarcity, whether derived from UK distribution or from other sources such as the IUCN red list or the list of BAP species, might better reflect conservation status. If the criterion of maximizing species richness is used this implies weighting all species positively, but many people would give invasive or untypical species, particularly non-natives, a strongly negative weighting.

The approach taken to predicting changes in biodiversity quality under the different land use scenarios is one of many possible approaches. However, it is pragmatic in view of the available data, and makes use of some of the best available models for predicting effects on species, which makes this part of the analysis reasonably objective. The choice of which habitats and species are important components of biodiversity is inevitably subjective. The categorisation of positive and negative indicator species included in the CSM guidance is based on a large body of experience and evidence, and may also be the best currently available. However, the perception of which are important positive and negative indicator species may change, with changes in rarity, unavoidable climate change, and shifting societal perceptions. Thus a deliberative review of conservation targets, focused on defining weights for evaluating individual species, would be extremely valuable to strengthen the analysis. Specialists in species groups, habitats, and biodiversity protection should probably be major contributors to such a review, but the views of other interested groups and of civil society should also be taken into account.

4.4.8 Summary and research gaps

- Changes in environmental suitability for individual species in response to land use drivers can be predicted using data available at national scale.
- Default inputs for particular soil types are based on limited datasets, and are currently not available for fen peats. More measurements would allow wider coverage and better site-specific predictions.
- Detailed models of soil-vegetation dynamics in peatlands are available (e.g. Eppinga et al. 2009) and could be used to more accurately predict changes in the abiotic factors governing environmental suitability, where input data are available.
- Models can also predict aspects of habitat structure and function that are directly relevant to biodiversity protection (e.g. SUMO; Wamelink et al., in press). Habitat- and soil-specific parameters could be developed to run such models at national scale.
- Translating species responses into biodiversity responses requires species evaluations in relation to conservation objectives, such as those embedded in CSM guidance for many habitats, BAP species lists, etc.. Species weightings used to generate a quantitative indicator need to be established in a transparent deliberative process.
- Targeted research would be required to develop niche models for rarer species.
- Assessing changes between habitats would require evaluations of species' conservation value independent of a particular habitat.
- Species occurrence is also affected by biotic factors such as disease, dispersal and presence in the local species pool, which could be more explicitly incorporated into niche models.

- Plants are key components of ecosystems, but more animal than plant species are considered to be of conservation concern. The modelling approach is currently being extended to birds, and could be applied to other animal taxa where niche models can be developed.

4.4.9 Biodiversity on Somerset Levels and Moors

Fenlands tend to have a larger biodiversity than upland blanket bog. The majority of the Somerset Levels and Moors is open wet grassland and ditches supporting a range of plant communities including species-poor grassland (e.g. perennial rye grass), with National Vegetation Classification (NVC) communities (Rodwell, 1998) MG13, MG6, MG7, MG10. Where agricultural improvement has been less intense, species-rich fen meadows and flood pastures occur with MG8 *Cynosurus cristatus- Caltha palustris* grassland with *Cirsium dissectum* and *Caltha palustris* and mire communities such as M23, M24 and M25 with more *Juncus* and *Carex* species. Smaller areas of drier species-rich hay meadows (MG5) also occur with *Centaurea nigra, Orchis morio* and *Briza media*. The Somerset Levels and Fens also support small areas of tall herb fen (S24) with *Lathyrus palustris, Peucedanum palustre* and *Thelypteris palustris* and small remnants of raised bogs, which are very degraded and support vegetation more akin to wet heath with *Erica tetralix* and *Molinia caerulea*. Open water, reed swamp and reedbed with a range of species from submerged plants to tall stands of *Phragmites australis* and *Typha latifolia* are found in the flooded peat workings. Wet woodland occurs where peat was extracted many years ago and dominated by *Salix* spp., *Betula* spp. And *Alnus glutinosa*.

Analysis of the trends of 18 characteristic species from 1900 to 1997 (Mountford *et al*, 1999) shows decline throughout much of the 20th century due to lowering of winter water levels by pumping and subsequent desiccation of the wetlands. However, later data (1980 and 1997) provide some evidence of the effectiveness of raising water levels under ESA in terms of overall vegetation status and quality. Species totals have improved since 1986/7, with significant increases for many species including *C. panicea, C. cristatus, L. pedunculatus, L. vulgaris, M. aquatica, P. australis and S. pratensis.* Those species that have continued to decline are typical of non-agricultural habitats (fen, carr *etc*) where the ESA has less influence. Most of the species show some apparent benefit from the introduction of the ESA are either constituents of these farmed wet grasslands, or associated with the drainage channels that separate the fields (Mountford *et al*., 1999)

Detailed studies were undertaken at Tadham Moor to compare plant communities between wetland and dryland systems. This was achieved by raising ditch water levels to mean field level in the winter and 300 mm below this level in the summer. Raised water-levels led to a decline in the species typical of semi-natural old hay meadows. Increased aeration stress in the raised water level plots produced an initial sward die-back and spread of *Agrostis stolonifera*, which subsequently declined to be replaced by a species-poor swamp with *Carex riparia, Glyceria* spp, *Ranunculus repens* and *Calliergon cuspidatum*. Some impact of previous fertiliser treatments was detectable up to 7 years after the cessation of fertiliser application (2000 in the N^+ plots and 1996/7 in the N^- plots). Those plots that received high levels of nitrogen for seven years continued to show higher cover of certain grasses, and reduced cover of low forbs *etc*.

Table 4.11: Example water bird records for Somerset Levels and Moors

Common name	**Latin name**	**Mean numbers 1998-2002**	**% GB population**
Tundra swan	*Cygnus columbianus bewickii*	112	1.3
Eurasian teal	*Anas crecca*	21231	5.3
Northern lapwing	*Vanellus vanellus*	36580	1.0
Mute swan	*Cygnus olor*	842	2.2
Eurasian wigeon	*Anas penelope*	25759	1.7
Northern pintail	*Anas acuta*	927	1.5
Northern shoveler	*Anas clypeata*	1094	2.7
Gadwall	*Anas strepera strepera*	522	3.0
Water rail	*Rallus aquaticus*	36	8.0
European golden plover	*Pluvialis apricaria*	3857	1.5
Ruff	*Philomachus pugnax*	16	2.2
Common snipe	*Gallinago gallinago*	1633	1.6

There was some interaction between altered water-regime and past fertiliser treatment, and it appeared that the previous agricultural management altered the invasibility of the community, favouring certain species. Within the span of the experiment, the implementation of raised water levels led to the partial replacement of an old meadow vegetation (NVC MG5 and MG8) by a ruderal community (*NVC* OV28), swamp (*NVC* S6, S22) or inundation grassland (*NVC* MG13).

Overall, application of raised water-levels to areas with high botanical (or invertebrate) biodiversity value should be exercised with caution, and consideration given to alternative prescriptions for increasing site wetness, especially with regard to avoiding anoxia and sward death at the start of the growing season.

The SLM are known particularly for the large numbers of waterbirds they support; the Ramsar designation (*www.jncc.gov.uk*) is based on, for example, a count of over 97,000 water birds per year from 1998/99-2002/2003 (examples of individuals species are given in Table 4.11). Nationally important invertebrate species occurring at the site are *Hydrochara caraboides, Bagous nodulosus, Odontomyia angulata, Oulema erichsoni, Valvata macrostoma, Odontomyia ornata, Stethophyma grossum, Pteromicra leucopeza, Lejops vittata, Cantharis fusca, Paederus caligatus, Hydaticus transversalis, Dytiscus dimidiatus, Hydrophilus piceus, Limnebus aluta, and Laccornis oblongus.*

4.5 Health benefits

Peatlands are a major source for recreation, inspiration and enjoyment. However, health benefits derived from the experience of nature, including peatlands, are not yet well understood (Sustainable Development Commission, 2008). This section is based on a small-scale stand-alone desktop exercise to formulate the research question and to scope future research potential.

4.5.1 Background and the research question

Of the three types of ecosystem services of peatlands, health benefits derived from provisioning services and regulating services are perhaps better researched. They have direct impacts on human health by providing food, clean water, shelter and safety from disease and natural hazards. There are also dis-benefits, for example during drinking water treatment, dissolved organic carbon (DOC) derived from peatlands streams can react with chlorine to form halogenated organic disinfection byproducts (DBPs), such as trihalomethanes and others, with associated health risks, such as bladder cancer, attributed to consumption of water that contains these and other DBPs (Villanueva et al., 2007).

Least researched are health benefits derived from cultural services of peatlands, which is the focus of this section. Nevertheless, the idea is quite old and intuitive as the access movement, including the iconic mass trespass of Kinder Scout in 1932, was surely also related to health benefits. These were not only to get fresh air away from polluted cities but also to find enjoyment and freedom of mind with slogans such as ‘A Rambler Man is a Man Improved’. Over centuries, peatlands have inspired literature, invoked sense of space, and formed part of the cultural heritage of the peoples who have lived nearby (see for example the Environment and Heritage Service webpage www.ukbap/org.uk). Peatlands have also offered a place for play and adventure with benefits for people’s health and well-being.

While there has not been any literature review on the health impact of peatlands specifically, there have been several literature reviews that looked at the issue of how nature and green space affects peoples’ well-being (see for example Bird, 2007; Newton, 2007; RMNO, 2004). These have identified a number of research papers on the impact of green space on well-being. Overall, these reviews have found that “the natural environment provides synergistic physical, mental and social wellbeing benefits” (Newton, 2007; p4). For instance, Natural England has summarised the ways in which people enjoy and engage with nature under three aspects: physical enjoyment by taking part in activities in nature, visual enjoyment by observing nature, and vicarious enjoyment through visual and verbal representations of nature (Natural England, 2008). In order to think about the health benefits derived from cultural services of the peatlands ecosystems, we can build on this substantial body of work.

The first question to ask is what health and well-being is. The ecosystems and well-being framework by the Millennium Ecosystem Assessment (MA) defines four “determinants and constituents” of well-being: security, basic material for good life, health, good social relations (see Figure 4.46). It also poses freedom and choice as an overarching component (MA, 2005). The intriguing issue about this framework is that it focuses on the influences from ecosystems into well-being, and seems indifferent regarding any interactions amongst the constituents of well-being. However, there can be (and probably will be) as much interaction amongst the constituents of well-being as there are influences from ecosystems to the constituents of well-being. The implication of this is that it is very challenging to single out a particular causal pathway from any given ecosystem service to a specific constituent, and to quantify the magnitude of its impact.

The MA framework has been criticised for not covering the mental side of health (Newton, 2007). Furthermore, it seems to conceptualise health as being adequately nourished, being free from avoidable diseases, having access to clean water and air, and having energy to keep warm or cool. Clearly, adequate nutrition, air, water, and temperature are determinants of health (and comfort) and not health per se. Thus health itself seems to boil down to an absence of avoidable disease (plus possibly some minimal standard comfort). Compared, for example, to the definition of health used by the World Health Organisation (WHO), this is a minimalist approach. The WHO defines health as “a state of complete physical, mental and social well-being, and not merely the absence of disease or infirmity” (WHO, 1948). Of interest here is the relationship between a clinical or medical conceptualisation of health and a more lay conceptualisation of health. Absence of avoidable disease suggests the former, whilst physical, mental and social well-being suggests the latter.

There is also a wide ranging debate over how to conceptualise and to measure well-being. For instance, most researchers in the field distinguish between objective measures (e.g. GDP per capita) and subjective measures of well-being, and divide the latter further into measures of:

- hedonic or subjective well-being (e.g. life satisfaction or self-reported happiness) and
- eudaimonic or psychological well-being (e.g. flourishing) (see for example Frey and Stutzer, 2002).

The MA definition of well-being is largely based on the objective account, with some reference to a flourishing account (freedoms and choice). On the other hand, the WHO definition of health is possibly compatible with any of these conceptualisations of well-being.

The question that we would ultimately like to explore is what the health impact of cultural services of peatland ecosystems amounts to. Methodologically this question needs to be addressed by examining population groups that currently have access to peatlands in contrast to a control groups without access to peatlands, who are otherwise identical to the study population in all relevant aspects. If there is any health impact, then the study population should be healthier than the control group. Another way to conceptualise the issue is to assess a policy or other intervention that would enable a whole new population group that had previously no access to peatlands to access peatlands freely. What would be the long term health benefits to this population group?

4.5.2 Complexity of the issue

There are two main hurdles to clear in order to answer the question. The first hurdle is the complexity of the causal pathways. People who newly acquire access to peatlands may (or may not) change their behaviour regarding their use of peatlands. Those who utilise peatlands may choose to observe the natural landscape from afar. Or, they may choose to put themselves in the physical environment, or choose to be more active in the new space. Each of these will have mental health implications and physical health implications. At the same time, there will be psychosomatic interactions, or a synergistic relationship, between mental health and physical health components. Alongside this within-individual level process, access to green space is likely to involve interaction with other people, which will result in mental and physical health outcomes. At a more global level, overall well-being will be affected by all the foregoing factors. And this global well-being (along side health) can be a determinant of how people utilise green space when they are given access to it. This is illustrated in Figure 4.41. However, compared to the reality, this illustration is likely to be grossly oversimplified.

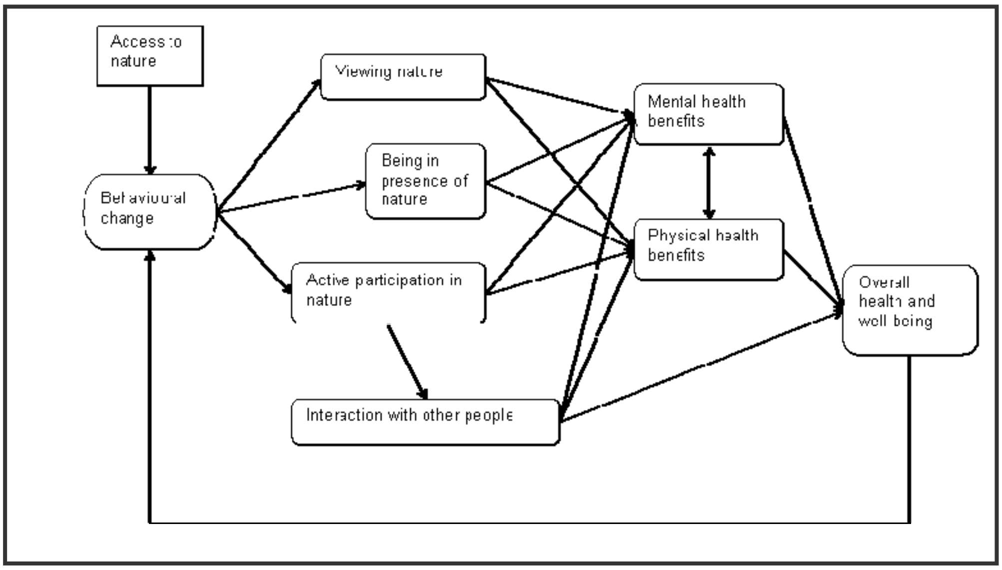


Figure 4.46: Causal pathways between access to green space and health

Various studies have looked at the different stages of this pathway. Classical examples include:

- Viewing nature speeds up recovery from an operation (Ulrich, 1983)
- Walking in green space reduces depression (Mind, 2007)
- Patients with contact with nature have reduced aggression (Whall et al, 1999)

In addition, studies have looked at the overall pattern at the population level:

- People living near parks have lower mortality (Takano et al, 2002)

However, in order to complete the chart above, it is not sufficient to identify statistical associations between the input variable (e.g. walking) and the output variable (e.g. depression). We will need a full explanation of the causal mechanism between the two. Further research is necessary to determine the direction of causality and to quantify the size of the expected benefit. In other words,

- Is access to nature making people healthier, rather than healthier people being more likely to access nature?
- Assuming causality goes from nature to health, would everybody's health improve, and by the same degree?
- Or, can nature, like some pharmaceutical products, also have adverse effects on peoples' health and well-being?

Furthermore, all these are likely to be probabilistic processes, varying by the size of the dose or exposure, and the physiological and psychological characteristics of the recipient. There is also an interesting research area exploring the more socioeconomic mediators in this process. A comprehensive understanding of these will require an interdisciplinary approach drawing on health sciences including epidemiology and physiology, psychology, and sociology.

A related issue is how to capture the benefits through time. It may be argued that there are two types of benefits from access to green space. One is the immediate consumption benefits. The individual simply feels better from the physical exercise, or by being calm. The other is the possible longer term, investment benefits. If people make a sustained effort to control hypertension and anger, then it will be less likely for them to go on to have strokes and heart attacks. However, it is not straightforward to capture the causal effect of this and to quantify the future benefits. In the absence of longitudinal data of sufficient duration, mathematical modelling can be used to model the future expected impact.

