Natural England Commissioned Report NECR020

Upland ecosystem services: Phase I

Part 1 - Report

First published 26 February 2010

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Introduction

Natural England commission a range of reports from external contractors to provide evidence and advice to assist us in delivering our duties. The views in this report are those of the authors and do not necessarily represent those of Natural England.

Background

There is growing interest in both the concept of ecosystem services and their links to human well-being. One of the key challenges is to improve our understanding of the relationship between ecological and social systems and how the various drivers of change may affect the benefits that these systems provide for people.

Natural England commissioned this study to develop a set of conceptual, evidence-based ‘systems-maps’ for the uplands of England, and to explore how they can be used to describe and better understand the geography of ecosystem services.

The work contributes to Natural England’s Upland Futures initiative, by helping to illustrate the importance of maintaining and restoring the functional integrity of ecosystems in the uplands, and the value that these areas have for society.

The findings have been used by Natural England to help to develop a future vision for the uplands of England. In particular they have been used to inform:

- NECR028 *Upland Ecosystems Service: assessing the links between environment, land management and service delivery for 4 key services*; and
- NECR029 *Economic valuation of uplands ecosystem services.*

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Keywords - Ecosystems, ecosystem goods and services, land management, land use, services, uplands

Further information
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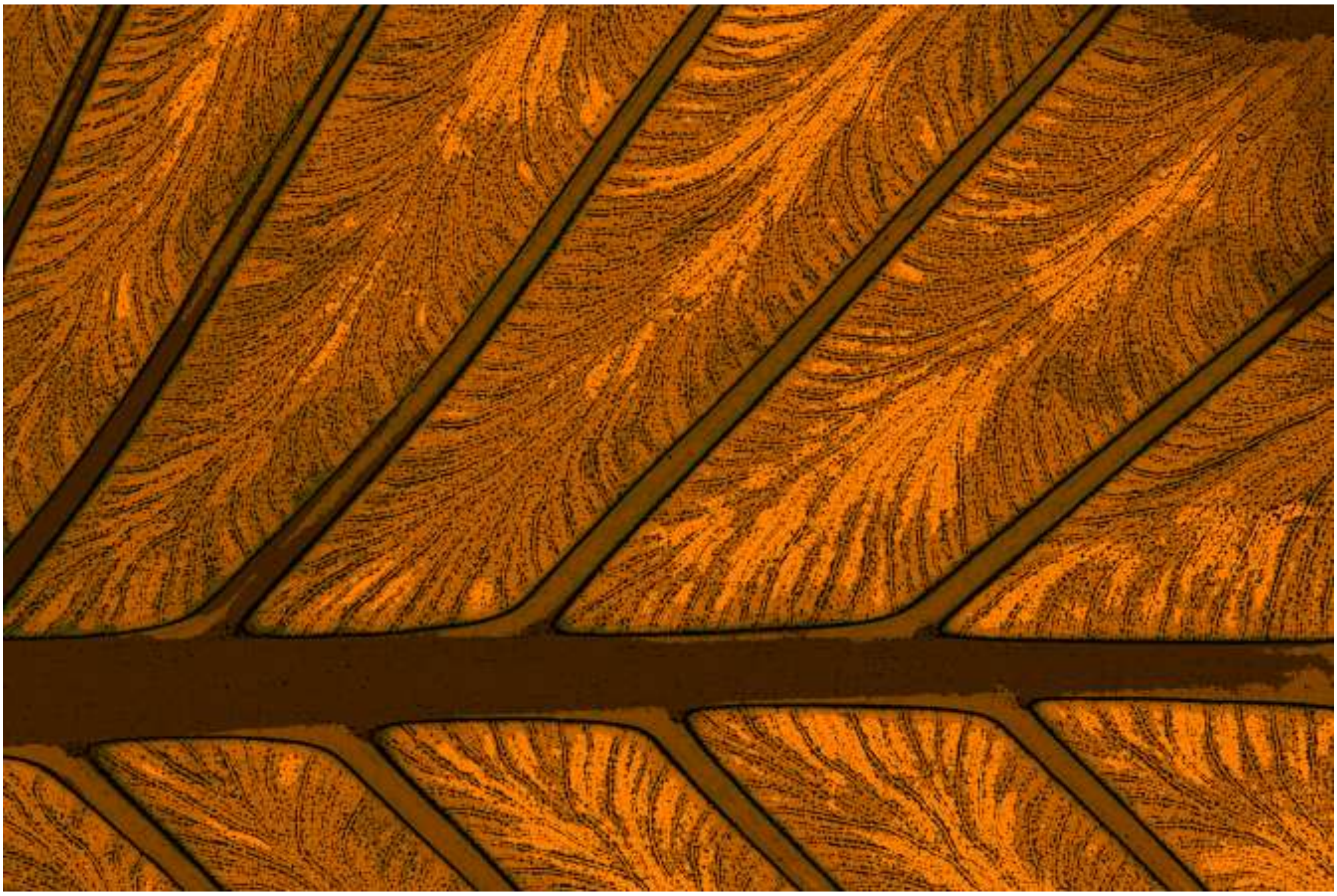
ISSN 2040-5545

England’s Upland
Ecosystem Services:
Phase I



Report To

(Project Code FST20/79/023)

Final Report
30th June, 2008

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If you use this document please quote as:

Haines-Young, R., Potschin, M.; Rollett, A. and Tantram, D. (2008): England's Upland Ecosystem Services: Phase I. Final Report to Natural England, 114 pp.
NE Project Code: FST20/79/023. CEM Report No 9.

Contents

Executive Summary

There is growing interest in the concept of ecosystem services and their links to human well-being. One of the key challenges for both scientists and policy advisors is to better understand the way ecological and social systems are coupled, and how the various drivers of change may impact on the output of the benefits that these systems provide for people. With such knowledge, it is argued, more robust and sustainable development strategies can be designed and achieved.

Study Aims

The aim of this scoping study was to develop a set of conceptual, evidence-based 'systems-maps' for the uplands of England, and to explore how they could be used to describe and better understand the geography of ecosystem services. The work contributes to Natural England's Upland Futures initiative, by helping people to better understand the importance of maintaining and restoring the functional integrity of ecosystems in the uplands, and the value that these areas have for society.

Although the concept of ecosystem services has been widely discussed in the research and policy communities, the task of modelling such services is a complex one. The work is essential, however, if the implications of different policy strategies are to be compared and the costs and benefits of different management options are to be determined. This study has examined the use of Bayesian Belief Networks as a way of constructing such models for a number of ecosystem services associated with the Uplands.

The services selected for detailed study were:

- Carbon storage and sequestration – A Regulating Service;
- Recreation – A Cultural Service; and,
- Renewable energy – A Provisioning Service.

In addition, water provisioning and flood regulation services were also considered in a more general way. Since it became clear that many of the systems had common direct and indirect drivers, the study also attempted to explore the construction of a systems-map to represent wider upland management and policy issues.

To support Natural England's future work on ecosystem services in the uplands, a further aim of this study was to develop a more general 'service typology' that describes the ways in which habitat quality, conservation status and biodiversity characteristics of a site relate to the output of selected ecosystem services, and to establish how such knowledge can be used for the *spatial* mapping of services and their valuation.

Conceptual Mapping

The approach used for conceptual mapping, based on the use of Bayesian Belief Networks proved useful as a way of helping people describe the systems and problems that they are interested in. The method was used with a range of experts and policy advisors within NE, and the work resulted in a number of networks covering all of the service themes identified in the project brief. The full calibration of these models, using empirical evidence proved to be a lengthy process, however. The study showed that network construction and calibration has to be undertaken in an iterative way, and that future work should ensure that sufficient development time is available for the work to be completed and operational networks built.

Given the value of the networks in helping people map out their ideas about different types of ecosystem and landscape, the process of network construction is likely to be valuable as part of future scenario studies for the uplands. Even though empirical data may be lacking, the network methodology can effectively capture people ideas about what elements are important in any future study and how the different elements are linked and may change under different sets of conclusions. **We recommend that Bayesian Networks are initially used in the context of scenario construction rather than as empirical models, intended to support specific operational decisions.**

Service Typologies

A number of service typologies exist in the research and policy literatures. Although useful as an *aid memoir*, none have proved comprehensive and unambiguous, in terms of describing what constitutes an ecosystem service in any particular situation. Thus this study did not seek to develop these lists of services any further, but instead showed how in the analysis of any particular problem, it is possible to identify certain key system elements so that ideas about ecosystem services and the factors influencing them can be expressed clearly.