The second hurdle towards answering our ultimate question is how to link the outcomes measured with a more general concept of health. For example, increased physical activities will reduce blood pressure, which will probably be associated with reduced cardiovascular diseases. The challenge at this stage is that any such effects in physical health will need to be compared against improved self-esteem and reduced depression. There already is an existing method that captures and quantifies various states of health in a single metric, that is used in technology assessment of health care interventions (see for example Brazier et al, 2007). This combines the length of survival with the health related quality of life of each time period of survival. So for example, 1 year of survival in full health by 1 person is defined as 1 Quality Adjusted Life Year (QALY). If 2 people survive in full health for 1 year each, that is 2 QALYs, and if 2 people survive in 50% health for 4 years each, then that is 4 QALYs. The QALY becomes a generic measure of health that allows the direct comparison between reduced symptoms of hypertension, improved mental state, and a rapid recovery from surgery, all on a common metric of health benefit. Thus, this approach aims to capture the more conventional elements of physical and mental health.

However, if the WHO definition of health is taken, we still need to link the reduction in disease to improvement in well-being. One research priority in this area is the development of a suitable outcome measure that will capture the various effects that peatlands, and green space in general, may have on people in terms of the physical, mental, and social components of well-being.

4.5.3 Potential for future research

To address these challenges, we suggest an interdisciplinary research programme built from four key components.

1) Building of a theoretical causal pathway model from ecosystem services provision by peatlands to health and well-being. The above Figure 4.46 may be seen as a starting point towards this.

2) Systematic review of the existing literature to update and to supplement the existing reviews. This review has three objectives.
    - to identify scientific studies that looked at the impact of green space and peatland on human health.
    - to extract the relevant information so that the pathway model can be improved, and so that each stage of the pathway can be better understood.
    - to identify and to quantify the relevant parameters associated with each arrow in the model. This last exercise should be carried out for the overall general population, and for policy relevant population subgroups. The latter may be by socio-economic class, or by ethnic groups, for example.

3) Synthesise the different segments of this pathway model, since different studies use different outcome measures (compatibility). There is already an established methodology in health economics

where different health outcome measures are mapped from the more specific to the more generic (Brazier et al, forthcoming). However, the exercise in the context of green space and health is likely to involve wider aspects of human well-being beyond physical and mental health typically addressed by health economists.

4) Identification of key stages of pathway model with greatest information value. As with any conceptual model, the models devised in this programme will involve uncertainties of varying degrees. Some uncertainties have a larger impact on the larger picture than other uncertainties. The size of the health and well-being impact of cultural services of peatland ecosystems will be affected by some uncertainties but less so on others. This last exercise will identify the topics for the next round of empirical research that will most effectively contribute towards improving the precision of our understanding of matter.

For accomplishing the above research programme we need a two-level approach. While we need individual empirical studies to evaluate different interventions and programmes, such as evaluating the Natural England/NHS Heath Walk Initiative using their questionnaires and empirical studies, no individual study is going to look at the entire pathway represented in the figure above. Therefore, alongside these, we need a desk-based study of the kind proposed above that tries to pull together all the different studies that each look at specific bits of the figure, by making these different studies comparable with each other. Furthermore, the value of information analysis will identify where the knowledge gap lies, in order to invest in the next round of empirical studies that will best fill these gaps and forward knowledge.

A five year plan would be

Month 1- 20	Causal pathway model development (1)
Month 1- 8	Systematic review (2)
Month 9 -14	Synthesis (3)
Month 15 -25	Evaluation of information and identification of prr
Month 26 - 60	A series of high priority empirical studies identified in the fourth component

A separate study following from the completion of the first component (pathway) is the development of a purpose built outcome measure for health and well-being to be developed in parallel to the empirical studies.

4.6 Other Ecosystem Services

As a scoping project this study did not consider all possible peatland ecosystem services. Here we list some additional services which can be considered important.

4.6.1. Energy provision: Wood fuel

The Forestry Commission (2007) have published a Woodfuel Strategy for England and provide extensive guidance on wood fuel generation and new planting schemes, also on peat. The Strategy report provides spatial maps of currently managed and undermanaged woodland resources. The UK Woodland Assurance Standard is currently in review and Forest Research (2009) have recently published a guidance on site selection for brash removal, following growing interest in harvesting brash material following timber extraction to supply biomass for heat and power generation. This considers in particular upland conifer forests with a focus on Sitka spruce stands and specifically lists peatlands as high risk sites. The PC based software Ecological Site Classification Decision Support System (ESC-DSS) http://www.forestry.gov.uk/fr/INFD-5V8JDG helps land managers to choose the most ecologically suitable species for potential sites, and there is extensive Forestry Commission research on effects on biodiversity. For ecosystem service mapping, potential wood fuel sites and risks to soil erosion and carbon loss could be mapped and evaluated in a spatial GIS.

The planting of trees for wood fuel will have an affect upon carbon storage. If the planting of trees is not allowed to mature before harvesting for fuel, the harvested fuel is substituted for fossil fuels, and the harvested material is replanted, then the planting of trees for wood fuel can increase overall ecosystem storage and through product substitution further mitigate greenhouse gas production. However, the planting and management of trees upon peat soils does cause the peat soil to become a net source of carbon and greenhouse gases but this is offset by the development and farming of the biomass in the trees. In effect, the planting of trees on peat soils causes a shift in carbon storage in the environment from being stored belowground to being stored above ground. The greenhouse gas and carbon benefit of wood fuel development can only be sustained if the trees are harvested and used for product substitution otherwise any benefit is time limited.

4.6.2. Air quality regulation

Regulating services in peatlands include air quality regulation through atmospheric deposition and cooling. While atmospheric deposition can be mapped using CEH data (see above), peatlands in this respect may be considered primarily as recipients of atmospheric pollutants (see e.g. Section 4.2.3) rather than as regulators; the impact of peatlands on air quality has not yet been quantified, but is likely to be fairly minor.

4.6.3. Natural hazard regulation: Wildfire risk

Sutherland *et al.* (2008) have identified wildfire as one of the top 25 priority risks to UK biodiversity. Wildfires are already contributing to huge environmental and economic losses in the Peak District peatlands, and with climate change wildfire risk is expected to rise. McMorrow et al. (2006, 2008) and Lindley *et al* (2009) have developed explicit GIS wildfire risk maps (Figure 4.47) in close collaboration with the Fire Operations Group (FOG) and Moors for the Future Partnership for the Peak District and currently for the South Pennines peatlands.

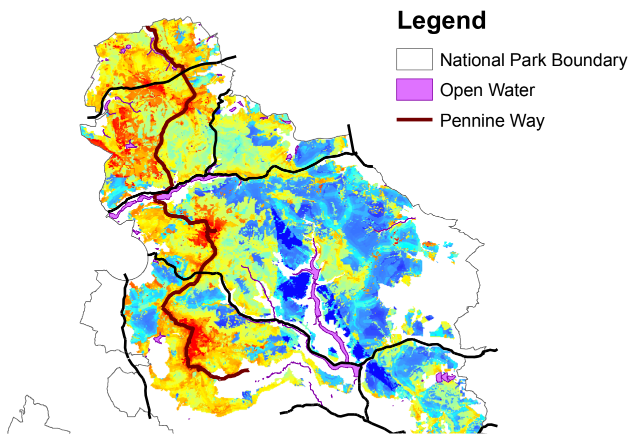


Figure 4.47: Example for wildfire risk-of-occurrence mapping for the Peak District moorland wildfire model, shown here for the Dark Peak area (blue to red – increase in wildfire risk; Lindley *et al,* 2009)

The 2008-2009 NERC/ESRC FiRES seminar series organised by McMorrow *et al* devoted a special workshop in the Peak District National Park ‘Adaptive management to wildfire risk: implications for ecosystem services of UK moorlands and heaths’ http://www.fires-seminars.org.uk. This seminar identified alternative physical interventions for managing wildfire risk, including fire-fighting techniques and discussed their relative costs and benefits for ecosystem services. Further research on fire management to maintain biodiversity and mitigate economic loss is underway in the 2009-2014 FIREMAN Biodiversa project led by Bradshaw et al, University of Liverpool, with the Peak District as upland peatland case study http://www.fireman-europe.com/ .

5. Economic valuation of ecosystem services

5.1 Ecosystem service valuation

The focus of this section is to identify the extent to which existing environmental valuation studies can be applied to strengthen the policy advice related to peatland restoration. The analysis has taken an ecosystem service approach in order to outline the nature of the various costs and benefits associated with peatland restoration.

This section is structured as follows. First, the rationale for the framework used in the project is outlined as this structures the economic analysis of appropriate policy actions. Secondly, the results of the literature review will provide an overview of the estimates provided by existing studies. Priority has been given to the studies relevant to the chosen case studies. This concludes with an evaluation of the current evidence of benefits from peatland restoration and more generally ecosystem services derived from peatlands. Thirdly, the section offers an analysis of the synergies and trade-offs between the provision of different ecosystem services quantified for each of the study sites. This allows an initial assessment on whether it may be economically efficient to prioritise different ecosystem services in different areas or whether joint production of groups of ecosystem service is likely to provide added value. Finally, an overview of the information gaps in ecosystem service valuation for peatlands thus proving recommendations on the types of studies that should be prioritised for future work.

In this part of the project we have focused on the following aspects of peatland ecosystem service provision as advised by Defra; i) carbon flows, ii) biodiversity, iii) water quality indicators and iv) run-off potential. This is to reflect the most significant changes the ecosystem services that are likely to be influenced by peatland management. Furthermore, the choice reflects the availability of data and status of scientific understanding allowing us to model the impacts of management changes.

5.1.1 Valuing ecosystem service changes

Peatlands provide a wide range of complex direct and indirect ecosystem services. This is however not in itself an economic rationale for peatland restoration. In order to assess the economic case for restoration action it is essential to determine whether specific management actions have an impact on the ecosystem services provided by peatland. Only by assessing the relationship between actions and changes in ecosystem services will it be possible to draw conclusions about appropriate allocation of economic resources for peatland restoration.
This is the rationale for the identifying key management scenarios and the modelling of changes in ecosystem service provision across the selected sites.

The required steps are therefore;

a) To identify the baseline situation for each site,
b) To identify management changes under different scenarios,
c) To identify existing data on the costs associated with each management change,
d) To link management changes to changes in ecosystem services,
e) To identify biophysical trade-offs in relation to management intervention,
f) To identify existing data on the economic values of the change in ecosystem service provision and
g) Identify existing data on variations economic values associated with ecosystem changes across stakeholders.

As a scoping study, a full implementation of all steps is not possible within this project. The report will however make some progress on each of the points outlined and identify areas where further work needed to support economic evaluation of peatland management options.

5.1.2 Defining the baseline situation

The baseline situation describes the current ecosystem services that are present under the current ‘state of the world’. This is the state that exists unless there is some specific policy intervention. The description of the baseline situation is an important part of economic evaluation since prioritising management intervention requires the comparison of the two states. The first is the state without the change and the second is a state after a management or policy intervention. The baseline situation or business as usual (BAU) used in this section of the report has been described in section 4.2.1 for carbon (Figure 4.11), section 4.4 section 4.2.3 for water quality indicators, exemplified here as DOC (Figure 4.31 and 4.32) and section 4.2.2 for run-off potential (Figure 4.19 and 4.20).

5.1.3 Characterising the management changes
Peatland restoration is considered over a number of change scenarios. The scenarios have been chosen to reflect management actions that are important determinants of the ecological state of peatlands and are realistic options across most of the case study sites. These scenarios have been reported earlier in the report. As far as possible we have defined the scenarios in a consistent way across the sites and across the individual ecosystem services. For this section we have simplified the data provided by the other work packages in order allow comparison across service provisions and across geographical sites.

Restoration of water table
This scenario focus on the impact of the level of the water table as draining has in the past been a widespread practise to increase productivity of the land for agricultural production. The management activity affecting this scenario is gully and grip blocking. The economic cost involved with this activity is considered to be a single investment of £1.95/meter drain (Dinsdale Moorland Services, pers. comm..). It is assumed that no other cost are associated with implementation of this scenario. Accurate estimates for the length of the drains have not been available across the sites, but it is straight forward to cost the implementation of this restoration initiative.

Restoration of vegetation
This scenario investigates the impact of restoration of vegetation on bare peat. Case studies reported in the compendium of UK Peat Restoration and Management project indicate the figure of £1000/ha (Walker et al 2008).

'Conservation led Rewilding'
This scenario maximises for conservation objectives by removal of grazing and burning and maximum restoration efforts for upland and lowland peatlands, respectively. The cost of this policy option is the combination of the restoration of the water table and re-vegetation plus the opportunity costs of farming and grouse shooting. Large-scale implementation of this option would clearly have significant social and socio-economic consequences for upland communities. An assessment of these is beyond the scope of this study.

Food Security
This scenario explores the impact of prioritising food production. The scenario is modelled by assuming an increase in the intensity of agricultural production. For the Peak District and Migneint this has been assumes increased sheep production. For Thorne and Hatfield this assumes conversion to arable production.

Grouse economy
This scenario investigates the impact of burning on ecosystem service provision. The rationale for this scenario is to understand the implications of managing the case study sites for grouse production. The scenario is modelled by increasing burning activities on all areas with heather cover. Information on the direct costs of implementing patch burning to maintain grouse moor productivity is available from the RELU upland project (Termansen et al 2009) based on a survey of moorland managers in the Peak District and Nidderdale. Economic accounts from three moors are available from the Moorland Association and report on highly variable moorland management costs and revenues (Moorland Association, unpubl.data). The data does not allow a more general assessment of the impact of heather burning on grouse shooting revenues and costs.

5.1.4 Linking management to ecosystem service change
Under the identified management change scenarios, the change in ecosystem services is identified for each site. The tables below draw together the initial findings reported in section 4 of this report. The list is a selected list of services and by no means and exhaustive list of relevant services. They have been selected due to their relevance in the sites and the available data to allow further analysis.

For each of the scenario Table 5.1 give direction of change in ecosystem service provision, e.g Carbon flux under the rewetting scenario minus Carbon flux under Business as Usual. Note that Table 5.1 uses the same convention for reporting for Carbon as in section 4, which means e.g. that the food scenario on average is predicted to result in an increase in the atmospheric CO_2 concentration.

Table 5.1: Summarised aggregated changes in selected ecosystem services. (Shaded cells indicate that the individual ecosystem service models have not been suitable for the scenario analysis. For convenience, + signs show positive changes, i.e. increase in biodiversity, food/ grouse production but reduction for Carbon and DOC flux and rapid run-off generation potential, while – signs show negative changes in the opposite direction.)

Scenario	Δ Carbon	Δ DOC	Δ Run-off Pot	Δ Biodiversity	Δ Food	Δ Grouse
Wet	~ 0	+	+	+		
ReVeg	+		+			
ReWild	+		+	+	-	-
Food			-	-	+	
Grouse	-	-		-	-	+

These results are consistent across the modelled case studies. Overall, restoration and conservation scenarios have positive impacts on regulating services and biodiversity, e.g. that conservation led rewilding is predicted to have, on average, positive effects on reduced Carbon emissions, increased run-off attenuation potential and overall benefits for biodiversity, while economy scenarios for increase in food or grouse production tend to have negative impacts on the provision of other services. However, large variability exists across the landscape and it is important to understand the nature of this variability in order to inform local management decisions. Further research is ongoing.

5.2 Economic valuation – review of existing studies

For valuation of the services there needs to be a link between peatland management and ecosystem service impacts identified below. This link is missing for many of the ecosystem services, and consequently there is a lack of studies that can directly address the value of services explicitly linked to the protection of peatland services. The large majority of the existing literature is populated with studies that have sought the value services from protection of the uplands in general and have indirectly included services provided from peatlands. This finding is echoed in a recent report by Natural England (EFTEC 2009) and also in this review below. However, what has been done is a determination of the types of values and methods that can be used to value services explicitly from peatland protection. These values can be used in economic appraisal tools to determine whether peatland protection is worth investing in. Table 5.2 gives a tabulated overview of the individual studies reviewed, environmental good valued and technique used.

Table 5.2: Review of valuation studies

Name of study	Socio-economic benefit/cost	Method	Value
Water quality and supply for peatlands and uplands)			
Beharry-Borg N. et al. 2009	Improved drinking water quality from reduction in DOC through gully-blocking in Nidderdale. Monetary incentive costs incurred by farmers to allow implementation of gully blocking.	Avoided ‘end of pipe’ water treatment costs. Choice experiment	On-going work
NERA and Accent (2007)	Households benefits of on water quality improvements from Water Framework Directive.	Contingent valuation	£44.5 to £167.9 per household per year (BT)
Johnstone and Markandya (2006)	Use value of rivers for angling in uplands and lowlands.	Travel cost method	CS value for a 10% improvement in specific river attributes is £0.04 to £3.93/trip.
Hynes S. and Hanley N.(2006)	Recreational use value of whitewater rafting in Ireland	Travel cost method	CS value of £220/trip

Pretty et. al (2003)	Damage costs of freshwater eutrophication in England and Wales.	Damage costs	£75-114.03 million per year
Willis, K.G. (2002)	Value of water quantity to provide abstraction of drinking water.	Short run marginal cost/long run marginal cost	Specific values in £/m3 based on water company and area.
Spurgeon et. al (2001)	Value of public to pay for environmental benefits of having healthy fisheries in England and Wales.	Contingent valuation	£2.40 per household per year.
Willis K.G. and Garrod G. 1999	Recreational benefits (including angling benefits), of increasing flow of rivers in South-West England.	Contingent valuation and choice experiments	Anglers WTP is £3.80 per day.
Downstream flooding of peatlands and uplands			
Drake (2009)	Benefits of avoiding flood risk	Choice experiment	On-going work
Jacobs (2008)	Total economic value flood control and storm buffering benefits provided by a subset of England's habitats	Market value, consumer surplus and total WTP.	£1.2 million
Werrity et. al (2007)	Damage to households (buildings and contents) in Scotland	Direct economic loss	Approximately £32,000 for damage to buildings and £13,500 for damage to contents.
Werrity 2002, Werrity and Chatterton 2004	Damage to property	Direct economic loss	Approximately £30 million for Tay/Earn flood in 1993 £100 million for Strathclyde floof in 1994.
RPA (2005)	Household benefits of reduced flood impacts	Contingent valuation, choice experiment and cost-benefit analysis.	Approximately £200 per household
Carbon sequestration from peatlands and uplands			
Drake (2009)	Benefits of reducing carbon dioxide emissions	Choice experiment	On-going work
DECC (2009)	Marginal abatement costs required to reach UK target (target consistent approach)	Social cost of carbon	Short term traded price of £25 per tonne in 2020, with a range 14-£31. Short term non-traded price of £60 per tonne, with a range of £30 to £90.
Glenk and Colombo (2009)	Benefits of a soil carbon program	Choice experiment	On-going work
Kulshreshtha S. and Johnston M (no date).	Value of carbon sequestration function of Canadian peatlands	Replacement cost and substitution cost for carbon.	Estimations between £46 - £49 billion.
O'Gorman & Bann (2008)	Total economic value of benefits from woodlands and associated soils, wetlands and peatlands in England.	Market value, consumer surplus and total WTP.	£1007 million per annum
Recreation opportunities in peatlands and uplands			
Zanderson and Tol (2008)	Recreational value of forests	Meta-analysis of TCM method	CS values 0f £0.45-£77.26 per trip
Hanley et. al (2002)	Value of rationing access to upland outdoor recreation areas for rock-climbing in Scotland.	Choice experiment	A 2 hour increase in walk time reduces predicted visits by 44%. A £5/day car parking fee reduces trips by 31%.

Liston-Heyes and Heyes (1999)	Value of day trip to Dartmoor National Park in England.	Travel cost method	CS values of £10.18 to £13.28 per day trip.
Bullock and Kay (1996)	Value of landscape changes from reductions in grazing levels in Central Southern Uplands of Scotland.	Contingent valuation	£49 per household, per year for visitors.

5.2.1 Water supply and quality

The main impacts of protecting peatlands on downstream catchments are the quality and quantity of water supplied. This has further impacts on the value of water for several uses such as drinking water quality, recreational uses of rivers and streams, fisheries, agricultural uses of water and risk of downstream flooding.

One way to value the downstream drinking water quality would be to determine the change in water quality from protection of peatland in a specific catchment. In a study by Beharry-Borg et al (2009), they argue that gully blocking has an impact on downstream water quality in Nidderdale. In order to value the cost of protection they use the choice experiment method to determine what the incentive costs are for paying farmers to allow their land to be gully-blocked. This cost is then compared to traditional treatment costs from water companies to calculate the avoided 'end of pipe' treatment cost of implementing peatland protection practices (i.e. gully blocking).

Other studies have not linked strategies for peatland protection (e.g. gully blocking) explicitly to water quality but they have estimated the impacts on water supply based on wider management decisions. For example Willis (2002) argues that forestry can affect water quality and quantity by reducing the amount of water available for (1) runoff into rivers and (2) amount of water percolating into the water table. These two impacts thus reduce the amount of water available for water abstraction and may increase abstraction costs to the water industry. They estimate these values using long run marginal costs (e.g. costs of new boreholes and increased abstractions) based on specific companies and areas. Similar methods could be employed to derive the benefits of protecting peatlands, if the contribution to peat within the forest can help to account for the marginal increase in water supply and quality.

A number of additional studies have derived use and non-use values of protecting water quality in the uplands and lowlands where peat soils are found. The use values include recreational benefits such as increased angling opportunities in uplands and lowlands using stated preference methods such as contingent valuation and choice experiments (Willis and Garrod 1999, Spurgeon et al. 2001, Johnstone and Markandya 2006). Other studies have used revealed preference methods such as travel cost to derive recreational benefits (Johnstone and Markandya 2006, Hynes and Hanley 2006).

These current studies are of limited benefit and applicability to deriving recreational values (e.g. angling) from protecting peatland services. This is because the link between recreation and protection of peatlands was not specifically investigated within these studies. Additionally, the relationship between peat cover and fisheries is complicated. However, one way forward to make this biophysical link and hence carry out these valuations would be to use model results of the predicted acid neutralising capacity (ANC) of the rivers from protection and restoration of peat around it. For example, different ANC concentrations will support differing fish populations for example:

Table 5.3: Acid Neutralising Capacity (ANC) and fish population viability

ANC	Availability of fish
> 50 ueq/l	Healthy salmon and trout population
20 to 50 ueq/l	Marginal salmon, healthy trout
0 - 20 ueq/l	No salmon, marginal trout
< 0 ueq/l	No salmon or trout

Although ANC is not the only factor that affects fish populations, it can provide a starting point to compare rivers with levels above and below these threshold values. This can provide the basis for valuing both the recreational benefits and actual market value of fisheries in rivers that benefit from peat restoration. In England and Wales, the Dark Peak area is an extreme example with fish populations declined or lost altogether due to acidification, while in areas such as the Migneint fish populations are slowly recovering. In the Peak District with very low fish populations peat restoration could have potential recreational values by increasing fish populations which could be attributed to restoration of peatlands (see Fig 4.24).

5.2.2. Down stream flooding impacts

The management of peatlands can also affect the frequency and severity of flooding events (see section 4.2.2 above). There are a number of studies using a variety of methods to estimate loss in value due to flooding (Werrity 2002, Werrity and Chatterton 2004, Werrity et al 2007, RPA 2005). However, only one ongoing study has linked the value of reducing flood risks to the protection of peatlands (Drake 2009). In this study, the choice experiment method has been used to determine how much people are WTP for reducing their flood risk from 1 medium sized flood every 4 years, to 1 in 6, 1 in 8 or 1 and 12 in York. Preliminary results indicate that people have positive WTP for reductions in flood risk and this increases for reduced frequencies of flooding.

The studies by Werrity and Chatterton (2004) and Werrity et al (2007) calculate direct economic loss from flooding events such as damages to property. Werrity (2007) estimates that direct economic losses for households average around £32,000 for damage to buildings and around £13,500 for damage to contents as a result of recent floods in Scotland. Werrity and Chatterton (2004) estimate a loss of £30 million for the Tay/Earn flood in 1993 and a total loss of £100 million for the Strathclyde flood in 1994.

A recent Defra report (RPA 2005) estimated the benefits of reduced health impacts as a consequence of reduction in the risk of flooding by using two sets of questionnaires. The first was designed to derive WTP to avoid flooding impacts and administered only to those who had experienced flooding within their house since January 2008. The second was designed to explore WTP of those who were at the risk of flooding but had not been flooded before. The overall value per household was £200 and this was derived using contingent valuation, choice experiments and a cost-benefit analysis. A combination of market value, consumer surplus and total WTP was used in a report by Jacobs (2008) where they estimated the total economic value of flood control and storm buffering benefits provided by England's terrestrial and ecosystem services. They have noted that this was indeed a challenging exercise and that these ''broad brush'' studies are 1) theoretically challenging and 2) of limited value to informing policy and decision making.

Restoration of peat has three main observable impacts that can be valued. The first impact is on the potential reduced discolouration of water through restoration activities such as gully blocking. This can be valued by using stated preference methods, avoided treatment costs, market value of water and avoided costs of using bottled water to determine the value of discolouration of drinking water.

The second impact of peat restoration is the effect on ANC values that has further impact on fish populations. Although this is not the only factor affecting fish populations, it can be used as a starting point to determine a lower bound value of fisheries such as salmon and trout for market and recreational uses such as angling.

The third impact is the risk, frequency and severity of downstream impacts of flooding. Once the protection of a particular area of peatland can be linked to downstream flood impacts, then it is possible to use a number of methodologies to value the benefits of costs of impacts of flooding. These include hedonic pricing which measure the impact on property prices; actual damage costs using market prices; production function approaches which can measure damages from agricultural losses due to flooding and stated preference approaches which can help to estimate non-market aspects (such as inconvenience and risk).

5.2.3 The value of carbon sequestration from peatlands and uplands

In the literature there are three main techniques used to value impacts of greenhouse gases. These are official i) based on the shadow price of carbon, ii) willingness to pay estimates for reductions in the expected damages due to climate change and iii) market prices based on carbon trading markets. There is little reason to believe that the estimates from these different types of studies would generate similar values. Government commissioned reports such as the Stern report (Stern, 2007) have been based on estimates of the shadow of carbon using integrated assessment model. The shadow price of carbon is defined as "The value of the *climate change impacts* from 1 tonne of carbon emitted today as CO_2, aggregated over time and discounted back to the present day" (IPCC 2007). Based on a meta-analysis of over 200 studies (Tol et al 2007) it is clear that are large variations in the estimates from existing studies. It is beyond the scope of this study to outline the debates over how such estimates should be used and not be used in public policy appraisal, as Defra has already commissioned report to review the current understanding of the issues involved. Downing et al.'s (2005) review, commissioned by DEFRA, highlighted that the range of uncertainty is at least three orders of magnitude, from £0 per tonne of carbon to £1000/tC (about £270/tCO2). The implication of many of the methodological issues are still not resolved such as the implications of the deviation between carbon shadow prices under optimal abatement policies and business as usual (Diez 2007).

Studies deriving WTP estimates for upland carbon sequestration include an ongoing study by Drake (2009) who uses the choice experiment method to determine whether people would be willing to pay to have trees planted in the local area or whether sequestration elsewhere would be preferred. Such studies may prove useful for evaluation of potential policy schemes to implement carbon sequestration schemes and the potential barriers to such initiatives. Additionally on-going research by Glenk et al (2009) uses the same method to determine people's WTP for a soil carbon sequestration policy in Scotland. The results of this study have shown that preferences for enhanced soil carbon sequestration are heterogeneous among the sampled population. In a latent class model that distinguished two groups, one group (about 2/3 of the sample) have positive and strong preferences for attributes in the soil program while the other group has less strong preferences

Carbon markets offer an alternative method to quantify benefits from carbon sequestration initiatives. These values have been fluctuating since their introduction in 2005, usually between €20-30/tCO_2. The scope of using such markets to finance peat restoration initiatives have been discussed in the literature. It is, however, important to note that assessment of potential financial flows is not equivalent to the assessment of economic value of changes in climate regulation, which are the appropriate values for cost benefit analysis of peatland restoration.

5.2.4 Biodiversity conservation

Estimation of the economic value of changes in biodiversity is challenging. Partly this is due to the variation of definitions of biodiversity itself, from diversity of genes to the diversity of landscapes, and partly due to the many ways in which biodiversity is valued as highlighted by the Millennium Ecosystem Assessment (MA, 2005). There is some scope for valuing changes in biodiversity in relation to peat land restoration but that would involve undertaking an additional study designed for this purpose. The expected changes in biodiversity and habitat quality related to peatland restoration assessed in this scoping study would need to be expressed in a suitable way for interpretation by the lay person.

5.2.5 Recreational opportunities within peatlands and uplands

About 190 000 ha of forest, almost wholly of conifers, are on deep peat (over 45 cm depth) and about another 315 000 ha on shallower peat (Pyatt 1993). Some of these forests would provide recreational value such as walking trips, viewpoints and picnic sites. In the literature on recreational values of forests in the UK (and which most probably contain a proportion of peatlands), the studies have estimated the enjoyment of benefits associated with the presence of the entire forest using travel cost and hedonic pricing methods (Willis and Garrod 1992, Garrod and Willis 1992, Bullock and Kay 1996). Other studies have used stated preference methods for e.g. Scarpa et al (1999) used the contingent valuation method to determine WTP for forest attributes such as tree coverage and the presence of nature reserves. Other studies use such as Zanderson and Tol (2008) use a meta-analysis of 25 European studies which utilized the travel cost method to determine consumer surplus for forest trips. Additionally, other related studies in the uplands examines the public's willingness to pay for landscape changes resulting from reduced grazing pressure in Central Southern uplands (Bullock and Kay 1997).

In all these studies there is an indirect link that forests on peatlands provide services that can be valued. However, none of them explicitly links the benefits to the quality or protection offered by intact peat. One way to do this would be to model the biophysical impacts of a specific area of forest on peatlands where peat was left to degrade (i.e. no maintenance or restoration). This would most probably lead to degradation of the forest and loss in aesthetic and recreational value. Stated preference methods can then be employed to determine the value of these losses by asking people their WTP to protect the peatlands that maintain the forest. The design of these studies should be done carefully as one of the concerns with hypothetical valuations of forests is the potential for double counting, since participants can easily provide not only recreational values but also biodiversity, aesthetic and cultural values.

5.3 Scope for economic valuation of ecosystem services associated with peat land restoration.

With the exception of a few studies the majority of reviewed studies were designed to derive values for ecosystem services from upland environments and not specifically from the protection of peatland environments. This therefore limits the use of these values within a cost-benefit analysis since it is not be possible to attribute existing valuations from general ecosystem services to those of services that flow specifically from peatland restoration. To date only few studies have sought to derive benefits and costs based on a bio-physical link between peatland restoration improved ecosystem services for water (Beharry-Borg et. al 2009, Drake 2009) and carbon sequestration (Drake 2009, Glenk 2009). These small number of studies means that the use of benefit transfer methods in order to derive values to be inserted into a cost-benefit analysis is limited at this stage in the research on peatland restoration. However, this gap in the valuation literature also provides an opportunity for future studies to be designed to ensure that there is a clearer link between the bio-physical role of peatland ecosystems and the monetary value of services which flow from them.

The bio-physical modelling in this report and an assessment of the current literature has revealed that there are observable impacts from peatlands restoration that can be valued. These include the value of 1) changes to discolouration of water, 2) fish populations, 3) risk and frequency of flooding events and 4) potential of carbon sequestration from specific peatland restoration activities. The valuation methods chosen would depend on the specific objectives of the study, the population impacted and the geographical scale that is being considered. Given that the uncertainty on the bio-physical modelling increases once the geographical scale increases, it is recommended that future studies should focus on specific and hence geographically limited areas where clear links can be established between the bio-physical impact of peatland restoration activities and the consequent change in ecosystem values. This allows for a more accurate representation of ecosystem values, which can then be used a reliable input into a decision support tool such as a cost-benefit analysis of peatland restoration

5.4. Analysis of the scope for targeting areas for selected ecosystem services

In this section we evaluate the scope for spatial segregation of ecosystem service production. Given that some ecosystem services such as carbon sequestration can be considered a pure public good, there might be an economic rationale for prioritising locations where such good and services are best produced as the location of service provision does not impact the economic value to any individual. For other goods and services location may be much more influential for the distribution of benefits such as protection from floods.

To assess this it is important to know the extent to which management with the view to increase the provision of one ecosystem services has an impact (positive or negative) on other ecosystem services.

It is clear from Table 5.1. that management for food production generally has a negative impact on the regulating services selected in this study, and that biodiversity, DOC and run-off potential is positively impacted from restoration initiatives. The impact on carbon fluxes is more variable across environmental characteristics.

Table 5.4: Synergies in the magnitude of ecosystem service provision for the Peak District and Migneint.

	Peak District			Migneint		
Raising water table						
ES	Biodiversity	Carbon	DOC	Biodiversity	Carbon	DOC
Biodiversity		N.S.	N.S.		N.S.	N.S.
Carbon	N.S.		N.S.	N.S.		N.S.
DOC	N.S.	N.S.		N.S.	N.S.	
FOOD						
ES	Biodiversity	Carbon	DOC	Biodiversity	Carbon	DOC
Biodiversity		N.S.			N.S.	N.S.
Carbon	N.S.			N.S.		
DOC				N.S.		
Conservation led Rewilding						
ES	Biodiversity	Carbon	DOC	Biodiversity	Carbon	DOC
Biodiversity		N.S.			N.S.	
Carbon	N.S.			N.S.		
DOC						
GROUSE						
ES	Biodiversity	Carbon	DOC	Biodiversity	Carbon	DOC
Biodiversity			N.S.			N.S.
Carbon						
DOC	N.S.			N.S.		

**N.S. – not significant.

Given that management of peatland is expected to continue to generate a range of services and not only focus on services of most economic benefit it becomes important to assess the implications of prioritising the locations of peat land restoration for a range of ecosystem services, here exemplified by biodiversity conservation, water quality improvements or carbon storage.

We assess this by ranking sites according to their potential for increasing each of the ecosystem service provisions and test the extent to which the ranks are correlated. High positive correlation indicates that managing for one service will also target sites that will bring high benefits for other services. High negative correlation indicates that one service is favoured at the expense of another, which implies that these ecosystems are more economically produced in different sites. No association of ranks imply that the provision of the services is largely linked to separate factors and that one service cannot serve as a proxy for the other.