The Bayesian Belief network approach enabled analytical strategies to be more clearly structured, so that measurable service outcomes could potentially be identified and modelled. **It is argued that the kinds of structural typology presented here can be used to describe rigorously what constitutes an ecosystem service, and how that service is related to wider environmental or landscape services.**

Spatial Mapping

A range of spatial data were reviewed, and assessed in terms of the extent to which they might support the mapping of ecosystem services. Although the data resource was extensive, it was apparent that few services could be mapped directly and simply.

Since, in general, ecosystem services have to be mapped using a spatial modelling approach, it is argued that such work should be undertaken in conjunction with conceptual mapping exercises, so that the logic underlying the design of the mapped output can be made clear. **The spatial mapping of ecosystem services is, however, an essential goal for future work, but the assumptions on which such maps are built must be identified clearly.**

Acknowledgements

First of all we would like to thank Chris Reid as Natural England Project Officer for the Upland's Project for guiding us through the process in a very motivating way.

We are indebted to the input from the Natural England Steering Group, namely:

- John Hopkins- Evidence Group, Terrestrial Ecosystems;
- Dan Hunt - Area Advisor, Upland SSSIs;
- Gary Kaas - Strategy and Futures, Futures Techniques; and,
- Dominic O'Neill – Strategy and Futures Group, Economies.

We are also very grateful for the input from the following invited experts (the original expert papers are given in Appendix F to I in the separate file, which is available from the NE project officer or the team project manager):

- Alletta Bonn (Moors for the Future Partnership) on "geographical Mapping of Recreation Opportunities as Ecosystem Service";
- Stephen Dangerfield (Environmental Consultant and Researcher at CEM) on "Systems-Maps on Flood Prevention and Water Provisioning" as given in Part 6 of this report;
- Robert Deane and Sarah Young (Land Use consultants, Bristol) on "Renewable Energy";
- Graham Rimmington (University of Nottingham) on "Upland Landscapes and Land Use: Economic and Social Drivers for Change"
- Fred Worrall (Durham University) on "Network Carbon Storage and Sequestration".

During a workshop, held in the Natural England Office in London on March 4th, 2008 we received very many helpful comments and inspiration. The workshop output is documented in Appendices A-E in a separate file, see above. We are indebted for the input from the following participants:

- Simon Bates (Natural England);
- Alletta Bonn (Moors for the Future Partnership);
- Steve Dangerfield (Environmental Consultant and Researcher at CEM);
- Chris Gordon (Natural England);
- John Hopkins (Natural England);
- Duncan MacKay (Natural England);
- Chris Mainstone (Natural England);
- Keith Porter (Natural England);
- Michael Rebane (Natural England);
- Chris Reid (Natural England);
- Matthew Shepherd (Natural England);
- Ian Soane (International Centre for the Uplands, Cumbria)
- Judith Stuart (Peat Project Lead);

- Pat Thompson (RSPB); and
- David Withrington (Natural England).

Many more people have contributed to this report, mainly in the form of feedback on the draft reports. We are grateful to the following for their constructive comments on the science and policy aspects of the project:

- Ian Soane (International Centre for the Uplands, Cumbria);
- Paula Harrison (Environmental Change Institute, University of Oxford, PI of EC Rubicode project, www.rubicode.net);
- Steve Dangerfield (Environmental Consultant and Researcher at CEM).

Part 1: Introduction and Background

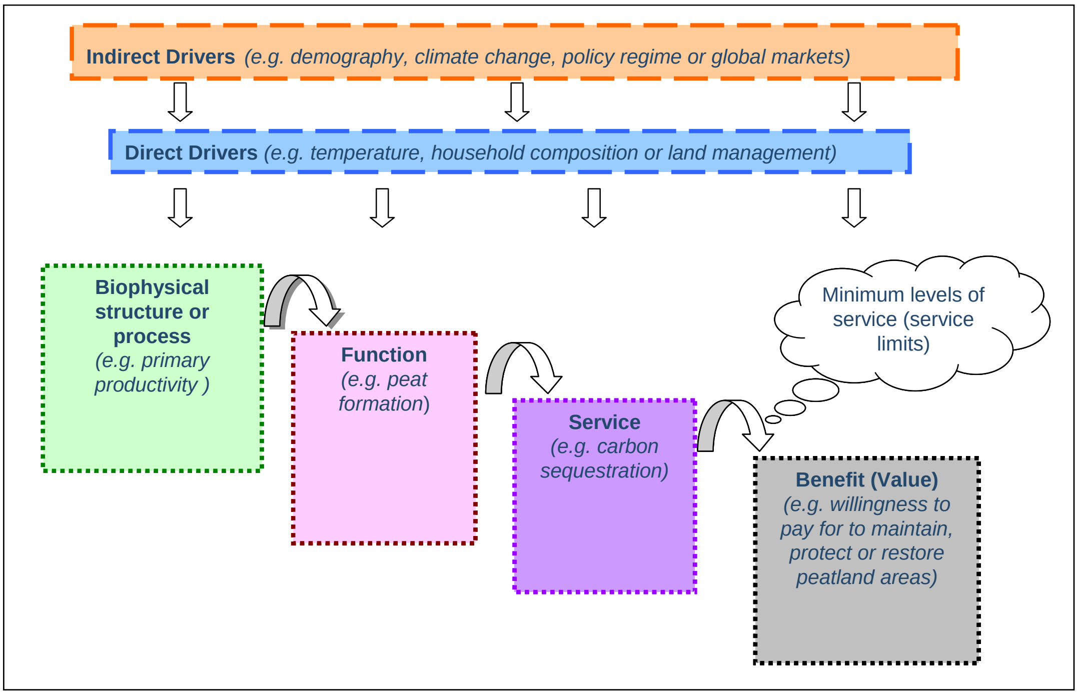
1.1 Study Aims

There is growing interest, in both science and policy communities, in the concept of ecosystem services and their links to human well-being. One of the key challenges is to better understand the way ecological and social systems are coupled, and how the various drivers of change may impact on the output of the benefits that these systems provide for people.

The aim of this study was to develop a set of conceptual, evidence-based 'system-maps' for the uplands of England, and to explore how they could be used to describe and better understand the geography of ecosystem services. The work contributes to Natural England's Upland Futures initiative, by helping people to better understand the importance of maintaining and restoring the functional integrity of ecosystems in the uplands, and the value that these areas have for society.

Figure 1.1 shows the framework in which this study was carried out. It attempts to describe the logic that underlies recent work in this area, such as that brought together in the Millennium Ecosystem Assessment (MA, 2005; see also Haines-Young and Potschin, 2008). The current 'ecosystem service' paradigm maintains that there is set of causal links or relationships between ecological structures and processes on the one hand and the benefits that people derive from ecosystems on the other, through various functions and services. For example, in the uplands, carbon that is taken up through primary productivity may, as a result of the ecological function we know as 'peat formation', deliver the service of carbon sequestration – which might have a benefit to society, say in terms of framing its response

Figure 1.1: The logic underlying the concept of ecosystem services (after Haines-Young at al., 2006)



to the problem of climate change. This benefit may be expressed in terms of some monetary value, represented by society's willingness to pay to protect or restore peatland areas.

The problem is that in the real world the links between the different elements shown in Figure 1.1 are complex, and so we need to find ways of unpacking them. The problem is particularly difficult because the links between these ecological and socio-**economic elements means that we have to connect up information across many different knowledge domains. Moreover, if such models are to be used to support decision making, it is also important that their structure relates clearly to the problems that policies and plans are trying to deal with.**

The aim of the first part of the study was, therefore, to expand the simple model shown in Figure 1.1, to create some real systems-maps for ecosystem services in the uplands, based on the best evidence available.

Given the short time span for the work the full range of ecosystem services associated with the uplands could not be considered. Instead a subset has been selected reflecting both immediate priorities and the different types of issue that need to be resolved to take such work forward. The choice was also dictated by the information available in the short time available to this project. The three service themes considered in detail, were:

- Carbon storage and sequestration - A Regulating Service;
- Recreation - A Cultural Service and,
- Renewable energy - A Provisioning Service.

For these services the aim was to prepare systems-maps and to attempt to operationalise them using an approach based on Bayesian Belief Networks. This methodology was selected as the basis for the study because it allows both rapid prototyping and provides a flexible framework in which different types of quantitative and qualitative evidence can be brought together to model the factors influencing service output. The study also looked at ways in which the 'geography' of these services can be represented; it was agreed that detailed mapping should be attempted for at least one of the services identified above.

Two further services were looked at in a more general way, namely:

- Water provisioning and,
- Flood prevention.