The result of this analysis (Table 5.4) indicates that in this study at the local level it has not been possible to identify consistent and systematic relationships between the magnitudes of change in individual ecosystem services.

The analysis discussed above only considers the supply side of ecosystem services. In the assessment of spatial targeting it is equally important to assess the nature of the consumption of the environmental good and service. Where location is important to demand this clearly plays a role in the economic assessment of restoration initiatives. The workshop revealed that the individual ecosystem services were not considered equally important in the different sites (Table 5.5). Only carbon storage was always ranked within the top three most important services for all sites. For example, most important services in the Peak District were freshwater provision, carbon storage and water quality, while for Thorne and Hatfield Moors carbon storage, wildlife watching and landscape aesthetics were judged the three most important services. For the Migneint, the three most important services were biodiversity, carbon and freshwater provision. Each group of stakeholders had also re-named and merged services based on their opinions. This information was useful and helped us to understand which services are important to different groups of stakeholders. However, it must be treated with caution since the relative small number of stakeholders present at the each sub-workshop may have unduly influence the ranking of these services.

Furthermore, the sites are situated in entirely different socio-demographic landscapes, which can potentially have very significant implications for economic valuation results as cost and benefit estimates are weighted by the number of affected individuals. This is of particular relevance for flood mitigation evaluations, as only a restricted part of the surrounding areas are likely to be affected by land use change in the uplands. It is clear from this study that the underlying science of flood risk mapping and flood risk reduction is still insufficiently understood. The importance of the spatial distribution of people around peat land sites also is particularly relevant for recreational values. These are however unlikely to be impacted by changes most of the scenarios considered and therefore not further discussed in this report.

Table 5.5 Ranking of ecosystem services for each site by stakeholder groups

Peak District	**Thorne and Hatfield**	**Migneint**
1. Fresh water provision	1. Carbon storage	1. Biodiversity
2. Carbon Storage	3. Wildlife watching	2. Carbon storage
4. Water Quality	4. Landscape aesthetics and Recreation	3. Freshwater provision
5. Fire risk mitigation	5. Flooding	4. Landscape
6. Recreation		5. Water quality
7. Education		6. Recreation
8. Aesthetics		7. Pollination
9. Biodiversity		8. Hydropower
		9. Fire risk mitigation
		10. Timber
		11. Wind power
		12. Peat extraction

5.5 Priorities for future research

- Based on the current bio-physical modelling work the expected trajectory of research in addition to the review of the literature, future valuation studies should first focus on obtaining values (i.e. costs and benefits) for 1) changes to water quality, 2) species population changes (species of conservation concern as well as recreation or economic concern, e.g. fish or grouse), 3) risk and frequency of flooding events and 4) potential of GHG flux from specific peatland restoration activities.

- Valuation studies should be designed so that they focus on specific and geographically limited areas where the bio-physical impacts of peatland restoration can be clearly linked to the impact on ecosystem services. This allows for the collection of more accurate and representative valuation data. The valuation methodology chosen should depend on objectives of the study, the population impacted and the geographical scale that is being considered.

- Once the requisite valuation data is collected it can then be inserted into cost-benefit analyses to determine the cost-effectiveness of investments in peatland restoration activities for specific sites.

6. Synthesis

6.1 Pros and cons of a mapping approach to ecosystem services.

Workshop participants at the project conference on 15/16 October 2009 were asked to identify pros and cons of mapping approaches to ecosystem services. Discussions were held with specialists for each case study site as well as with national-level staff. In general, maps were accepted as being a useful and good approach to ecosystem services of peatlands (see also section 1 of this report and Natural England 2009b).

Figure 6.1: Impressions of workshop discussions

They act as a good visual way of communicating information and stimulating discussion and understanding (Fig 6.1). However, there are some things, which are more difficult to map such as health benefits or cultural/heritage/education components of peatlands. A main positive outcome from mapping approaches was deemed to be that the approach identifies multiple service areas without prior judgement, and can also highlight current knowledge as well as data limitations or gaps. The mapping usefulness and approach depends on the policy purpose (e.g. a LiDAR map may be more appropriate for floods) but the workshop discussions suggested that maps did allow users to link issues and work across sectors, rather than focus on one service at a time which was very important. However, therefore the right map layers are needed at the start of the process so that key issues can be identified. Thus, in future projects, the full range of ecosystem services must be evaluated and mapped from the start (which was not possible in our scoping study) so that all can then be put together to aid decision-making (e.g. heritage sites etc). It was also pointed out that the maps, that some maps illustrated bio-physical characteristics, rather than services or service flows. The latter is an important aspect to pursue in a Phase II programme. Some of the other pros and cons identified are listed below (in no order of priority):

<u>Pros</u>

- Good thinking tool
- Helps with decision making about land use (e.g. flood water storage, biodiversity, etc)
- Good for public awareness raising
- Ecosystems approach depoliticises things
- Highlights different types of information
- Can relate and compare different services
- Identifies multiple service areas and helps to prioritise opportunities
- Not really an alternative way of getting this information over
- Allows targeting of effort and prioritise options
- Helps with planning for change
- Identifies areas with data deficiencies and where work is needed
- Highlights data limitations
- Highlights factors/services that might have been omitted

Cons
- Does not capture off-site benefits
- Demand not shown by maps only supply.
- Over simplifies / over generalises
- Poor resolution / scale issues – 1km^2 not good for small peatlands like Thorne & Hatfield, locally more high resolution data available also for all other case study sites
- Economic valuation would be more useful
- Key link needed to valuing ecosystem services is defining who (and how) are impacted by information contained in maps. How is this processed determined?
- Absence of cultural heritage assets
- Cannot tell whole story, serious risk of over generalising
- Too much human focus (current generation versus future)
- Very simplistic input can seem more profound than it is.
- Snapshot in time – when? Maybe not comparing over same time periods.
- Need strong/robust evidence base for establishing cause and effect. Assumptions and generalisations in maps could drive wrong policy.
- Caveats for data presented should be placed on maps

6.2 Synergies and conflicts between services

Workshop discussion gathered information on where there were seen to be synergies and trade-offs between services (see also section 5). The data were collected using a scoring matrix and through discussion with a prepares table (Tables 6.1 and 6.2, both facilitation tools used for all case study sites).

For Thorne and Hatfield and the Somerset Moors and Levels key synergies were seen as:
- Cultural heritage and C storage
- Biodiversity and C storage, recreation

while key conflicts were:
- Peat extraction and carbon storage, GHG emissions, cultural heritage
- Biodiversity and peat extraction, arable

There were also a number of conflicts/synergies that depended on circumstances and points of view such as between biodiversity and recreation or flood risk and cultural heritage, which participants scored as both a synergy and a conflict. Services that consistently were seen to provide high trade-offs with other services were arable food production and peat extraction. Spatial and temporal scales of impact are also important, e.g. the scale of impact ranging from global in the case of greenhouse gases to local in the case of flood risk. Table 6.1 shows some written comments from the workshop on the synergies and trade-offs between ecosystem services for Somerset Moors and Levels and for Thorne and Hatfield. Table 6.2 provides the scoring matrix for synergies and trade offs between ecosystem services for the Peak District and Migneint.

In the Somerset Moors and Levels most ecosystem services are based on the wetland having high water tables; consequently the services are consistent and mutually consistent. The exceptions are flood storage and methane emissions. Flood storage is maximised under dry conditions. While large volumes of above-ground flood water storage are likely to exist under raised water levels, the below ground storage, in soils and ditches, will be full and not available for flood water. Additionally, raising water levels may decrease CO_2 but may increase methane production (Baird et al 2009), which can exacerbate global climate change. In these respects, raised water levels can be considered to reduce flood storage and global climate control. Further analysis is required to quantify the total greenhouse gas and carbon balance trade-off between CO_2 and methane production for the Somerset Levels and Moors.

For the Migneint and Peak District, generally the conflicts were associated with different forms of land use for provisioning services (wind power, peat extraction). From the scoring matrix, water quality and biodiversity were assumed to have excellent synergy. However, when the detail of this was discussed it was realised that the relationships are quite complex and attempts to aggregate might be difficult. It may in fact be that maintaining monocultures of a particular species (e.g. *Molinia*) could have synergies with water quality but trade-offs with aspects of biodiversity. As we outline below, more science is needed to assess synergies and trade-offs of services as well as drivers to provide adequate information to inform and ecosystems service approach.

Table 6.1: Ecosystem service synergies and trade off comments produced at the October workshop for a) Somerset Moors and Levels and b) Thorne and Hatfield.

(a) Somerset Moors		**Benefits to people/synergies**	**Limitations/trade-off**
Provisioning Services	Food	Livestock grazing	Nutrient content of natural grass lower than improved grass -Improved livestock grazing may mean lower biodiversity
	Freshwater	Freshwater available	Resource less with higher water levels, more wet grassland and reed area
	Peat	Fuel and horticulture resource available	Peat not renewable in the short term; loss of peat results in loss of many other services
	Withies and teasels	Wetland provide withies for basket making and teasels for textile production	More land for withies and teasels may mean less land for grazing and natural habitats
Regulating Services	Microclimate	Wetlands modify their own climate	Synergy with services supported by high water levels
	Floods	Flood storage available	Flood water storage assumes low ditch water levels before the flood
	Carbon	Wetlands have potential to sequestrate carbon	High water levels reduce CO_2 emissions and increase biodiversity but increase methane emissions
	Diseases		Wetlands can host insects with vector borne diseases, especially if water levels are kept high to support biodiversity
Cultural Services	Archaeology	Anaerobic conditions preserves organic matter	Synergy with services supported by high water levels
	Recreation	Wetlands provide a landscape and birdlife favoured by many people and angling	Synergy with services supported by high water levels
	Education	Wetlands provide range of scientific, social, economic educational subjects	Education is supported by archaeology
Supporting Services	Biodiversity	Wetlands support unique plants and animals	Biodiversity may be less with high water levels

(b) Thorne & Hatfield		**Benefits to people/synergies**	**Limitations/trade off**
Provisioning Services	Food	Low intensity sheep and deer grazing	
	Freshwater	Freshwater available	Standing water encourages reeds in places
	Peat	Fuel and horticultural resource available	Peat not renewable in short-term; loss of peat results in loss of many other services
	Energy provision	Coal seams beneath Thorne (previously mined) Gas reserves below Hatfield Renewable Energy: Wind farm permission granted	
Regulating Services	Microclimate	Peatlands modify their own climate	Synergy with services supported by high water levels
	Flood risk prevention	Can only store water that falls on site. Cannot take water from off-site and store. Minimum impact of floods downstream	
	Climate regulation	Peatlands have the potential to sequester carbon.	High water table reduces CO_2 emissions and increase biodiversity but may increase methane emissions.
	Drinking water provision/ water quality	No provision of drinking water, although bore hole at edge of Hatfield Moor where water come from aquifer below the raised mire.	
	Cultural Heritage	Sites of archaeological interest including Mesolithic boats and a rare Bronze age pathway at Thorne and a Neolithic wooden trackway at Hatfield.	Synergy with services supported by high water levels and minimum disturbance to peat
	Recreation	Peatlands provide a landscape and wildlife favoured by many people. 120 km of tracks, many way marked	Synergy with services supported by high water levels and minimum disturbance to peat
	Education	Peatlands provide a range of scientific, social, economic educational subjects	Education is supported by Cultural Heritage and biodiversity
Supporting Services	Biodiversity	Peatlands support unique plants, invertebrates, birds and animals	Biodiversity may be less with high water table

Table 6.2. Ecosystem service synergies and trade off. The scoring matrix of synergies and conflicts regarding ecosystem services in the Peak District. Numbers in blue represent votes as a synergy and numbers and red as votes for conflicts.

	Food	Energy (wind)	Energy (peat)	Carbon storage	GHG	Water quality	Flood risk	Recreation	Game	Cult. Herit.	Biodiversity
Food											
Energy (wind)	1										
Energy (peat)	1										
Carbon storage	11	3	4								
GHG		12	2	31							
Water quality	14	1	4	10	1						
Flood risk	1		3	3		1					
Recreation	1		2			21					
Game	13	1	2	2	1	1	2	1			
Cultural heritage	1	1	3					11	1		
Biodiversity	28		3	3	2	7	2	53			

6.3 Ecosystem service flows - Spatial aggregation of providers and beneficiaries

As discussed above one of the issues raised at the project conference, was that the project ecosystem service maps predominantly addressed ecosystem service supply, and service demand was seen as equally important to assess service flows. Maps of freshwater provision (Figure 4.10) or realised recreation use (Fig 4.37) indicate the demand. Equally important for economic valuation and practical decision making as well as targeting political instruments is the spatial aggregation of ecosystem service providers and beneficiaries. As Fisher et al (2009) outlines, there may be spatial disparities of providers and beneficiaries. We therefore provide some examples of how to map and quantify demand and spatial aggregation of providers and beneficiaries.

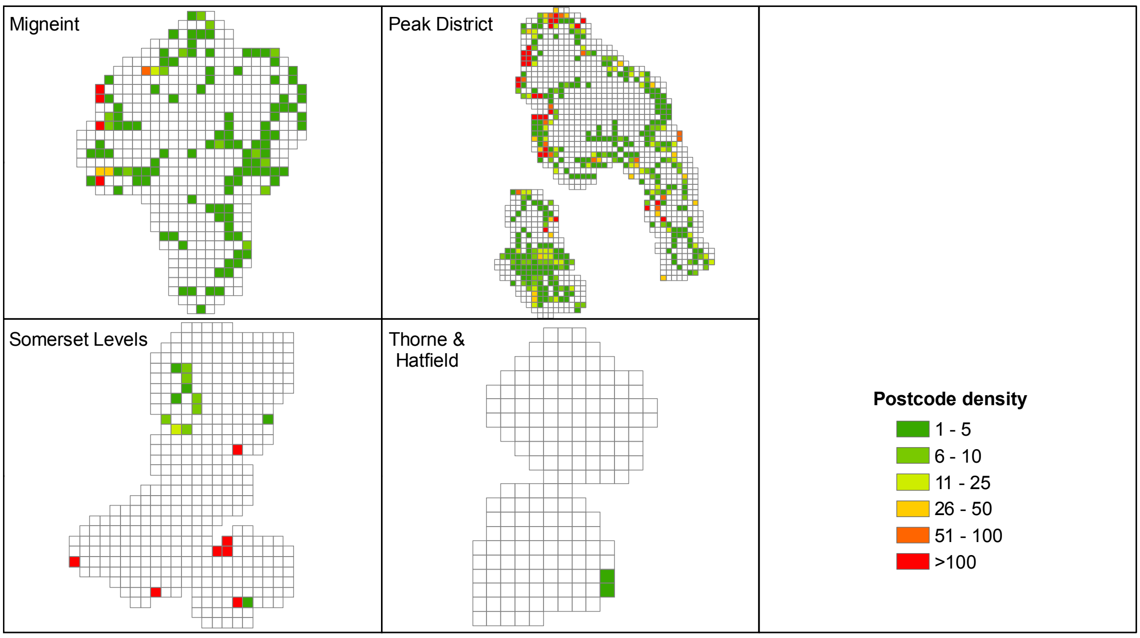


Figure 6.2.: Population density as expressed in postcode density within case study peatlands.

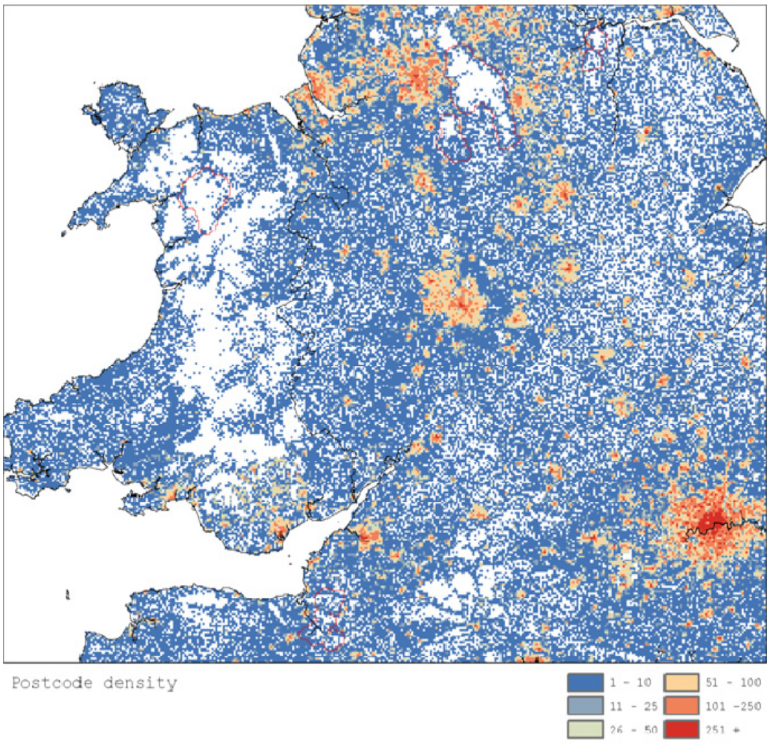


Figure 6.3: Population density as expressed in postcode density around case study peatlands.

Peatlands are in general sparsely populated (Fig 6.2), while depending on their geographic location and their size, they may provide different services to surrounding populations (Fig 6.3) with different orders of magnitude. For the Peak District 16M people live within 1h drive from the Peak District. Any benefits and disbenefits derived from this area with local to regional importance, such as fresh water quality or floods, will also affect a greater number of people. All other case study sites have much smaller surrounding and downstream population densities with the Migneint as the most remote area, while 5M people live within 1h drive from Thorne and Hatfield Moors. The size and location of downstream beneficiaries will also determine weighting for the importance of services from stakeholders (see Tab 5.6)

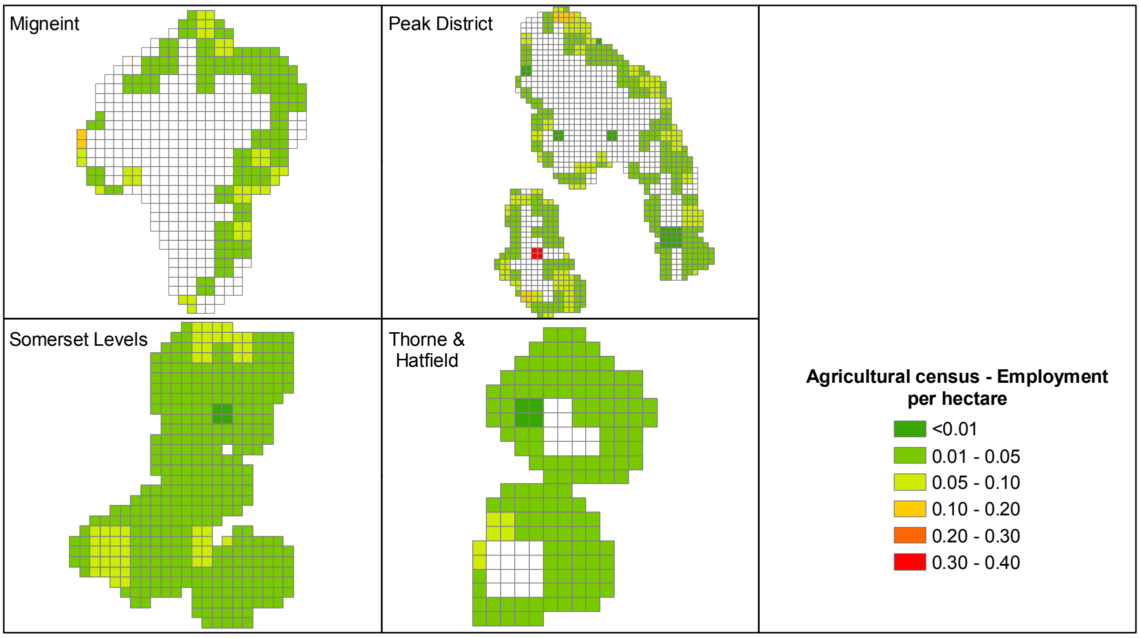


Figure 6.4 : AgCensus data- employment in agricultural sector

Peatland ecosystem service may be provided at different scales (Fisher et al 2009):

- in situ: providers and beneficiaries both live in the peatlands and may belong to the same community, e.g. benefits of food provision accrue directly to the land manager or through local markets to the local community (Figure 6.4).
- omni-directional: beneficiaries live (inside and) outside the peatlands, e.g, recreation opportunities may be maintained by land managers/ area wardens working in peatlands, but are taken up by people living within the peatland and in surrounding areas (Fig 6.5). Some cultural services such as health walks are provided predominantly for local participants (Fig 6.6). Conversely, climate mitigation benefits through carbon storage and GHG sequestration are globally important to all people.
- directional: Providers do not directly benefit from land management for services, as these occur elsewhere, such as clean drinking water provision (Fig. 4.10) or potential flood risk mitigation downstream through cumulative management for water quality or run-off attenuation (Fig.4.14).

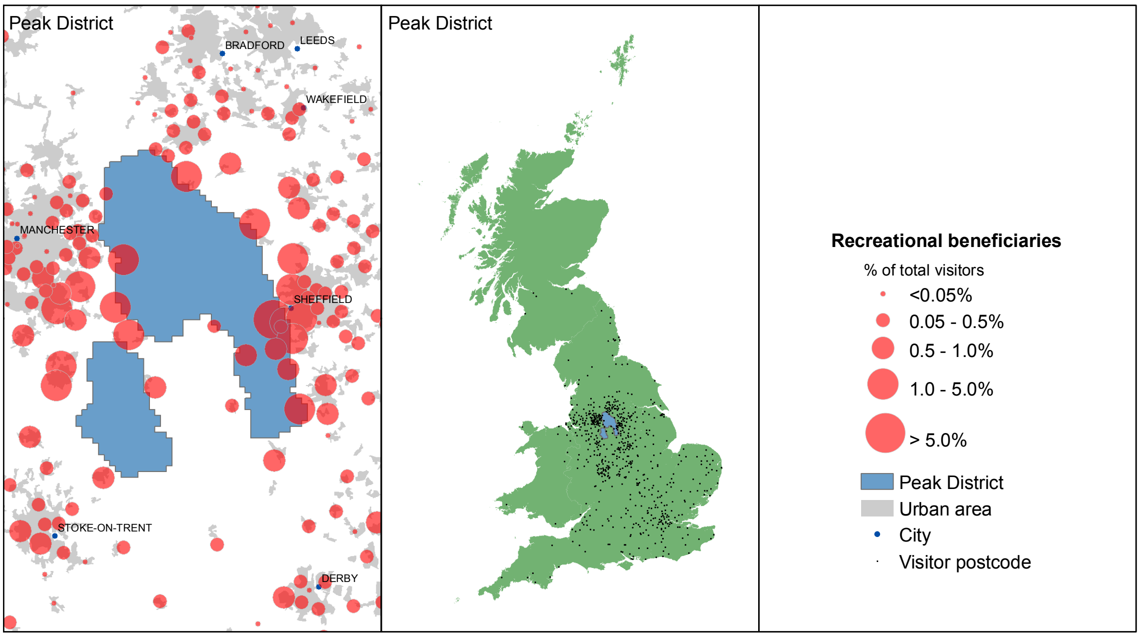


Figure 6.5: Percentage visitor origination for Peak District peatlands. 40% of all visitors come from urban (large conurbation), 60% from rural local areas.

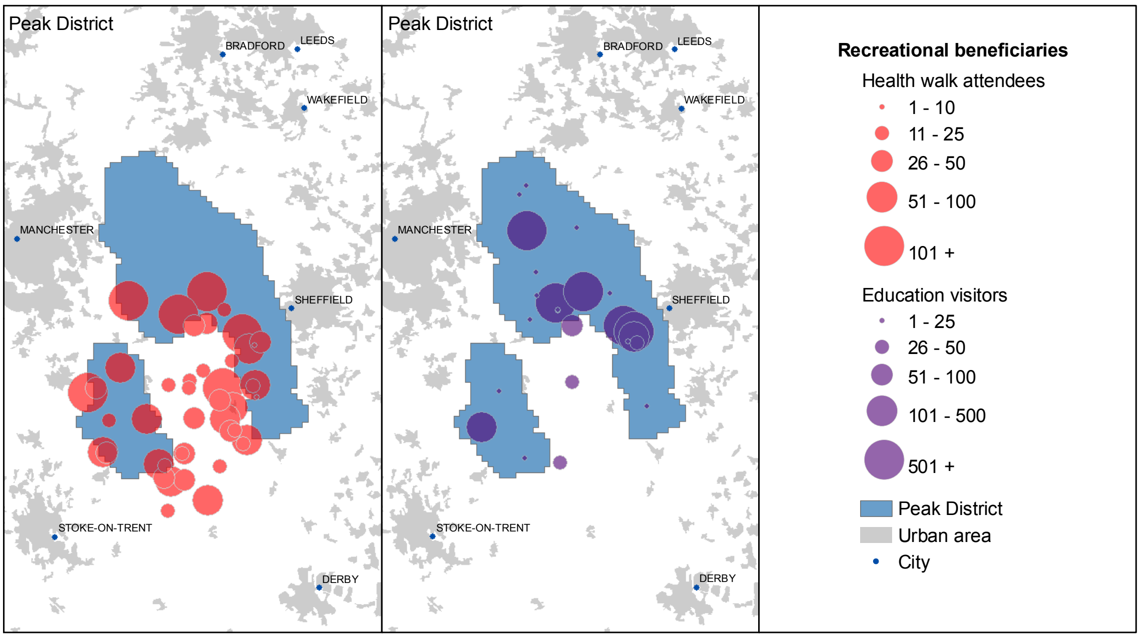


Figure 6.6: Locations and participants in a) health walks (PDNPA ranger service 2007) and b) education visits in the Peak District (school education visits in 2007, Losehill Hall Peak District National Park Centre for Environmental Learning)

6.3 Transferability between sites

Overall our approach is transferable between sites. However, the exact findings, nature of services and synergies and trade-offs between services vary between sites. For example, the value and magnitude of return from management actions may differ. For example, due to the severe degradation of some of the Peak District peatlands, the magnitude of gains achieved from restoration work in the Peak District may not necessarily be realised at other less degraded sites. Broad questions have to take account of different types of peatland and local and national circumstances. This is also important for consideration of the best spatial configuration of services, e.g. can food production in one place be better achieved in other places? Furthermore, ecosystem service flows need to be assessed in detail. E.g. water abstraction may serve different purposes, either industry or public consumption; both will have different long-term impacts. In addition, the origin is of the water source is important, whether derived from the peat or from the aquifer below the peat. In the case of Thorne and Hatfield, it may seem on face value that the sites provide an important water provision service, but this water is not derived from the peat but from deep groundwater far below the peatland.

While population maps and travel time are useful to understand the leisure services offered by peatlands such as the Peak District (large surrounding population with 16 M people living in 1h drive and 10M day visits per year) and the Migneint (sparse surrounding population and few visitor numbers) this may not be always a transferable and reliable indicator. For example, 5 million people live within an hour's drive of Thorne and Hatfield and yet this site receives very few visitors. Active recreation management through provision of visitor facilities (interpretation, visitor centres, etc) and transport opportunities (car parks, roads, public transport) plays a major role in visitor attraction.

One of the key findings from this scoping study and which was clearly outlined at the workshop was that local knowledge must be used to interpret national, regional or even local maps and datasets. For example, maps of car parks at Thorne and Hatfield do not actually indicate that car parking is an issue and that more information is required. Moreover, there are often more fine scale and more accurate maps available, e.g. for vegetation cover. The land cover map 2000 was used here as a national standardised and comparable dataset. LCM vegetation classification for uplands, however, is in many areas not optimal or even accurate, and e.g. both Peak District and Migneint have much better habitat maps, based on Phase I surveys or aerial photo interpretation (e.g. Chapman et al. 2009).
Therefore, it is recommended that when national or regional datasets are applied that local interpretation of these maps and datasets is provided.

To highlight that each type of peat behaves differently, Figure 6.7 shows the pore water chemistry of Migneint, Peak District and Thorne moors as an example of different responses of different peats. Differences are largely explicable in terms of evapo-concentration, vegetation condition and water table. Our understanding is thus transferable, but one cannot just assume that one site looks exactly like another.

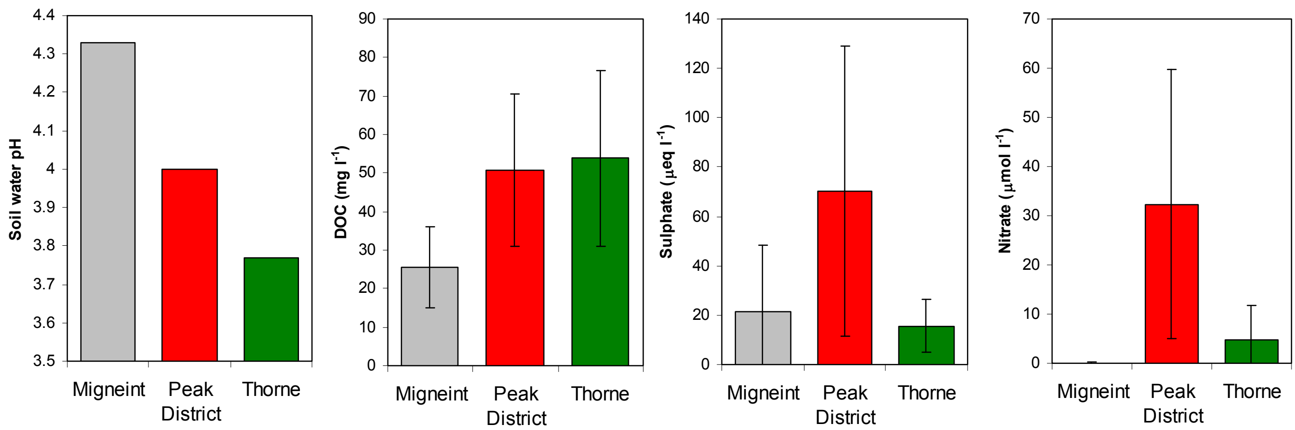


Figure 6.7: Porewater concentrations for soil water pH, DOC, Sulphate and Nitrate for Conwy (Migneint) and Peaknaze (Peak District) from Tim Jones (unpublished). Data for Thorne Moor from Pippa Chapman (unpublished)

There were also clear differences between upland and lowland peatlands, which means that the services provided by upland and lowland peatlands can be different thereby affecting transferability. Some examples are:

- Carbon storage is important in both upland and lowland peatlands but the management is different

- Food production - sheep production dominated in uplands, whereas cattle often more important in lowland peatlands (e.g. Somerset Moors and Levels). In contrast some lowland peatlands use grazing by sheep or cattle or deer as a means to manage site, but not too much. Lowlands also provide potential for fertile ground for arable production, when cultivated through warping and liming. They have therefore faced different pressures historically and today.

- Recreation - access controls recreation use and this is dependent on (i) awareness of site/area, e.g. Thorne & Hatfield Moors used to be industrial sites for peat extraction, whereas the Peak District has a long history and special importance for the Access movement in Britain (ii) presence/absence of roads, car parks & public transport through site/area,), (iii) foot paths. (vi) visitor centres. Interest in sites might arise through (iii) protection status (e.g. National Park status (vi) special features related to a particular site such as rare birds/plant or archaeological and cultural heritage interests or (vii) historical importance and sense of place, such as Kinder Scout (Peak District), where Right of Access was claimed.

- Water supply - uplands are an important source of drinking water in the UK, with ca 70% of drinking water sourced from uplands, most of which are peatlands. In lowland peatlands there is a more mixed use of water for potable supply, industry and agriculture. Due to their size water abstraction is minimal.

- Flood water – there is no or limited storage of flood water in upland peatlands hence these sites are often seen as source of flood water, whereas lowland peatlands are often able to store flood water from upstream for weeks/months in the winter to prevent flooding downstream (e.g. Somerset Moors and Levels). In contrast, other lowland peatlands are situated above the surrounding land (e.g. Thorne and Hatfield raised bogs), so they can store water that falls on the site but cannot take water from outside to mitigate flooding downstream.

6.4 Implications of scenarios for each site

The workshop participants were asked to evaluate the likely impacts of the change scenarios described in this scoping study for their chosen sites. Tables 6.3 to 6.6 provide results which also include contributions from workshop participants after the event. Some potential ecosystem services are not included in the tables, such as pharmaceuticals or ornamental resources, as we did not have data on these.
However, in a full study, as a matter of principle, it is important to at least assess the likelihood of significance of all services otherwise the work will not be systematic.