In each case the aim was to prepare conceptual systems-maps and assess the prospects for refining them to the same level of detail as the others in any later stage of Natural England's Uplands Futures project.

Initially is was planned to add a sixth service to the set of those considered, but it was noted that the conceptual maps for the other services had a number of direct and indirect drivers in common, many related to the structure and dynamics of the upland 'socio-economic system'. Thus the initial aims of the study were modified and a final element of the conceptual mapping exercise attempted to construct a systems-map to represent upland management and policy issues.

In order to support Natural England's future work on ecosystem services in the uplands, the final aim of this study was to develop a more general 'service typology' that describes the ways in which habitat quality, conservation status and biodiversity characteristics of a site relate to the output of selected ecosystem services, and to establish how such knowledge can be used for the spatial mapping of services and their valuation.

1.2 Background

The Millennium Ecosystem Assessment (MA, 2005) was the first comprehensive global assessment of the consequences of ecosystem change for human well-being. It found that around 60% of the ecosystem services evaluated were currently being degraded or used unsustainably. It was argued that such a situation has major implications for development, poverty alleviation, and the strategies needed by societies to cope with, and adapt to, long-term environmental change.

The significant contribution that the MA has made globally has been acknowledged by the House of Commons Environmental Audit Committee (2007), who reviewed its relevance in the UK context. They noted the slow uptake of the implications of the MA in the UK, and recommended that 'ultimately the Government should conduct a full MA-type assessment for the UK to enable the identification and development of effective policy responses to ecosystem service degradation' (para. 125).

Although Defra are currently examining the case for an 'England MA', they have commissioned a number of other studies, which have looked at issues surrounding the assessment of the state and trends of the services associated with England's major terrestrial ecosystems, and how they might be valued. In a recently completed report for Defra1, for example, it was shown that of the 19 terrestrial Biodiversity Action Plan Broad Habitats considered (not including urban):

- There was evidence that nine may be experiencing changes that could impact on service provision, particularly in the area of genetic resources; the evidence was strongest for Acid Grassland, Bog, and Calcareous Grassland.
- One, Broad Habitat, namely Broadleaved, Mixed and Yew, showed evidence of change that was possibly enhancing services, particularly for recreation and landscape.

Although such evaluation exercises are important, if thinking about ecosystem services is to be taken forward, then other studies that examine the ecological mechanisms that underpin them are required. The Uplands[2] are a useful arena in which this might be done, because they represent a suite of ecosystems whose structure is relatively well understood, and in which the links between biodiversity, ecosystem services and well-being is apparent. English Uplands are also significant because they contain a large proportion of the country's semi-natural habitats. They provide vital water catchments and wildlife habitats while at the same time some of the most valuable and popular areas for recreation. The majority of England's protected landscape areas (National Parks and AONBs) include upland areas.

If appropriate policies and management strategies are to be developed for the uplands, then we need access both to monitoring data and models that can allow decision makers to explore the consequences of different policy and management options. Unfortunately, in the context of ecosystem services, the evidence base upon which policy advisors depend

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[1] Haines-Young, R.H. and Potschin, M.P. (2008), see also www.ecosystemservices.org.uk

[2] Which we take to be defined by the *Severely Disadvantaged Area Boundary*

tends to be fragmented, incomplete and diverse in character. The diversity of information is a particular problem. It means that any modelling approaches have to resolve the difficulties of combining both quantitative and qualitative information, empirical data and expert judgement in ways that are open and transparent. In this study we examine the extent to which Bayesian Belief Networks offer the basis for developing such an approach.

1.3 Structure of the Report

In order to show how the three aims set out above were achieved, this Report describes the general approach adopted by the Project Team for the design of the conceptual maps of ecosystem services (Part 2).

Parts 3 through 6describe in more detail what has been achieved in relation to each of the topic areas. Each part presents one or more systems-maps for the topic, together with information about what aspects of the service can be mapped spatially. Each Part concludes by considering how the conceptual and spatial mapping might be developed further. Part 7 attempts to consider the extent to which all the models are linked through some common set of direct and indirect drivers.

Part 8 presents a service typology that can be used to consider services in the uplands more generally, and suggests that it might be useful to distinguish between service types that have a stronger or lesser link to biodiversity and ecological structures. In Part 9 we review the mapping issues for ecosystem services in more general terms, and seek to identify important data availability and gaps.

The report concludes with our recommendations on how this type of work might be carried forward, and how it might contribute to the broad aim of developing a future vision for the uplands of England.

Part 2: Developing conceptual systems maps

2.1 Introduction

There have been some recent attempts to use 'systems-mapping' approaches in the context of the uplands of England. For example, Holden et al. (2007) have provided a review of the ways in which moorland responds to the various drivers of change, which drew upon both current scientific evidence and information gained from stakeholders about the most important factors that they thought were likely to change the uplands. Prell et al. (2007) have also recently described the outcomes of some of this work with stakeholders, which resulted, amongst other outputs, in a conceptual map describing the socio-economic and biophysical factors related to burning management in moorland areas (Figure 2.1).

Conceptual mapping of the kind illustrated in Figure 2.1, particularly where it involves stakeholder participation, can be a lengthy undertaking. The exercise that Prell et al. (2007) describe extended, for example, over two years. The time available for this project was more tightly constrained (3 months), and was set up more as a scoping or exploratory study. The focus of the initial phase of this work was to better understand Natural England's requirements in relation to modelling ecosystem services, and in particular the level of thematic detail that is needed to inform decision making in this area, and support the later stages of Natural England's *Upland Futures* initiative.

The work involved developing an initial set of conceptual maps and using them as the basis for discussion both with a 'Project Steering Group' and a workshop involving a much wider range of people from Natural England, Defra and RSPB. In both cases, the aim of the discussion was to gain feedback from NE staff on the level of detail required in the maps and the way these maps might service long-term needs. Attention was also given to understanding the extent to which such conceptual models might be used to explore trends in service supply in future scenarios studies, and what uncertainties might be involved in undertaking such exercises.

In Section 2.2 we describe the approach used to construct the conceptual systems diagrams, and the how they could be made 'operational' given the evidence potentially available.

2.2 Building a systems-maps

2.2.1 Background

As noted in the Introduction to this Report, at the outset it was proposed that the conceptual mapping would be attempted using Bayesian Belief Networks (BBN). Their structure and use is best illustrated by way of a simple example. Since it was agreed that the problem of understanding the factors that control carbon storage and sequestration in upland ecosystems would be one of the main concerns of this study, we use this topic to describe the BBN methodology.

Cain (2001) defines a Bayesian Network as a ‘graphical tool for building decision support systems to help make decisions under uncertain conditions’. The key phrase to focus on in this definition is ‘uncertain conditions’. As Cain points out, BBNs were originally developed to allow the impact of uncertainty about management systems to be accounted for so that decision makers could balance the desirability of an outcome.

Figure 2.1: Conceptual model of socio-economic and biophysical processes related to burning management (after Prell et al., 2007)