Table 6.3: Workshop participants' views on direction of change of service provision from each scenario - Thorne & Hatfield

	Scenarios						
	Peatland Restoration			**Peatland Management**			**Optimise for one Ecosystem Service**
	Restoration (water)	**Restoration (vegetation)**	**Low intensive mgmt**	**Food security (livestock)**	**Food security (arable)**	**Economy**	**Carbon Management**
Thorne & Hatfield	**Raising water levels**	**Scrub clearance**	**Removal of livestock + restoration**	**Increased grazing**	**Increased arable**	**Extract peat**	**Carbon Management**
Provisioning Services[1]							
Food (livestock & arable)	0 (-) Surrounding landowners argue raising water levels increases wetness of farmland. This	0 (weak +) Some potential here for sheep grazing (as part of scrub clearance)	0 Food production very small at present so minimal impact	- Couldn't sustain a large sheep population	_ Loss of peat to warped soils and arable and horticultural crops	– loss of peat and associated biodiversity	0

	is true in some places, but not all						
Fresh Water (river flow/ quantity of water)	– higher evapotranspiration (but only in the short-medium term. Long term should be neutral)	+ Reduced evaporation	0	– higher nutrient pollution	– higher nutrient and sediment pollution	- Increased drainage	– higher evapotranspiration
Renewable energy (wind)	Potential unaffected	0	0	0	0	0	0
Fuel & Fibre: Peat	+ greater peat formation	+ greater peat formation	+ greater peat formation	- less peat formation	- loss of peat	+ more jobs in extraction but less in other uses of the land (need to compare with other services)	- But there has to be a market for peat for this service to occur.
Genetic resources	+?	-? Possibly reduced with decreasing complexity of vegetation structure	+? Possibly increases if vegetation structure recovers	-	--	--	+?
Regulating Services							
Air quality regulation	?	-? May lead to reduced atmospheric deposition of particulates due to decrease in roughness	+? Likely to enhance atmospheric deposition of particulates due to increase in vegetation roughness	?	?	?	?
Climate regulation: GHG	+? Not clear as increased C sequestration may be offset by increase in CH_4 emissions (knowledge gap)	+	++	--	--	--	++
Carbon storage	+ higher water levels increases carbon sequestration	+	+ more vegetation for peat accumulation	- less vegetation for peat accumulation	- less vegetation for peat accumulation	- -- less peat	+
Water quality regulation	+ Higher water levels reduce S and N inputs from atmosphere and hence buffer against acidity	0	0 or +?	- Higher nutrient pollution	- Higher nutrient pollution	- Greater peat erosion	
Natural hazard regulation: Floods	- less flood storage	0	+ less soil compaction so more infiltration	+ lower water levels increase flood storage	+ if lower water levels, then increased flood storage	+ lower water levels and depressions increase flood storage	- higher water levels reduce flood storage
Natural hazard regulation: Fire risk	na	na	na	na	na	na	na
Pollination	?	? Likely to be	?	?	?	- Lost	?

		suppressed if habitat complexity lost				vegetation structure will reduce natural pollinators	
Disease/ Pest regulation[2]	? (-) Short-medium term significant increase in potential insect pest (mosquitoes etc) breeding habitat	?	+ Destocking = less cryptosporidi um	- Overstocking = more pests and diseases	?	? Lost vegetation structure may reduce natural pest predators	? (-) As first column. Main method for reducing carbon loss would be raising water levels
Cultural Services							
Recreation & tourism[3]	+ more natural environment, but wetness may reduce access	+ more natural environment	+ more natural environment, but loss of cult. heritage	- less natural environment	- less natural environment	- less natural environment	+ more natural environment
Recreation: Field sports	na	na	na	na	na	Na	na
Education	+ more natural environment	+ more natural environment	+ more natural environment, but loss of cultural heritage	- less natural environment	- less natural environment	- less natural environment	+ more natural environment
Landscape Aesthetics[4]	+ Rewetted peatland more aesthetically pleasing than bare peat.	+/- As first column, but some people don't like the openness and want to see more trees.			- Less differntiaition from surrounding land, and intrinsically less complex landscape	-- Peat extraction very ugly	+ See first/second column
Historic environment Archaeology & Palaeo-ecology	+ Higher water levels protects relics. However some loss of industrial heritage as evidence of the peat cutting lost	+ Reduction in tree cover reduces disruption of peat stratigraphy	0	- Nitrate & phosphate fertiliser application can accelerate the oxidation of organic remains; fluctuating water table trends can exacerbate decay	- higher risk of damage to artefacts & peat through dessication, plough damage & wind erosion	- higher risk of loss or damage to artifacts; loss of palaeoecolo gical resource (peat)	+ less disturbance to artefacts
Cultural Heritage: Rural culture	0 (-) Loss of history of peat working	0	0	0?	0?(-) See first column	? (-) See first column	0 (-) See first column
Biodiversity[5]	++ (+) more typical bog & heath species	? (+) Relative biodiversity value of different habitats is hard to assess. However general acceptance that bog ecology highest priority and potential impacts on others can be mitigated	+ (0) More typical bog & heath species, but sp. dependent on grazing may be lost. (however no historic grazing on the site)	- Fewer typical bog & heath species	-- fewer typical bog & heath species	--- Loss of biodiversity due to loss of peat itself	+ + (+) more typical bog & heath species

Positive impact +++, ++, + no impact 0 negative impact ---, --, - don't know ?

Notes: [1]all deemed to be of low importance; [2]Ticks and diseases, Malaria risk with climate change; [3]open spaces versus peatlands - how to determine if recreational use is because site is a peatland or a nice open space; [4]could be measured via a wilderness value; [5]Thorne and Hatfield known for their biodiversity through internationally important bog habitat, species richness, designations, legal protection of some species, rare species such as night jar.

Table 6.4: Workshop participants' views on direction of change of service provision from each scenario - Somerset Levels & Moors

	Scenarios						
	Peatland Restoration			**Peatland Management**			**Optimise for one Ecosystem Service**
	Restoration (water)	**Restoration (vegetation)**	**Low intensive mgmt**	**Food security (livestock)**	**Food security (arable)**	**Economy**	**Carbon Management**
Somerset Levels	**Raising water levels**	**Scrub clearance**	**Removal of livestock + restoration**	**Increased grazing**	**Increased arable**	**Extract peat**	**Carbon Management**
Provisioning Services							
Food (livestock & arable)	- lower grass nutrition	+ more farm land available	- food is primarily farmed animals	+ Improved grass is higher in nutrient	0 replacement of dairy and beef prod. with vegetables	– loss of farm land to peat extraction	– higher water levels reduce grass nutrition
Fresh Water (river flow/ quantity of water)	– higher evapotranspiration	0	++ less nutrient pollution	– higher nutrient pollution	– higher nutrient and sediment pollution	? lower evapotranspiration	– higher evapotranspiration (but greater storage too, buffering flows?)
Renewable energy (wind)	Potential unaffected	0	0	0	0	0	0
Fuel & Fibre: Peat	+ greater peat formation	+ greater peat formation	+ greater peat formation (only if below a threshold)	- less peat formation	- loss of peat	+ more jobs in extraction (but less in other uses of land… we have to assess this on a comparative basis)	-
Fuel & Fibre: Withies and teasels	+ more land for withies and teasel	+ more land for withies and teasel	+ more land for withies and teasel	- less land for withies and teasel	- less land for withies and teasel	- less land for withies and teasel	0
Genetic resources	+?	+? (possibly reduced with decreasing complexity of vegetation structure)	+? (if vegetation structure recovers there may be a boost to genetic resources)	-	--	--	+?
Regulating Services							
Air quality regulation	?	? (Less complex vegetation structure may reduce fallout of aerial particulates due to roughness effects)	?	?	? [Conversely, roughness of croplands may boost some air quality services]	- loss of vegetation structure and emissions from peat cutting and processing plant	?
Climate regulation: GHG	+	+ (although methane may make a short term problem)	++	--	--	--	++
Carbon storage/ Erosion regulation	+ higher water levels increases carbon sequest.	0	+ more vegetation for peat accumul.	- less vegetation for peat accumul.	- less vegetation for peat accumul	- - less peat	+
Water quality regulation	+ Higher water levels reduce S and N inputs from atmosphere and hence buffer	0	0	- Higher nutrient pollution	- Higher nutrient pollution	- Greater peat erosion	0

	against acidity						
Natural hazard regulation: Floods	- less flood storage	- vegetation buffering of floods may be reduced	+ less soil compaction	- more compaction	+ if lower water levels, then incr. flood storage	+ lower water levels and depressions increase flood storage	- higher water levels reduce flood storage
Natural hazard regulation: Fire risk	Na	Na	Na	Na	Na	na	Na
Pollination	?	-? Likely to be suppressed if habitat complexity lost	+? Likely to be enhanced if the habitat benefits from deintensifica tion	- ?	?	-? Lost vegetation structure, etc., will reduce natural pollinators	?
Disease/ Pest regulation	?	?	?	?	?	?	?
Cultural Services							
Recreation & tourism[1]	+ more natural environment (but some loss of values i.e. wet grassland that has taken over from historic peat)	+ more natural environment	+ more natural environment, but loss of cult.heritage	- less natural environment	- less natural environment	- less natural environment	+ more natural environment
Recreation: Field sports	N/a	N/a	N/a	N/a	N/a	N/a	N/a
Education	+ more natural environment	+ more natural environment	+ more natural environment, but loss of cult.heritage	- less natural environment	- less natural environment	- less natural environment	+ more natural environment
Landscape Aesthetics	+	+	+	-	-	-	+
Historic environment Archaeology & Palaeo-ecology	+ higher water levels protects artefacts though dependant on water quality (limit oxygen & nutrients)	0	0	Nitrate & phosphate fertiliser application can accelerate the oxidation of organic remains; fluctuating water table trends can exacerbate decay	- higher risk of damage to artefacts & peat through dessication, plough damage & wind erosion	- higher risk of loss or damage to artifacts; loss of palaeoecological resource (peat)	+ less disturbance to artefacts
Cultural Heritage: Rural culture	0	0	-?	-?	-?	--	0
Biodiversity	+ more typical bog & heath species	? Rel.biodiv. value of different habitats hard to assess	+ more typical bog & heath species, but sp. depend. on grazing may be lost.	- fewer typical bog & heath species	-- fewer typical bog & heath species	- little but negative change in bog & heath species	+ more typical bog & heath species

Positive impact +++, ++, +   no impact 0   negative impact ---, --, -   don't know ?

Notes: [1]This is really uncertain as it is not clear there is a relationship between naturalness and tourism.

Table 6.5: Workshop participants' views on direction of change of service provision from each scenario - Peak District

	Scenarios					
	Peatland Restoration			**Peatland Management**		**Optimise for one Ecosystem Service**
	Restoration (water)	**Restoration (vegetation)**	**Low intensive mgmt**	**Food security (livestock)**	**Economy**	**Carbon Management**
Peak District	**Grip/gully blocking**	**Revegation, Clough woodland regeneration , Sphagnum propagation**	**Restoration (all), Removal of livestock, stop burning**	**Increased grazing**	**Increased managed burning for grouse**	**Carbon Management**
Provisioning Services						
Food (livestock)	- lower grass nutrition, wetter ground less good for livestock	+ more grazing available in future	-- Livestock grazing not high in Peak District	++ improved in short term, but may not be sustainable in future	- ? Reduced sheep production if land managed for grouse	-/+ Short term exclusion of grazing, possible grazing once peat is stabilised
Fresh Water (river flow/ quantity of water)	0	0 potentially more evapotranspir ation?	0 potentially more evapotranspiration	0	0/+ lower evapotranspiration	0/– higher evapotranspirati on
Renewable energy (wind)	0 Potential affected through wet ground	0	-- Conservation management	0	0	0
Fuel & Fibre : Peat	+ Stop decline in resource	+ Stop decline in resource	0 Resource won't e used	- Decline in resource	+ more jobs in extraction	-
Fuel & Fibre : Timber /wood fuel	- Wetter ground	+ More potential land for timber	+ If active clough woodland afforestation	- less land for timber	- less land for timber	?
Regulating Services						
Air quality regulation	?	?	?	?	?	?
Climate regulation: GHG	? Balance of increased CO2 sink and CH4 source uncertain	+ Increased CO2 sink,CH4 emissions very low in PD situation	+ Increased CO2 sink, CH4 emissions very low in PD	- Heavy grazing can destabilise peat	-- Heavy burning can destabilise peat	+++
Carbon storage/ Erosion regulation	+ Gully/grip blocking maintains carbon storage	+++ Stops carbon loss and intensive erosion within 4 yrs	+++	- may encourage erosion	- Heavy burning decreases peat stability	+++
Water quality regulation	+ Possibly reduced DOC and water colour	0	+ Reduced acidity and nitrate leaching. Possibly lower DOC	0 Increased soil erosion so higher suspended sediment	0 May increase DOC and soil erosion so more suspended sediment in rivers	
Natural hazard regulation: Floods	+ Less run-off potential	+ Less run-off potential	+ Less run-off potential	- Higher run-off potential on tightly grazed swards	-/ ?	+ Less run-off potential
Natural hazard regulation: Fire risk	+ Reduces habitat vulnerability	+ Reduces habitat vulnerability	+/- Depends on wildfire mgmt	? Reduced fire risk with conversion from heath to grassland?	+ More keepers, but heather also very flammable	+/- Depends on wildfire mgmt
Pollination	?	?	?	?	?	?
Disease/ Pest regulation	?	?	?	?	?	?
Genetic resources	+?	+?	0 Loss of hill sheep	+? Increase in hill	-?	+?

				sheep?		
Cultural Services						
Recreation & tourism	0 Recreation depends on access routes and access mgmt, eg. footpaths & car parks	0 Walking may be improved on revegetated peat	+ more natural environment, but loss of traditional agricultural landscape	0	0	0
Recreation: Field sports	+ more grouse habitat available in future	+ more grouse habitat available in future	-- Not permit burning	-? less grouse habitat available	+++ more grouse habitat available in future	-- Not permit burning
Education	0 Education depends on access routes and education mgmt	0	0 Education depends on access routes and education mgmt	0	0	0
Landscape Aesthetics	?	+ Reduces bare peat	?	?	?	?
Historic environment: Archaeology & palaeoecology	+ higher water levels protects artefacts though dependant on water quality (limit oxygen & nutrients); - action may cause localized damage to remains: use of peat to block drains may affect unique palaeoecology records (peat) that have no analogous or unaffected sites nearby; drains themselves may be significant landscape features of historic significance deposits and artefacts	+ Stabilizes peat and stops erosion	+ Stabilizes peat and stops erosion	- Heavy grazing destabilizes peat, but may reveal archaeological features clearly	- higher risk of damage to artefacts & increase of erosion – however, uncontrolled burns can get into peat and damage remains, whereas. controlled burns which are quick and cool may be of benefit in exposing features.	+ less disturbance to deposits and artefacts
Cultural Heritage: Rural culture	0	0	-- Loss of jobs in farming/ fieldsports, maybe offset by jobs in conservation mgmt	?	- Creation of jobs in grouse industry offset by loss of farming and forestry jobs, disruption to existing rural economic structure	0
Biodiversity	+ more typical bog & heath species	? relative biodiversity value of different habitats is hard to assess	+ more typical bog & heath species, but species dependent on grazing may be lost.	- fewer typical bog & heath species	-- fewer typical bog & heath species	0 little change in typical bog & heath species

Positive impact +++, ++, +   no impact 0   negative impact ---, --, -   don't know ?

Table 6.6: Workshop participants' views on direction of change of service provision from each scenario - Migneint

	Scenarios					
	Peatland Restoration			**Peatland Management**		**Optimise for one Ecosystem Service**
	Restoration (water)	**Restoration (vegetation)**	**Low intensive mgmt**	**Food security (livestock)**	**Economy**	**Carbon Management**
Migneint	**Grip blocking**	**Conifer plantation removal and moorland restoration**	**Removal of livestock/conifer forest/grip blocking**	**Increased grazing**	**Increase managed burning for grouse**	**Carbon Management**
Provisioning Services						
Food (livestock)	- lower grass nutrition, wetter ground less good for livestock	+ more grazing	--- Loss of grazing	++ improved in short term with liming, but maybe not sustainable in future	- Reduced sheep production if land managed for grouse.	-/+ Short term exclusion of grazing, possible grazing once peat is stabilised
Fresh Water (river flow/ quantity of water)	0	+ decreased evapo-transpiration	0 potentially more evapotranspiration	0	0/+ lower evapotranspiration	0/– higher evapotranspiration
Renewable energy (wind)	0 Potential affected through wet ground	+ More available land, higher wind speed in cleared areas.	-- Conservation management	0	0	0
Fuel & Fibre : Peat	+ Stop decline in resource	0	0	- Decline in resource	0	-
Fuel & Fibre : Timber / wood fuel	- Wetter ground	--- Timber production reduced to ~zero	--- Timber production reduced to ~zero	- less land for timber	- less land for timber	?
Genetic resources	+?	+?	0 Loss of hill sheep	+? Increase in hill sheep?	-?	+?
Regulating Services						
Air quality regulation	?	?	?	?	?	?
Climate regulation: GHG	? Balance of increased CO2 sink and CH4 source uncertain	? Balance of increased CO2 sink and CH4 source uncertain	? Balance of increased CO2 sink and CH4 source uncertain	- Heavy grazing can destabilise peat	- Heavy burning can destabilise peat	++
Carbon storage/ Erosion regulation	+ Gully/grip blocking maintains carbon storage	+ Probable restoration of peat accumulation in forest areas and decreased sediment loss	++ Probable enhancement of peat accumulation, reduced erosion	- may encourage erosion	- Heavy burning decreases peat stability	+++
Water quality regulation	+ Possibly lower DOC	+ Reduced acidity and nitrate leaching	+ Reduced acidity and nitrate leaching. Possibly lower DOC	+/- Possibility of increased nutrient levels, but acidity offset by liming.	- Possibly higher DOC. Probably higher POC.	
Natural hazard regulation: Floods	+ Less run-off potential	+ Less run-off potential	+ Less run-off potential	- Higher run-off potential on tightly grazed swards	-/ ?	+ Less run-off potential
Natural hazard regulation:	+ Reduces habitat	+ Reduces	+/- Depends on	+ Reduced fire	+ More keepers, but	+/- Depends on

Fire risk	vulnerability	habitat vulnerability	wildfire mgmt	risk with conversion from heath to grassland?	heather also very flammable	wildfire mgmt
Pollination	?	?	?	?	?	?
Disease/ Pest regulation	?	?	?	?	?	?
Cultural Services						
Recreation & tourism	0 Recreation depends on access routes and access mgmt, eg. footpaths & car parks	0	+ more natural environment, but loss of traditional agricultural landscape	0	0	0
Recreation: Field sports (game /fish)	0 (not relevant to area)	+ Improved habitat quality for fishing	+ Improved habitat quality for fishing	+ Increased fishery quality in limed rivers	+++ Creation of grouse estates	-- Not permit burning
Education	0 Education depends on access routes and education mgmt	0	0 Education depends on access routes and education mgmt	0	0	0
Landscape Aesthetics	?	+ Reduced visual impact of plantations	+ Reduced visual impact of plantations	?	?	?
Historic environment: Archaeology & palaeoecology	+ higher water levels protects artefacts though dependant on water quality (limit oxygen & nutrients); - use of peat to block drains may affect unique palaeoecology records (peat) that have no analogous or unaffected sites nearby; drains themselves may be significant landscape features of historic significance	+ Stabilizes peat and stops erosion	+ Stabilizes peat and stops erosion	- Heavy grazing destabilizes peat, but may reveal archaeological features clearly	- higher risk of damage to artefacts & increase of erosion	+ less disturbance to artefacts
Cultural heritage: Rural culture	0	- Loss of jobs in forestry sector (may be partly offset by increased farming?)	--- Loss of jobs in farming and forestry	?	-? Creation of jobs in grouse industry offset by loss of farming and forestry jobs, disruption to existing rural economic structure	0?
Biodiversity	+ more typical bog & heath species	+ increased area of semi-natural habitats	+ more typical bog & heath species, but species dependent on grazing may be lost.	- fewer typical bog & heath species	-- fewer typical bog & heath species	0 little change in typical bog & heath species

Positive impact +++, ++, + no impact 0 negative impact ---, --, - don't know?