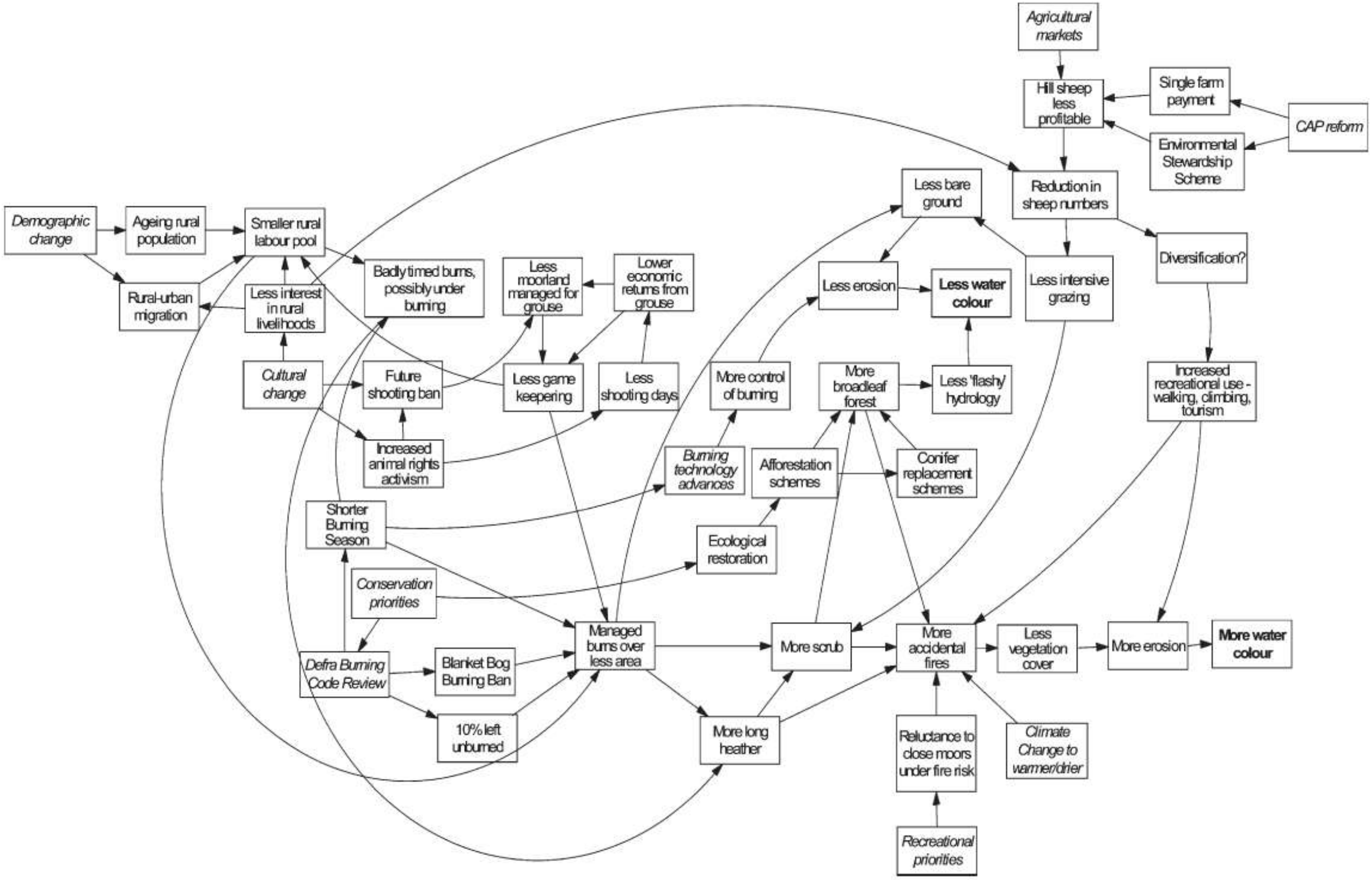
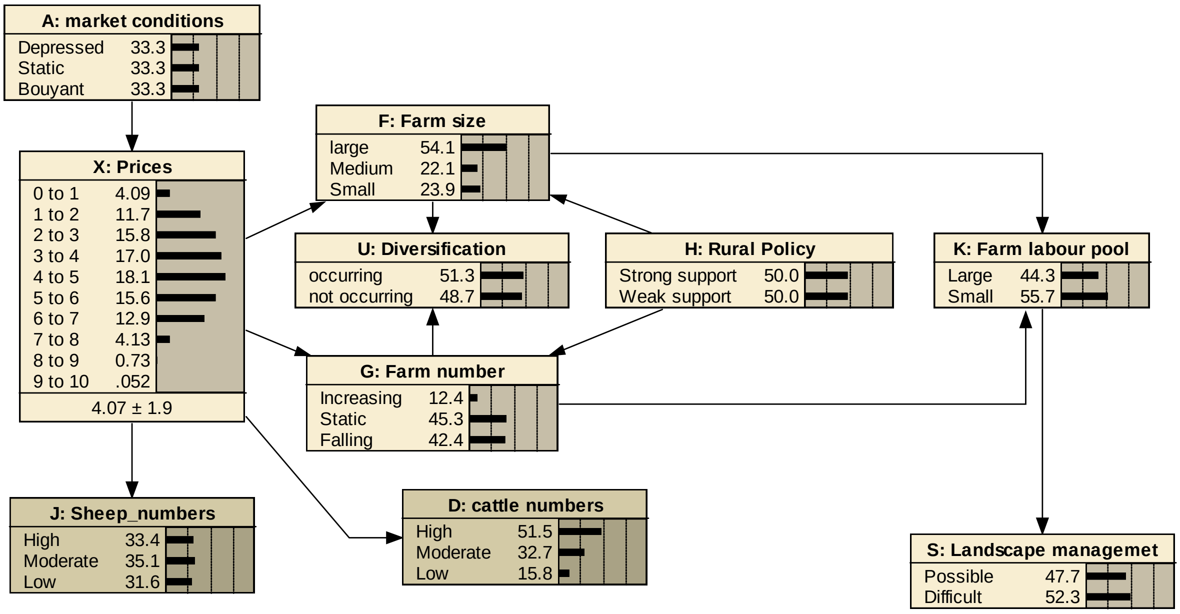


Figure 2.2: Example BBN for drivers of upland land management



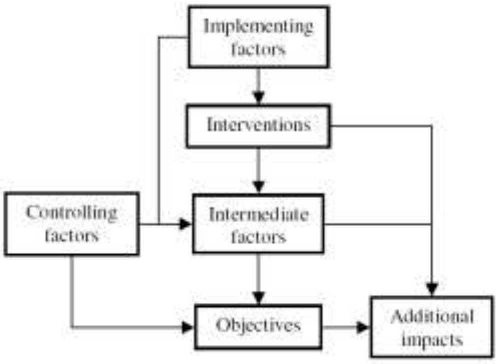
against the chance that the management option selected might fail. The representation of a system in terms of a set of relationships that have probabilities associated with them is at the heart of the Bayesian approach.

By way of example, Figure 2.2 shows the BBN developed as a 'first attempt' to represent some of the factors influencing land management decisions in the uplands. The network consists of a set of **nodes** representing the key variables in the system, and a set of directional **relationships** (represented by the arrows). Each of the nodes can assume a number of different **states**, represented most conveniently as a set of categories, although the representation of continuous variables is also possible using such networks. The relationships describe how the system variables affect each other.

Thus in Figure 2.2, Nodes F, U and G shows three aspects of farm structure, which each can assume different states. The average farm size of holdings in an area of interest can be large, medium or small, or the general nature of the enterprises may show evidence of diversification or not. The probability that a node is in a particular state, given the pattern of other nodes that affect it, is shown both numerically and as a bar-chart. In a BBN, connecting arrows represent the relationships between nodes; these set up the cause-effect linkages in the system. When the network is activated, the probabilities propagate through the system, so that the most likely configuration, given what is known about the states of the various nodes, is calculated. This is illustrated in the relationship between the node for market conditions and prices. Depending on the state of the market Node X shows the probability distribution of possible prices. In this example network the units are arbitrary, but the network could be set up to reflect real market prices for, say, livestock.

In any kind of network there are different kinds of node (Figure 2.3). Those which do not have any inputs are called **controlling factors**. In Figure 2.2 these would be nodes for market conditions and rural policy (Nodes A and H). The way market conditions affect prices has already been explained.

Figure 2.3: Types of Node in a BN (after Cain, 2001)



In Figure 2.2, farm size and farm number are intermediate factors in the network. They are distinguished by the fact that they have both inputs (parent nodes) and outputs (child nodes linked to them). The interactions between them determine the way outputs, such as sheep and cattle numbers (Nodes J and D) change.