6.5 Guidelines for monitoring the health of ecosystems

Identifying appropriate indicators for peatlands and the services they deliver requires a clear link between biophysical measurement, an ecosystem function and the benefits which flow. In general, the metrics identified within the scientific community will relate to the intermediate services which identify the relative status of the ecosystem structure and function rather than the service *per se*. The latter requires more input from social science, psychologists, historians, archaeologists and economists to name but a few and is beyond the scope of this project although input at the stakeholder workshop is summarised.

Ideally, metrics should be clearly derived from empirical evidence of the intermediate or final service. However, evidence often requires the synthesis of several metrics or in many cases result from expert judgement of underlying processes alone. This can be illustrated using the apparently simple case of climate regulation and carbon storage. This metric in peatlands could be:

1. Absolute change in soil carbon storage e.g. erosion rates and reduction in peat depth. Evidence for this could come from change in quantity sediment levels in rivers or peat in lake sediments, % area of erosion scars or change in direct measures of peat depth.

2. Measure of physical parameter linked to capacity for carbon storage e.g. anaerobic conditions and bog-forming plants with recalcitrant litter. Evidence for this could be change in water table height, loss or gain of bog-forming plants

3. Measure of activities in place likely to improve processes (2 above) leading to improved desired outcome (1 above).

4. General measure of quality for a habitat or service generally accepted to be linked to good status of a habitat

Inevitably, the quality and certainty of the evidence of actual change in benefits (i.e. services) diminishes from 1 to 4.

In our approach to identify appropriate indicators for the monitoring of peatlands, we have identified five key criteria by which possible candidates can be scored (Table 6.7) taking into consideration the issues described above. These criteria were agreed following the Stakeholder workshop at which clear guidance was provided concerning: (i) the desire to identify good quality indicators relevant to peatlands and their services irrespective of costs and interpretability by stakeholders which were dropped as possible candidates and, (ii) the immediacy with which indicators could be applied in a new or enhanced monitoring scheme for which scores are combined to provide a secondary score.

Table 6.7: Criteria and scoring system for assessing candidate indicators for the monitoring of peatlands and peatland services

Criteria	**Score**		
	3	**2**	**1**
Primary score			
Relevance to peatlands	Major relevance for processes fundamental to peatland functioning	Generic interest as for any habitat	Often used for other habitats but inappropriate for peatlands
Secondary score			
Relationship to function or service	Direct measure of function or service	Direct measure of underlying process or mechanism with well accepted link to function or services	Indirect measure of activity, measure or process thought to be linked to function or service but with underlying science still in under development
Established methodology	Accepted protocols available	Minor modification needed or work in progress	Needs major development
Ease of implementation	Easy to acquire data (no licensing issues) and/or accepted protocols and methodologies	Some effort required to modify existing scheme and/or development of methdologies	Major effort in establishing new scheme and / or development of methodology
Specialist input	None required or data available	Some training by specialists required	Only possible by specialists

Applying these criteria and scoring system to the full range of ecosystem services resulted in Tables 6.8-6.12. Explanatory comments on the service and a section on research gaps and needs for each major service category

Table 6.8: An assessment of potential indicators of peatland habitat and biodiversity

Habitat / biodiversity	There is continuing controversy as to whether biodiversity is a service itself. Within the MEA it was seen as underpinning all other services. The definition of biodiversity is also important – species richness, functional diversity or 'life on earth'? The relationship between species richness is tenuous or not proven in some cases, the concept of functional diversity is under development and therefore appropriate diversity and habitat quality which integrate the concept of a healthy functioning ecosystem provides the most helpful indicator of the likely delivery of ecosystem services currently. Here we assume indicators of the 'status' of the organisms and natural resources within the physical environment i.e. an ecosystem , provide an important indictor of the likely delivery of services as is the area of habitat available**.** This is also the approach being taken by the NEA. Within peatlands the most relevant category will concern the presence and cover of appropriate diversity primarily relates to bog-forming species which is captured in several national and specialised schemes. This is captured in the regulating section. Relationship to service is not applicable as these measures relate to habitat provision and status alone. It should be noted that the section on cultural services focuses on the central role of habitats and biodiversity in forming our historical landscapes which underpins much of the conservation aims within the UK							
Service	**Category**	**Metric proposed as indicator of change in service**	**Relevance to peatlands score**	Relationship to function or service	Established methodology	Ease of implementatio n	Specialist input required	**Secondary score**
Habitat	Subsample	Common standard monitoring	3	N/A	3	3	1	7
Vegetation	Subsample	Appropriate plant diversity (e.g. CEH CS data)	3	N/A	3	3	1	7
Vegetation	Subsample	Bog-forming species	3	N/A	2	3	1	6
Vegetation	Subsample	Number and cover of non-native species (e.g. CEH CS data)	2	N/A	3	3	1	7
Animal	Subsample	Trends in wild bird populations	2	N/A	3	3	1	7
Water	Subsample	Rivers of good chemical quality (e.g. % river length)	2	N/A	3	3	1	7
Water	Subsample	Drinking water quality (e.g. % of water failing standards)	2	N/A	3	3	1	7
Water	Subsample	Mean trophic rank of water plants (e.g. CEH CS data)	2	N/A	3	3	1	7
Water	Subsample	Freshwater invertebrate diversity (e.g. CEH CS data)	2	N/A	3	3	1	7
Soil	Subsample	Soil biological community structure	2	N/A	2	2	1	5
Area	Trends in area	UK BAP reporting	2	N/A	3	3	1	7
Area	Trends in area	CEH Landcover mapping	2	N/A	3	3	1	7
Area	Subsample of area	CEH CS mapping	2	N/A	3	3	1	7
Area	Subsample of area	Area of habitat protected	2	N/A	3	3	1	7
Landscape	Subsample	Appropriate landscape diversity (e.g. CEH CS data)	2	N/A	3	3	1	7

Research gaps	The relationship between many of the metrics suggested above and provision of other services whether intermediate (e.g. primary production and nutrient cycling) or final services (e.g. water regulation) remains unclear. The nature of the relationship also needs clarification e.g. the relationship between soil biological community structure and peat formation may be by association only rather than causal. Work ongoing in SQID project and Countryside Survey may help resolve this specific issue together with standards by which peatland soil biological community structure can be assessed in the future. There is currently no accepted list of peat-forming plant species this methodology requires further development work

Table 6.9: An assessment of potential indicators of the provisioning services of peatlands

Provisioning	An indicator of provisioning of food by peatlands is challenging due to the problem of attribution animal numbers to specific areas and the manipulation of the potential of the land by current agri-environment and designation land policies. All that is possible is to assess indicators of current provision rather than potential. To our knowledge, this is also the approach of Phase I of the NEA (2009). This will allow any proposed change in management to be quantified against this baseline. A potential provisioning assessment for this or any other service e.g. water regulation or hydro production requires a major modelling effort beyond the scope of this assessment. Relevance of food production for peatlands is scored low as land abandonment is an increasing problem and productivity is low. The emphasis on animal production will be greater under cultural service section.							
Service	**Category**	**Metric proposed as indicator of change in service**	**Relevance to peatlands score**	Relationship to function or service	Established methodology	Ease of implementation	Specialist input required	**Secondary score**
Food	Animal production	Agricultural census map	1	1	2	2	2	7
		Agricultural land value	1	1	2	2	3	8
	Fish	EA records	1	3	3	3	2	11
Fibre	Wood	Timber extracted	1	3	3	3	2	11
Energy	Wind	No metric identified						
	Hydro	No metric identified						
	Biomass crops	No metric identified						
Water quantity	Flow	National River Flow Archive (appropriate metric for peatlands needs developing)	3	3	2	3	1	9
	Storage	Levels of reservoir capacity (EA) reliant on peatland systems	3	1	2	3	1	7
	Storage	Water storage (modelled)	3	3	2	3	1	9
	Storage	Water stress (modelled)	3	3	2	3	1	9
Genetic resources		No metric identified						
Biochemicalms, pharmaceuticals,		No metric identified						
Ornamental resources	Horiticulture (e.g. moss)	No metric identified						
Research Needs								

Table 6.10: An assessment of potential indicators of the regulating services of peatlands

Regulation	This is one of the major category for peatlands with high value placed on the services by stakeholders. Climate regulation has been differentiated into two separate components – the carbon stocks and the rate of current sequestration. Stocks are important per se as they are a potential source of GHG if lost. Sequestration is the ongoing service provided. Stocks may still be present providing a valuable services even if sequestration lost due to damage of peatlands which is why they have been separately scored. Pristine bogs are thought to be net sources of GHG due to methane production, while these however might be less significant than CO_2 sinks through Carbon sequestration. Interest is therefore in maintaining carbon stored while not enhancing methane fluxes. Stakeholders proposed a range of indicators such as presence of peat forming species for climate regulation. However, it is possible that e.g. carbon sequestration rates could increase with afforestation of peatlands in the short term as some work has indicated the drawdown of the water table can significantly reduce methane fluxes. Peat-forming plants would not be a useful indicator in this situation. We propose the direct measures of the service i.e. measurement of change in peat carbon stores, all dissolved and particulate carbon fluxes and greenhouse gas fluxes. Air quality regulation relates to the effectiveness of the system to 'scrub' the atmosphere of pollutants. Peatlands have a high capacity to capture pollutants, but this is not sustainable as indicated by low critical loads and levels and damage observed in peatlands in areas with large pollutant loads. It is debatable therefore as to the scoring system, which should be applied for non-sustainable services and low values have been proposed here to protect services more valued by stakeholders. Natural hazard regulation, e.g. of wildfires, is complex but relates to the management of peatlands to reduce the risk of wildfires. Some synergies may be achieved with food production or management for field sports or recreation.							
Service	**Category**	**Metric proposed as indicator of change in service**	**Relevance to peatlands score**	Relationship to function or service	Established methodology	Ease of implementation	Specialist input required	**Secondary score**
Flood risk mitigation		Duration-return curves and rainfall:runoff ratios (National River Flow Archive)	3	3	2	2	1	8
		Water storage (modelled)	3	3	2	3	1	9
		Presence of grips	3	2	3	3	3	11
		Area of bare peat	3	2	3	3	3	11
		Presence of peat-forming species	3	2	2	3	1	8
Water quality regulation / purification of untreated water	Chemical	Rivers of good chemical quality (% river length)	3	3	3	3	1	10
	Biological	Drinking water quality (% of water failing standards)	3	3	3	3	1	10
	Fish	EC freshwater fish compliance	3	3	3	3	1	10
Climate regulation	Carbon stock	Soil organic matter content (NSI and CS data)	2	2	3	3	2	10
		Peat depth	3	3	2	2	2	9

Table 6.10 An assessment of potential indicators of the regulating services of peatlands (continued)

Service	**Category**	**Metric proposed as indicator of change in service**	**Relevance to peatlands score**	**Relationship to function or service**	**Established methodology**	**Ease of implementation**	**Specialist input required**	**Secondary score**
Climate regulation (cont.)	Carbon stock (cont.)	Ecosystem carbon stock (vegetation biomass + peat carbon store (combination of 2 above)	3	3	2	2	1	9
	Carbon sequestration	Primary production (carbon fixation rates by vegetation)	3	3	2	2	1	9
		Ecosystem carbon sequestration (change in soil carbon or peat depth + change in vegetation biomass)	3	3	2	2	1	9
		Erosion (% area)	3	3	3	3	3	12
		% bare peat	3	3	3	3	3	12
		Dissolved and particulate losses of carbon	3	3	3	3	3	12
	Greenhouse gas fluxes (GHG i.e. CO2, N2O and CH4)	GHG flux measurements at all scales (chamber to landscape)	3	3	3	3	3	12
Air quality regulation		Critical load and levels for acidity, nitrogen and metals	1	1	3	3	3	10
Natural hazard regulation		Wildfires fuel stock	3	2	2	2	2	8
Pest / disease regulation		No metric identified						
Erosion regulation		No metric identified						
Pollination		Number of butterfly and bee food plants	3	2	3	3	3	11
Research needs	There is currently no accepted list of peat-forming plant species. This methodology requires further development work. There is continuing controversy surrounding the impact of various remediation measures such as the blocking of grips on GHG gas emissions. There remains an urgent need to monitoring and assessment of peatlands across uplands and lowlands in the UK to establish all fluxes of both atmospheric and riverine fluxes of carbon and GHG including the ultimate fate of losses in dissolved or particulate losses to rivers.							

Table 6.11: An assessment of potential indicators of the cultural services of peatlands

Cultural	Cultural services cover a wide range of benefits. Many rely on the presence of appropriate diversity but not all. For example walkers often appreciate the openness of peatlands rather than the vegetation per se. Peats undergoing succession or other transitions may provide easier access for some visitors in the short term and some may appreciate a change in vegetation following invasion by mesophytes. Historical and archaeological features may often benefit explicitly from the anaerobic conditions of the peat.							
Service	**Category**	**Metric proposed as indicator of change in service**	**Relevance to peatlands score**	**Relationship to function or service**	**Established methodology**	**Ease of implementation**	**Specialist input required**	**Secondary score**
Aesthetics	Tranquillity	Tranquillity mapping	3	3	3	3	1	11
Cultural	Sense of place	Countryside quality mapping	3	3	3	3	1	11
		Appropriate plant diversity (e.g. CEH CS data)	3	3	3	3	1	10
		Area of habitat protected	2	3	3	3	1	7
		Appropriate landscape diversity (e.g. CEH CS data)	2	3	3	3	1	7
		Density of historical and archaeological monuments	2	3	2	2	2	9
		Number of historical and archaeological features protected	2	3	2	2	2	9
		No. of visitors (various metrics e.g. bird watchers, walkers etc)	3	3	3	2	2	10
Recreation	Field sport	National gamebag census	3	3	3	3	3	12
		Red grouse populations and area of grouse moors	3	3	3	3	3	12
	Tourism	Area of recreational facilities (e.g. Local footpath network)	3	3	3	3	3	12
		Area of designated land / national park	3	3	3	3	3	12
	Historic environ-ment	Density of historical and archaeological monuments	2	3	2	2	2	9
		Number of historical and archaeological features protected	2	3	2	2	2	9
Spiritual / religious		No metric identified						
Inspiration		No metric identified						
Social relations		No metric identified						
Research needs	Metrics need to be defined for many of the indicators here and major work to identify additional indicators to cover the full range of services peatlands deliver							

Table 6.12: An assessment of potential indicators of the supporting services of peatlands

Supporting	Supporting services underpin delivery of many intermediate services such as pollination and final services such as provision of food, clean water and recreation. They describe the inherent ecosystem structure and function of the habitat. Peatlands are categorised by nutrient poor conditions and thus the concept of 'appropriate' nutrient cycling or primary production is important. Indicators of high productivity for example may indicate nutrient enrichment and invasion by a productive grass species.							
Service	**Category**	**Metric proposed as indicator of change in service**	**Relevance to peatlands score**	**Relationship to function or service**	**Established methodology**	**Ease of implementation**	**Specialist input required**	**Secondary score**
Nutrient cycling		Soil quality indicators e.g. national maps of N and P cycling (e.g. Countryside Survey data)	2	3	3	1	1	8
		Peat metrics (depth, erosion, areas of bare peat etc)	3	2	2	3	1	8
Primary production		Modelling and plant traits	2	2	2	2	1	7
		Remote sensing	2	2	2	2	1	7
Soil formation		Peat formation (e.g. (depth, erosion, areas of bare peat, CO2 exchange etc)	3	3	2	2	1	8
Research needs	Work is ongoing to develop threshold for many of these indictors appropriate to a range of habitats.							