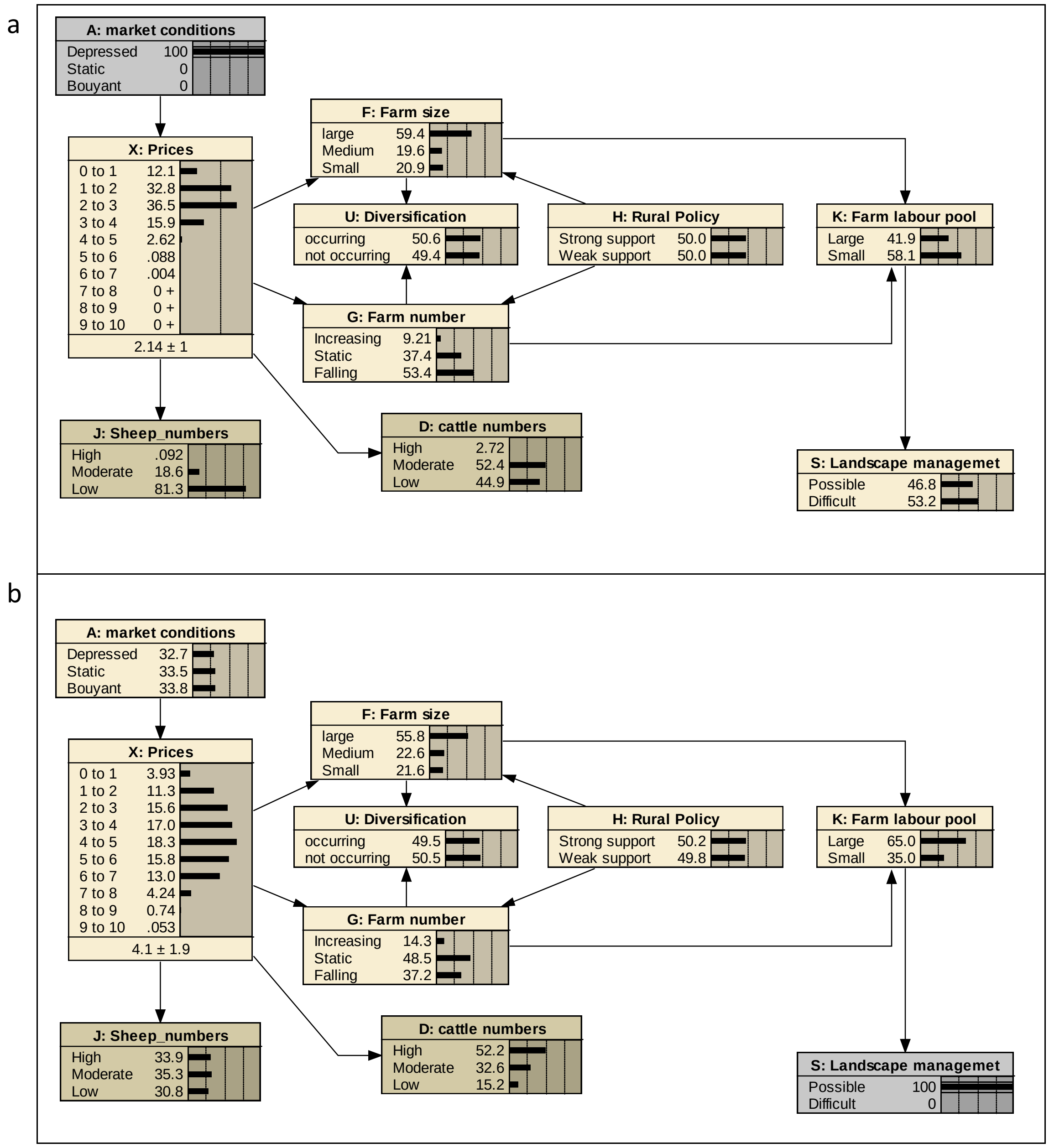
Livestock numbers and the general ease with which landscape management activities can be undertaken (Node S), given the size of the rural labour pool (Node K) represents the **objective** of the system – in that the network aims to help explore the factors that control their dynamics. Nodes that represent objectives often only have parent nodes, although as Figure 2.4 illustrates, the consequences of whether certain objectives are achieved can also be included through nodes representing ‘additional impacts’. In order to keep Figure 2.2 as simple as possible, no additional impacts were included, although potentially the consequences of a decline in animal numbers on biodiversity, say, could be added.

Not all the general types of node shown in Figure 2.3 have to be present in every BBN – networks have to be tailored to meet the needs of the problem in hand. Nevertheless, this general structure is relevant, because it shows how the logic underpinning the ‘ecosystem services’ paradigm’ can potentially be implemented through such networks. The biological structures and functions shown in Figure 1.1 are the intermediate factors in the network, and service is the output or ‘final product’, the change in which can be valued potentially in monetary terms.

Figure 2.4, illustrates how the BBN can be used to explore the way different variables in the system can influence each other. Thus to explore the consequences of a depressed market conditions change, we can switch the state of Node A to one of certainty – i.e. the market *is* depressed, and trace through the consequences for the other elements of the model. In Figure 2.4a, the spread of prices is now lower and narrower, and there is a greater chance that farm sizes will be large while farm number is falling (i.e. there is consolidation of farm enterprises). As a consequence, the effect of the size of the labour pool on landscape management activities is likely to make them more difficult.

By contrast, Figure 2.4b shows how the network can be used to ‘backcast’ the effects of particular policy or management goals. Suppose we desire to achieve conditions under which landscape management is most likely to be possible. By setting this outcome to 100%, we see that (fortunately) only a small increase in market prices might be needed to secure a sufficient labour force.

Figure 2.4: Illustration of using BN to explore change scenarios

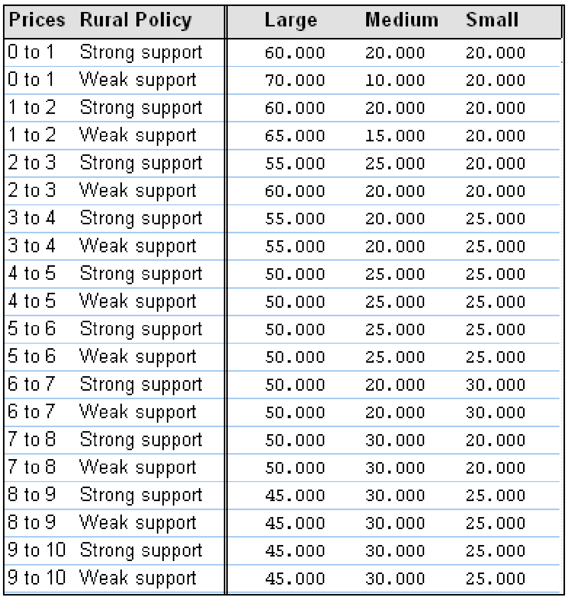


2.2.2 Designing and Calibrating Bayesian Networks

There are two major steps in designing and calibrating a BBN. The first is to ensure that the network structure captures all the variables and relationships that need to be considered in order to address the problem in hand – in the example above, an understanding the drivers of upland land management. **This building process clearly depends on current understandings of how 'ecosystems work' and an insight into the level of detail that users need represented in the system.**

During the study in order to take this work forward we prepared a questionnaire for users/experts associated with the Upland Futures project, to help identify the appropriate level of thematic resolution that we should be aiming for in constructing a BBN for carbon sequestration. The results are summarised in a separate document available from the project manager or Natural England's Project Officer. This exercise helped us to refine the initial draft maps such as those shown in Figure 2.2, and so create a framework in which the underlying evidence base could be examined in detail, and the 'calibration' of the network attempted.

Figure 2.5: Conditional Probability Table for the node for 'farm size' (see Fig 2.2 and 2.4)



Prices	Rural Policy	Large	Medium	Small
0 to 1	Strong support	60.000	20.000	20.000
0 to 1	Weak support	70.000	10.000	20.000
1 to 2	Strong support	60.000	20.000	20.000
1 to 2	Weak support	65.000	15.000	20.000
2 to 3	Strong support	55.000	25.000	20.000
2 to 3	Weak support	60.000	20.000	20.000
3 to 4	Strong support	55.000	20.000	25.000
3 to 4	Weak support	55.000	20.000	25.000
4 to 5	Strong support	50.000	25.000	25.000
4 to 5	Weak support	50.000	25.000	25.000
5 to 6	Strong support	50.000	25.000	25.000
5 to 6	Weak support	50.000	25.000	25.000
6 to 7	Strong support	50.000	20.000	30.000
6 to 7	Weak support	50.000	20.000	30.000
7 to 8	Strong support	50.000	30.000	20.000
7 to 8	Weak support	50.000	30.000	20.000
8 to 9	Strong support	45.000	30.000	25.000
8 to 9	Weak support	45.000	30.000	25.000
9 to 10	Strong support	45.000	30.000	25.000
9 to 10	Weak support	45.000	30.000	25.000

Calibration of the network involves assigning the probabilities that control the way the network operates. In a BBN, underlying ***each*** node is a 'conditional probability table' (CPT). By way of illustration, the CPT underlying the node for 'farm size' and the way it is controlled by prices and the level of rural support is shown in Figure 2.5. To complete the CPT, we need data that describes how each node is linked to its parents, and therefore how it changes as the input states vary. Cain (2001) suggests that four types of information can be used to complete this task, namely:

Information Type 1: Raw data provided by measurement (e.g. soil carbon content, bird population numbers, market prices or levels of agri-environmental payment).

Information Type 2: Raw data collected through stakeholder consultation and interview (e.g. people's understanding of pollution risk, likely responses to changes in market conditions, management goals)

Information Type 3: Output from process-based empirical models (e.g. an estimate of erosion levels, flood discharge, grazing pressure).

Information Type 4: Expert opinion, based on theoretical insights, judgements or past experience (e.g. how changes in levels of rural support will impact on farming communities)

Cain (2001) argues that we should always use Type 1 in preference to Type 3, and Type 2 in preference to Type 4. However, in many real world applications, those constructing networks may have to use a mixture of types, and in any case, judgements about what types of data are appropriate are mainly determined by the specific questions that need to be answered. The example CPT shown in Figure 2.5 has been constructed simply on the basis of “expert” judgement.