Overall assessment combines (i) the optimum combination of indicators of high relevance for peatlands and peatland services, (ii) the secondary score of other indicators of relevance, which identify the link to services or interest and the practicality of their immediate application in a monitoring scheme and (iii) indicators which are indicative of several functions and services. This process identifies the following as the most promising indicators for a new monitoring scheme (Tab 6.13).

Table 6.13: Key indicators for a new monitoring scheme

Indicator	**Service / Function**
Common standard monitoring	Habitat / biodiversity
Appropriate plant diversity (e.g. CEH CS data)	Habitat / biodiversity
Bog-forming species	Habitat / biodiversity; regulating
National River Flow Archive (appropriate metric for peatlands needs developing)	Provisioning
Water storage (modelled)	Provisioning; regulating
Water stress (modelled)	Provisioning; regulating
Presence of grips	Regulating
Area of bare peat	Regulating
Erosion (% area)	Regulating
% bare peat	Regulating
Dissolved and particulate losses of carbon	Regulating
GHG flux measurements at all scales (chamber to landscape)	Regulating
National gamebag census / Red grouse populations and area of grouse moors	Cultural
Area of recreational facilities (e.g. Local footpath network)	Cultural
Area of designated land / national park	Cultural

6.6 Case for Restoration

At the conference, workshop participants were asked to assess the risk and impact of a range of peatland restoration and management interventions in both upland and lowland setting. The votes for upland settings are given in Table 6.14 and shows that while there is a high degree of agreement regarding restoration through re-vegetation opinion about re-wetting is more mixed and indeed bimodal when grip-blocking is being considered. With regard to peat management the opinion appears to be mixed because of the particular concern of individuals and the organisations they represent. In terms of the lowland peats (Table 6.15) the group attempted to achieve consensus and therefore the group only expressed concern over the planting of trees upon deep peats.

Table 6.14: Summary of consensus for each proposed restoration interventions on upland peat soils. Workshop participants voted on the risk with one vote (before discussion), and the range of opinions was captured as sum of votes.

	Risk & Uncertainty				**Impact**				**Notes**
Upland peatlands	No regrets	Low regrets (reversible)	High regrets (irreversible)	Dangerous	Benefits	Threats	Extent (spatial)	Extent (temporal)	
Restoration (water)									
Grip-blocking	4		2	1	Carbon storage, biodiversity, atmospheric pollutant retention, lower POC	Methane	national	years to decade	Multiple benefits and threats. Restoration impossible without it.
Gully-blocking	1	2	3	1	Carbon storage, biodiversity, atmospheric pollutant retention, lower POC	Methane	locally in heavily eroded peatlands	years to decade	Gully taken as erosion feature, differs in scale
Restoration (vegetation)									
Bare peat revegetation	5	1			soil erosion, carbon storage, biodiversity, lower POC	threats to ES if not followed up with ongoing restoration, risk of short term nutrient enrichment, if fertiliser and lime added	locally in heavily eroded peatlands	years	Risk of "job done" after first revegetation (revegetation will achieve gound cover, but characteristic species assemblages will be achived in a longer time frame only)
Sphagnum propagation	5				biodiversity, run-off attennuation, GHG , carbon storage, nitrogen retention, lower POC		regional - degraded and fragile peatlands (not only bare peat areas but e.g. across most of Peak District moorlands)	years	Trial on Bleaklow (MFF), success yet unknown
Tree removal	1	4			biodiversity of moorland plants, less POC in long term, less acid runoff	aesthetics (depends on preference), risk of losing other species, POC loss and soil disturbance during forest clearance	limited in many areas without Forestry Commission plantation	years	Plantation removal and blanket bog restoration on Migneint as part of RSPB EU-LIFE project
Regenerate clough woodland	4	2			biodiversity, run-off attenuation, GHG, riparian buffers for pollutants, aethetics (depends on preference)	aesthetics (depends on preference)	limited to cloughs and steep slopes only	years to decade	Some schemes in Peak District and elsewhere
Peat management									
Reduce grazing		6	1		Carbon storage, biodiversity	Development of fuel load, food provision, some biodiversity dependent on grazing	Regional to national	years	Undergrazing can also be an issue
Liming to improve grazing				1	food production, less acid runoff	GHG, biodiversity, increased DOC	Regional to national	years	Other chemicals can be problem, eg. fertiliser
Avoid burning	2	4			Carbon storage, biodiversity, GHG, POC and DOC	Development of fuel load, loss of field sports	Regional	years	Can leave large areas of degenerate heather, habitat needs to move into different vegetation to gain resilience
Planting trees on deep peats				3	Short-term GHG improvement, timber provision	Carbon storage, biodiversity, increased atmospheric pollutant deposition to canopy	Regional	years to decades	
Manage wildfire risk	1	2	1		natural hazard regulation, carbon storage, erosion, GHG, water quality, biodiversity	depends on management type	regional in southern fringe of peatlands	ongoing	Wildfire risk management can be through biomass control (burning/cutting), recreation management & vegetation succession managament towards more resilient habitat with higher soil moisture and less flammable vegetation

Table 6.15: Summary of consensus for each proposed restoration interventions on lowland peat soils. Workshop participants worked towards consensus, which is captured in the table.

	Risk & Uncertainty				**Impact**				**Notes**
Lowland peatlands	No regrets	Low regrets (reversible)	High regrets (irreversible)	Dangerous	Benefits	Threats	Extent (spatial)	Extent (temporal)	
	Restoration (water)								
Drain-blocking	yes				C storage, biodiversity, conservation of historic environment & relics	Methane emissions, if water tables too high; potential flood risk on off sites or reduced flood storage capacity	National, but small scale compared to uplands	years to decades	Water tables need to be carefully controlled to achieve multiple aims
	Restoration (vegetation)								
Bare peat revegetation	yes				C storage, peat formation, landscape aethetics, biodiversity		local, on former peat extraction sites	years	Can be very quick, as on Thorne & Hatfield
Sphagnum propagation		yes			GHG, Carbon storage (peat formation)			years	Trial on Bleaklow (MFF), success yet unknown
Tree & scrub removal	yes				Reduced evapo-transpiration & disruption of peat stratigraphy, landscape aesthetics, biodiversity	landscape aethetics (diff. preferences), some species may disbenefit such as night jar	Local sites	short term	Additional benefit of wood fuel. This is occuring on Thorne & Hatfield Moors. Management of water regime may lead to natural decay of trees
Regenerate woodland on shallow peat		yes			Short-term GHG improvement, biodiversity (some species will benefit)	Carbon storage, biodiversity	Local sites	years	careful evaluation of effects on carbon flux, hydrology and bioidversity needed
Stop peat extraction	yes				more natural environment, less disturbance to relics, increase C storage & biodiversity	loss of history of peat working	National	short term-decades	
	Peat management								
Reduce grazing			yes			food provision		short term	Undergrazing can be a problem. Not much grazing occurs at Thorne & Hatfield Moors
Liming to improve grazing			yes		food provision	biodiversity, Carbon storage		short term	
Increase arable			yes		food provision	biodiversity, Carbon storage		years	
Planting trees on deep peats				yes	Short-term GHG improvement	Carbon storage, biodiversity, hydrological functioning		years to decades	Planting schemes on deep peat are inadvisable
Flood water storage		yes			water storage	biodiversity (depends on management)		short term	Depends on topography whether peatlands are water sinks or source; flood risk on off site areas at Thorne & Hatfield Moors, flood storage potential on Somerset Levels

7. Suggestions for the Phase II research programme

The following section summarises points that should be considered in a Phase II programme on the Ecosystem Services of Peat. It was compiled based on lessons learnt from this scoping study combined with advice from workshops held at the project conference on 15/16 October 2009. In summary, there needs to be an improved evidence base, expanded spatial coverage, additional case studies for new peat types, inclusion of climate change scenarios in assessments, improved valuation including additional (e.g. non-use) services, and provision of practical / policy outputs.

1. There are a number of major research gaps that need to be filled before work can be rolled out to evaluate some of the major ecosystem services. It is therefore proposed that an integrated research programme is carried out over five years that ends up in the full roll out of ecosystem service plans for UK peatlands. Example major research gaps that have proven to be obstacles in this scoping study are:

- There is continuing controversy surrounding the impact of various remediation measures such as the blocking of grips on GHG gas emissions, as well as management measures such as burning. There remains an urgent need to monitoring and assessment of peatlands across uplands and lowlands in the UK, especially different fenland types, to establish all fluxes of both atmospheric and riverine fluxes of carbon and GHG including the ultimate fate of losses in dissolved or particulate losses to rivers.
- The overall impact of gullying and ditch blocking not only on DOC, but also N, S and acidity remains uncertain, as does the impact of water table on N retention.
- Research is needed to address the issue how rising trends of dissolved organic carbon (DOC) in streams can be halted or managed.
- Further work is required to quantify the impact of peat condition on the quantity and timing of runoff in relation to water supply, and to the dilution of diffuse and point-source pollution.
- Determining overland flow velocities for a wider range of peatland vegetation covers will aid assessment of flood risk attenuation benefits from peatland management.
- Understanding is needed how woodland clough planting impacts stream flow, water quality and carbon cycling.
- To address UK CC goals, research is needed, which renewable energy schemes are most efficient in their carbon balance, cost-effectiveness and have least impact on other ecosystem services and biodiversity and in what locations can they be best deployed.
- Targeted research is required to develop niche models for rarer species and build consensus on characteristic peat forming species.
- Major work is needed to identify additional indicators, especially for cultural services, to cover the full range of services peatlands deliver.
- More specific and in-depth valuation studies with regards to peatland restoration and management practices are required to inform cost benefit analyses.
- A greater understanding of the spatial (dis)aggregation of providers and beneficiaries of services is needed to assess ecosystem service flows.
- The links of ecosystem service provision to wellbeing and health are a pivotal area of research to be addressed.

2. Coupled to the above this suggests that there needs to be an integrated research programme to assess effects of peatland management and restoration options on peatland ecosystem services, with a cost-benefit analysis to lead to spatial and temporal targeting of resources and efforts. There still needs to be direct investigation to support assessment.

3. A roadmap is needed to determine ecosystem research on peatlands with a timeline of how different research projects will feed in. There needs to be co-ordination of all current work on ecosystem services of peatlands (even if funding is from non-Defra sources).

4. There should be a UK upland hub for peatlands, which forms one unitary platform for knowledge exchange between science, policy and practice and develops new integrated research. Such a platform has recently been proposed to the LWEC Directors and steering group who are keen to see stakeholders and the policy community support this through funding and staffing. This would build on the many excellent, but currently disjointed and replicated initiatives, to align and integrate activities. It is crucial that representations from stakeholder organisations are used to co-ordinate and develop work for peatlands.

5. There should be support for strategic long-term monitoring. The lack of long-term datasets is a real hindrance for evaluating ecosystem services. Effective monitoring of landscape peatland restoration

programmes, for example, would allow for adaptive management and addressing some of the major knowledge gaps. This should be standard requirement with any new funding for practical work. Another avenue would be to feed standardized peatland ecosystem service monitoring into the biological network sites of the ECBN network, and encourage and facilitate large landscape restoration projects to take part.

6. We have shown that different types of peatland offer different ecosystem services and/or provide services in different ways (e.g. flood mitigation). Therefore, care must be taken in Phase II to ensure that peatlands are properly characterised when the work is rolled out to other peatland types. That said, blanket peat forms 87 % of the UK's peatland and research will necessarily need to be targeted proportionally.

7. Phase II should include all services (beyond the ones we could cover in this scoping study).

8. The scale of approach needs to be carefully considered. For example, for some services the focus is within the peatland itself, while for others the focus may be off-site and the scale of the off-site service provision must be appreciated. Additionally, while using the same scale of approach for all services allows some comparative maps to be produced (e.g. 1km2 grids), such scaling is not as appropriate to some services as it is to others.

9. The UK Peat Geonetwork www.ukpeatgeonetwork.org.uk should be used as a source of metadata and a way of managing datasets when the work is rolled out across England and Wales. The approach should encourage active sharing of information, facilitate collaboration between scientists and science users and ensure avoidance of duplication of efforts.

10. Climate change will need to factored into an ecosystem service approach to evaluate how the service provision may change and/or ways of i) taking advantage of climate change ii) mitigating and adapting to negative impacts on ecosystem services and iii) understand how land management and climate change will interact.

11. A key objective for Phase II would be to determine whether we can find an optimal geographic configuration for managing different services in different areas that maximises overall benefits. Thus, maps showing where and what restoration could be applied will be very useful.

12. Research is needed to establish how costs for (un)sustainable management can be internalised and stewardship for ecosystem services be rewarded, e.g. through payment for ecosystem services (PES) schemes), reform of environmentally harmful subsidies, regulation or new market options.

13. Clear policy advice is required at different levels (e.g. support/guidance for agri-environment schemes) along with information on the uncertainty present.

14. As ecosystem services are a matter of societal choice a participatory process with full engagement with landowners and managers is needed; this would be challenging at a national scale and therefore an integrated national, regional and local approach is required. In any case, as we recommend in Section 6, local stakeholders are required to interpret national datasets covering their peatlands.

15. The work and approach needs to be communicated effectively to the public.

8. Dissemination of main findings

The project findings are disseminated in a range of formats for the general public as well as peatland managers and researchers

a) **Web-based metadatabase**: A major focus of this Phase I study was the collation and evaluation of available data to perform an ecosystem service analysis of peatlands. Data were collated were possible on a national scale (England and Wales) or specific to the case studies. We designed and developed a specific web-based metadatabase www.ukpeatgeonetwork.org.uk to make all relevant metadata available for phase II, including information on sources and IP holders. This tool is open for peatland research and practitioner input and use across all UK peatlands.

b) **UK Peat Geonetwork research note**: A UK Peat Geonetwork research note was produced in an easily accessible 4 page format to facilitate and encourage website access and search options, as well as to foster user expansion of the metadatabase for other UK peatland data and science projects. The research note is available in print and digital format and will be posted on various websites (see Appendix 3, www.ukpeatgeonetwork.org.uk, www.moorsfortherfuture.org.uk, www.peatlands.org.uk).

c) **Website pages**: The executive project summary, a link to the Defra report (when available) and additional summary material will be posted on the Moors for the Future website www.moorsforthefuture.org.uk and the peatland network site www.peatlands.org.uk, that was developed in 2008 as part of the Defra Peat Compendium.

d) **Defra Ecosystem Services of Peat project conference**: The project conference served as dissemination point of main findings and constructive feedback loop with case study partners and national peatland stakeholders.

e) **Presentations**: The project and (part) results were presented at the following meetings: The State of our Peatlands, Natural England conference, Birmingham, 25 Feb 2009 (invited talk); Predicting the Future for Highly Organic Soils, British Society of Soil Science, Edinburgh, 5-7 May 2009 (poster); Ecosystem services: building tools for policy and practice, NERC/ESRC FRESH seminar, Liverpool, 24 June 2009 (invited talk); Moors for the Future research day, Bakewell, 7 July 2009 (talk); Wales - Ecosystem Services Science Workshop, Environment Centre Wales, Bangor, 15-16 July 2009 (invited talk); Peatlands in the Global Carbon Cycle, Prague, Czech Republic, 25 - 30 Sep 2009 (poster); From Policy to Practice: Challenges and Opportunities of Ecosystem Service Research for Ecologists, Helmholtz Centre for Environmental Research - UFZ, Leipzig, 9-12 Nov 2009 (invited talk)

f) **Publications**: We are in negotiation with several journals to see if we can publish this project as a special issue of a journal with around 8 papers in the issue based entirely on this project.

10. Acknowledgements

Many thanks to all partners of the Defra Peat Partnership Project and all agencies and organisations and their staff who have supported this project through data delivery and licensing, namely Defra, CADW, CCW, CPRE, Cranfield University (NSRI), English Heritage, Environment Agency, Department of Transport, Natural England, PDNPA, RSPB, SNPA and WAG. Special thanks go to Claire Hill and Judith Stuart (Defra) for overseeing this project and chairing the project conference, Tim Kohler, Matthew Shepherd (Natural England), James Skates (WAG), Andy Framer and Jenny Waller (PDNPA) for their active support, Steve Dury (Somerset County Council), Mark Everard (EA) and Jen Heathcote (EH) for their advice, and Maggie Logan (Wales Northern), Brian Leigh (NE), Lisa Sivori (NW), Frieda Davies (NW), Richard Severn (Midlands) and Rob Ellis at the Environment Agency for providing flow data. We would also like to thank all area rangers and wardens from the Peak District, Migneint and Thorne & Hatfield Moors and Anne McKenzie and Alexander David for their support and crucial involvement in the expert recreation survey.
We are especially grateful to all participants of the start up workshops and the October 2009 conference who provided excellent guidance to the project team and whose feedback was embedded in this project report.

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