Although knowledge about availability of information will clearly shape the construction of any network, it is not possible to begin the process of developing the probability tables that underlie it until the basic structure of the network has been worked out. This is best done in an iterative way because of the complexity and open-ended nature of the problems that surround the modelling of ecosystem services. Formally ‘systems’ are integrated entities which function due to processes which integrate their components. However ecological, economic and social systems frequently lack such clear identity, and it is not easy to see where boundaries of such systems lie. For example, if an upland is seen as system from a combined ecological, social and economic perspective, to what degree are not only the heather plants and sheep which graze them, but also the farmer, and in turn his or her family and customers and government decisions about levels of subsidy also part of it? How does the upland system relate to the local village community - if at all?

In practice the systems which support ecosystem services do not have clearly defined boundaries; they are influenced directly and indirectly by a range of factors as diverse as vegetation productivity, climate, markets for food and fibre, and public policy. The practice of systems analysis, in its many forms, rests heavily upon the practitioners’ ability to define systems in a way which is meaningful to specific problems or situations; the systems are human constructs not natural entities. This study explores the application of systems analysis to ecosystems services using Bayesian Belief Networks, and their ability to link knowledge about the dynamics of ecological, social and economic elements. It needs to be recognised, therefore, that one of the key areas where specific analyses can be improved is in: (i) clarifying the purpose of the analysis, and (ii) redesigning the system to add components which are critical to its functioning, or remove ones which have a negligible role in system function.

Table 2.1 sets out the key steps that were followed in an attempt to adopt this iterative or exploratory approach to building conceptual maps of the systems that describe ecosystem services associated with the uplands. The steps mapped onto the key elements of the work plan. Following an initial kick-off meeting with NE staff, draft system maps were prepared by the project team, using material derived from discussion and a preliminary literature review. On the basis of the initial feedback provided, the draft maps were circulated to a range of experts so that their structure could be refined and the data needed for the calibration identified.

The work programme outlined in Table 2.1 took place in parallel to other elements of the project, which included the development of a typology of upland services and a review of the extent to which the systems maps could be used to describe the geography of these services and the way they might change over time. However, given the short duration of the Project it was not possible to hold a second workshop to test and refine the networks. Thus those presented here are essentially in draft form.

Table 2.1: Building the ecosystem service BBNs in this study

Task	Project element and timing
Scoping problem	Initial kick-off meeting
Establish contacts with stakeholders	
Initial stakeholder group consultations	Interim Report & Workshop
Construct preliminary BBNs	
Consultation with expert panel	Briefing papers for NE and external experts
Refine structure of BN	Collect data and specify CPTs
Hold an expert/stakeholder workshop to discuss networks	Workshop to test initial nets
Construct 'master' BBN diagrams	Final outputs

Part 3: Carbon Storage and Sequestration

3.1 Introduction

The carbon stores represented by different ecosystems in the uplands are an important asset for the UK in relation to climate regulation. It has been estimated, for example, that peatland ecosystems represent the single largest carbon reserve in the UK[3]. Moreover, the ability of upland ecosystems to sequester and store carbon is highly sensitive to land management decisions as well as long-term climate change. Any future strategy for the uplands in England that takes account of ecosystem services would clearly have to consider how interventions might impact on the ability of these systems to store and sequester carbon.

Thus the aim of this part of the study is to examine the extent to which a conceptual map for this ecosystem service can be built using a Bayesian Belief Network (BBN). The motivation is to examine these tools both as a way of representing what is known about the processes that underpin the generation of this service, and to explore the extent to which these conceptual models can be used as a framework for looking at the consequences of different future scenarios. The exercise will also enable us to examine the potential relationships between conceptual and spatial mapping approaches and the benefits of linking them in a decision-making context.

3.2 Scoping the Modelling Exercise

Carbon storage and sequestration was chosen as a focus for this study because of its intrinsic importance as an “ecosystem service” and because the ecological processes that underpin it are well researched. Thus it was thought that there was some prospect of developing a conceptual map that both captured and quantified some of the key cause-effect relationships, and that the outputs might help inform current policy debates. The task of developing such a conceptual map has nevertheless been complex, and it is important at the outset to consider the rationale behind some of the key decisions that shaped the exercise.

Important issues that must be resolved when developing any conceptual map concern the level of *spatial* and *thematic* detail that is to be captured. The modelling of carbon budgets can be undertaken both at the local and global scales, and can be focused at the level of individual vegetation or habitat types through to the complete set of land covers that can be found in an area. Our consultations with NE staff and workshop participants[4] suggested that a fairly broad scale approach was required, covering all the main land use components

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[3] Moors for the Future Research Note No 12

[4] A workshop with the purpose of discussing initial draft systems-maps was held with NE experts and non-NE experts in the London EN office on March 4th, 2008. The outcomes of this workshop are collated in a separate file which can be obtained from the project manager or the NE Uplands Project Officer.

in the uplands. Nevertheless, as the diversity of responses indicated, there was also a tension between the need for a model that mainly described general relationships found within the uplands, and one that was capable of giving quantitative measures of the consequences of particular types of actions in particular geographical contexts, especially in relation to the peat resource.

For example, many of those consulted felt that for the conceptual map to be useful then it ought to include reference to the potential impact of climate change on upland carbon budgets generally. This is a particularly important issue, because it is possible that some terrestrial carbon sinks are vulnerable to warming and so could become major net carbon sources thus amplifying effects of warning (Stern, 2006). Other indirect drivers identified for possible inclusion in the conceptual model, by those we consulted, included the effects of changes in agri-environmental policies and agricultural markets on upland land management.

By contrast, alongside these indirect or more exogenous drivers, workshop feedback also suggested that the conceptual map should try to take account of more specific and localised, direct influences on carbon budgets. These factors included the effects of land management practices, including grazing regimes, burning, land drainage, as well as interventions through such processes as afforestation or habitat restoration.

Thus in terms of the kinds of structural process that people felt should be included in the conceptual model, the feedback suggested that the model should be wide-ranging and attempt to deal with pressures over a range of spatial and temporal scales. There was interest in understanding the relationships between the major carbon stores in the upland, and the influences upon them, and the extent to which upland ecosystems are presently taking up (sequestering) or emitting carbon and how these balances are likely to change under future climate and land management scenarios. As a result, it was decided that the model should attempt to deal explicitly with both the structure and composition of the various *carbon stores* that are found in the uplands, and what is known about soil and vegetation *carbon budgets.*

Despite the widespread interest in ecosystem services, there is often a lack of precision about what particular function or capacity of an ecosystem actually represents the service. Thus issues related to carbon storage and uptake are often lumped together as part of the service of ‘climate regulation’, with very little attempt to describe exactly what such ‘regulation’ actually involves - since it potentially includes much more than the carbon balance. If ecosystem services are to be properly assessed then they must be quantifiable and measurable. Moreover, if that service is to be valued, then in some sense it must represent a ‘final product’ of the particular ecosystem concerned, to avoid the problem of double counting.

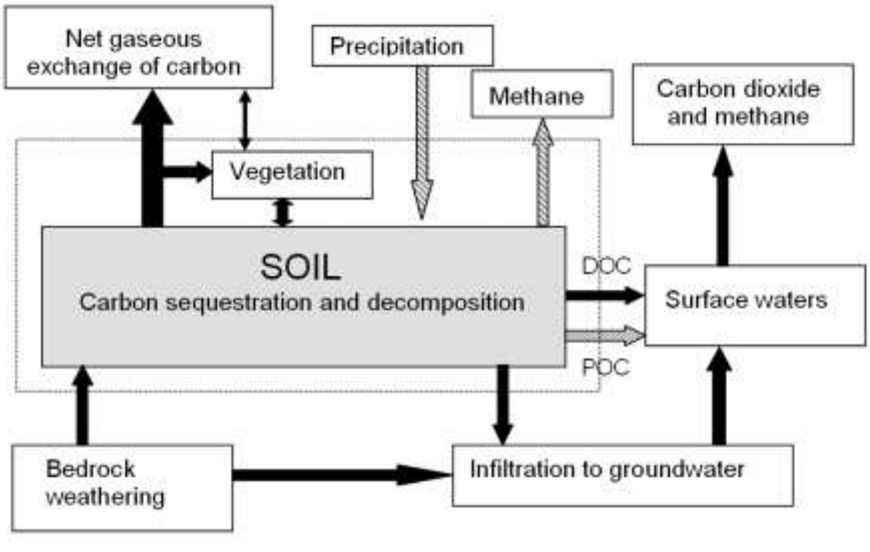
An important aim of the preliminary discussions with NE and workshop participants was to identify precisely how the particular services associated with the uplands were to be framed or defined. The conclusions drawn in relation to the carbon issue proved particularly interesting, and they illustrate more deeply what the notion of an ecosystem service actually represents.

Thus the ‘standing crop’ of carbon in the vegetation and soils of the uplands is more of an asset than a service, if we follow the definition of a service used in the Millennium

Ecosystem Assessment (MA, 2005). A carbon store is not a service because no 'final product' arises directly from its existence. Instead, carbon sinks are best regarded as part of the ecological infrastructure that supports other kinds of service. On the other hand, it is easier to think of carbon sequestration, or the ability of upland ecosystems to take up carbon from the atmosphere, as a service since this process has identifiable benefits associated with it. In the context of developing strategies for dealing with climate change, for example, the ability of peatland systems to continue to remove CO_2 from the atmosphere and retain it within a carbon sink has a direct *monetary* value given the shadow price society has assigned carbon dioxide.

Interestingly, in the context of the present exercise, while carbon sequestration is indeed a service, it is probably not a 'final product', in that it does not capture all that we need to know in understanding the role of upland ecosystems in overall carbon budgets. If the value of the asset, represented by the various carbon sinks that we find in the uplands, are to be retained, then it is the overall balance between sequestration and loss of carbon back to the atmosphere that is the key parameter that needs to be assessed. Thus the service that is the 'final product' is the net carbon flux; that is the part of the carbon cycle shown in Figure 3.1 within the dotted line. Just as there is a benefit that flows from peatland systems by its ability to sequester carbon, so there is, for example, a dis-benefit to society if it is released. As Holden et al. (2007) notes, the peatland areas of England and Wales store an amount of carbon roughly equivalent to the emissions of UK greenhouse gases for three years. There is thus clearly a benefit, in terms of achieving current policy aims of reducing overall CO_2 emissions, of ensuring that overall peat loss through decomposition and erosion is minimised.

Figure 3.1: Simplified carbon flux pathways from soil and vegetation (after Orr et al. in press, and Worrall et al., 2003)



On the basis of our initial consultations it was, therefore, decided that for the purposes of this project, the conceptual model should describe the key influences upon the carbon budget of the uplands; the ecosystem service whose 'output' the model was to explain, was the balance between overall C uptake and loss.

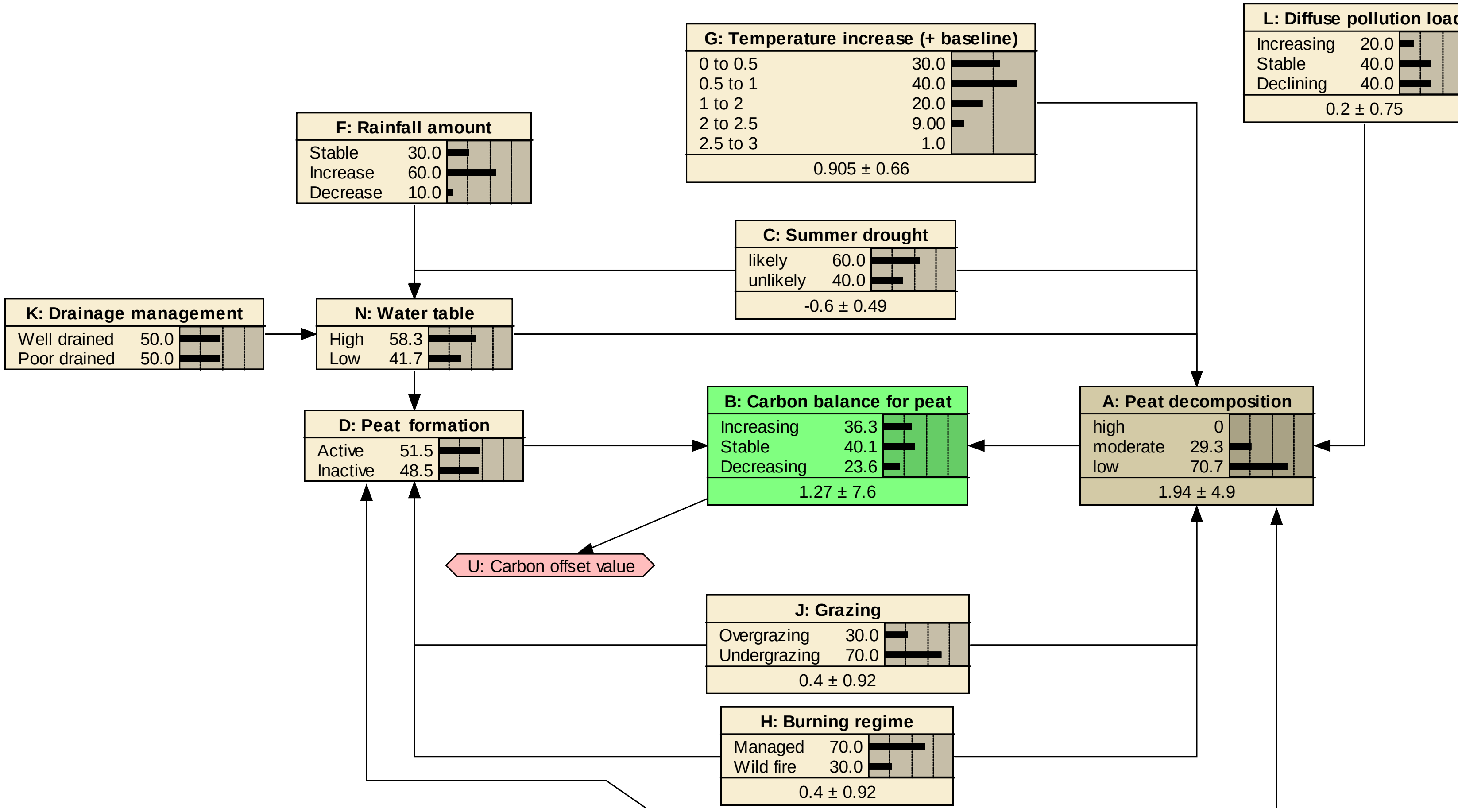
3.3 Developing a Bayesian Belief Network for Carbon

In order to develop a BBN for the carbon budget associated with upland landscapes, a number of prototypes were tried and discussed. Initial work focused on the particular case of peatland systems, which have been the focus of a number of recent reviews that are helpful in structuring a model (Holden, 2007; Orr, 2008).

Figure 3.2 shows the BBN that was developed as a 'first attempt' to represent the carbon budget of peat in the uplands in England. Node D shows the carbon store represented by peatland ecosystems, which can assume various states; the state of the balance between accumulation and loss represents the ecosystem service.

Within a BBN, the probability that the node is in any particular state is determined by the pattern of other nodes that affect it. When the network is activated, the probabilities propagate through the system, so that the most likely configuration given what is known about the states of the various nodes can be calculated.

Figure 3.2: BBN for carbon balance in peatland ecosystems



For example, suppose we wanted to understand if it is likely that the size of the carbon store represented by peat was increasing, stable or declining in a particular situation. If we assume that the size is set by the balance between the rate of peat accumulation and the rate of peat decomposition (and erosion), then depending upon the judgement we might make about the state of these two input variables we might determine the probability that the store was stable or not.

In order to make the BBN active, it has to be calibrated by setting up all the conditional probability tables that lie behind the different nodes in the model. For the model shown in Figure 3.2, this was done qualitatively using an understanding of the broad types of relationship and their relative strengths from the reviews of Worrall (2003) and Holden et al (2007). Figure 3.3 shows how the model can be used to explore, say, the consequences of climate change, by comparing present conditions (Figure 3.3a) with the conditions described by a future climate scenario (Figure 3.3b):

In Figure 3.3a, to represent present conditions, no temperature increase is assumed, rainfall is set to stable, diffuse pollution load is assigned to stable or declining, and summer drought is judged to be unlikely. This configuration suggests that while there are uncertainties in the system, it is more likely that the store is stable or increasing than declining. The system has been set up with a simple indicator to measure the relative change in the carbon store; a positive figure indicates net accumulation and a negative figure net loss. The system has been set up to show that under present conditions the most likely situation is that peat represents a small net sink for carbon (cf. Holden et al., 2007).

By contrast in Figure 3.3b the configuration of the system states has been modified to reflect the potential impacts of future climate change. Thus the probability of a future temperature increase of around 0.5°C to 1°C is set to around 0.4, an increase in rainfall amount and the occurrence of summer drought is assumed to be more likely than not, and the changes in the likelihood of uncontrolled burns is also assumed to have increased substantially. These changes result in the outcome that that the soil carbon store is now more likely to be stable or decreasing; in line with the general suggestion that under future climate change scenarios the strength of carbon stores such as peat are likely to weaken (Anon, 2007).

As a final illustration of what might be attempted using a BBN, we may use the model to determine the extent to which management might serve to mitigate against the effects of climate change. Figure 3.4 shows the same state for the climate nodes as Figure 3.3a, but by ensuring that water tables are kept high through drainage management, the intensity of grazing is low and burning is managed, the probability that the carbon balance is stable or increasing is much higher compared to the situation when these management factors are not present.

Figure 3.3a Illustration of using BNN to explore effect of climate change scenarios – base-line conditions

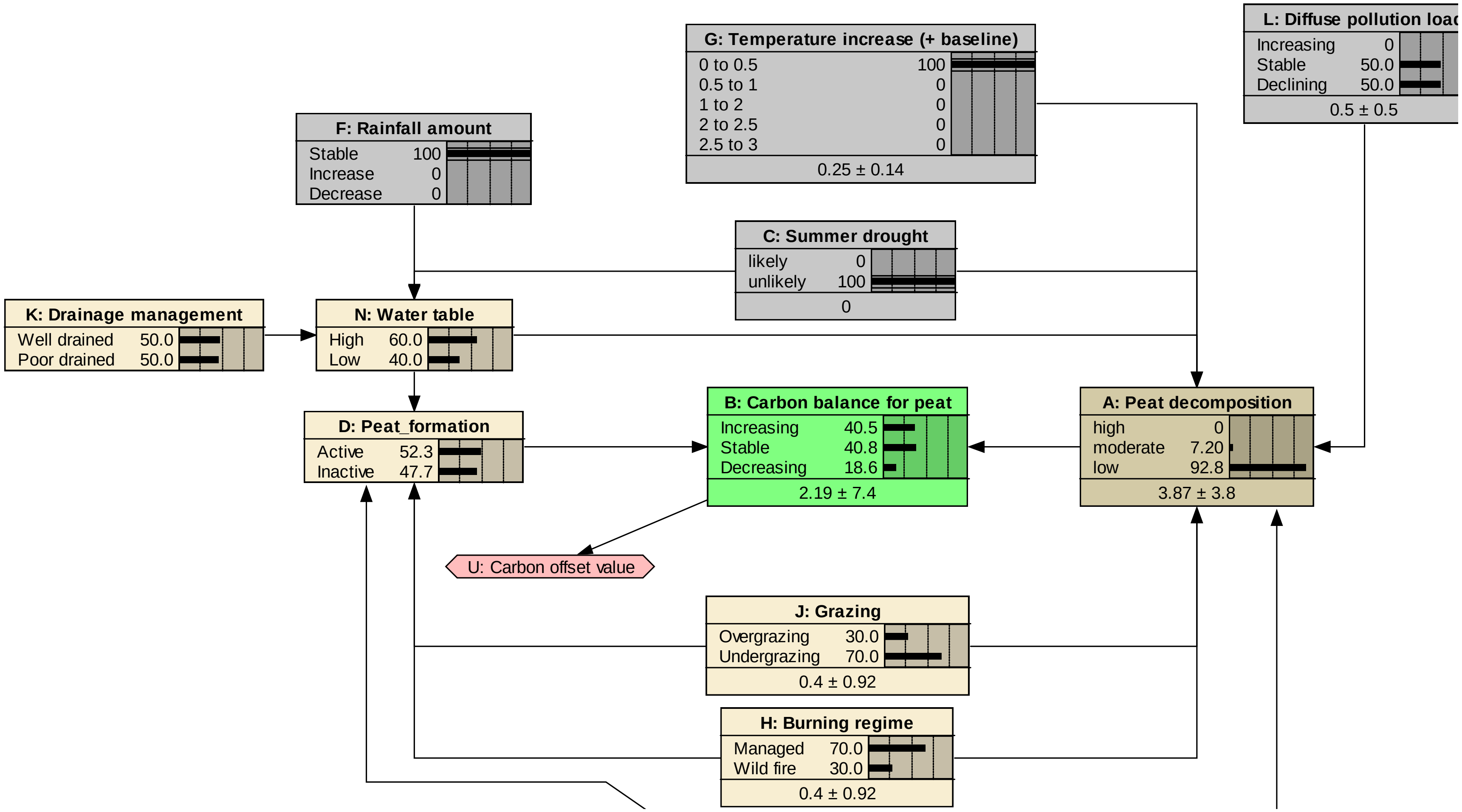


Figure 3.3b Illustration of using BNN to explore effect of climate change scenarios – increased temperatures and likelihood of summer drought

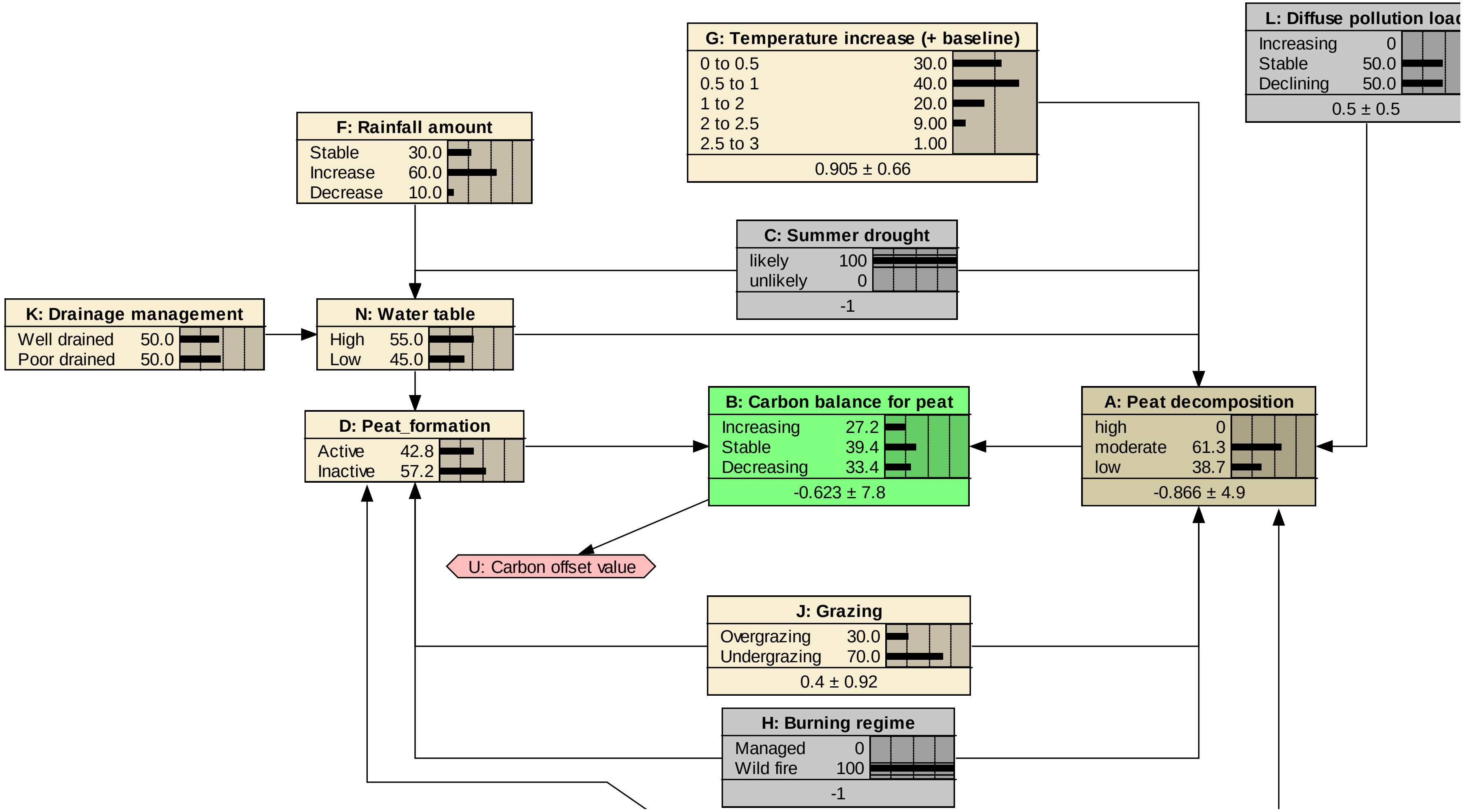
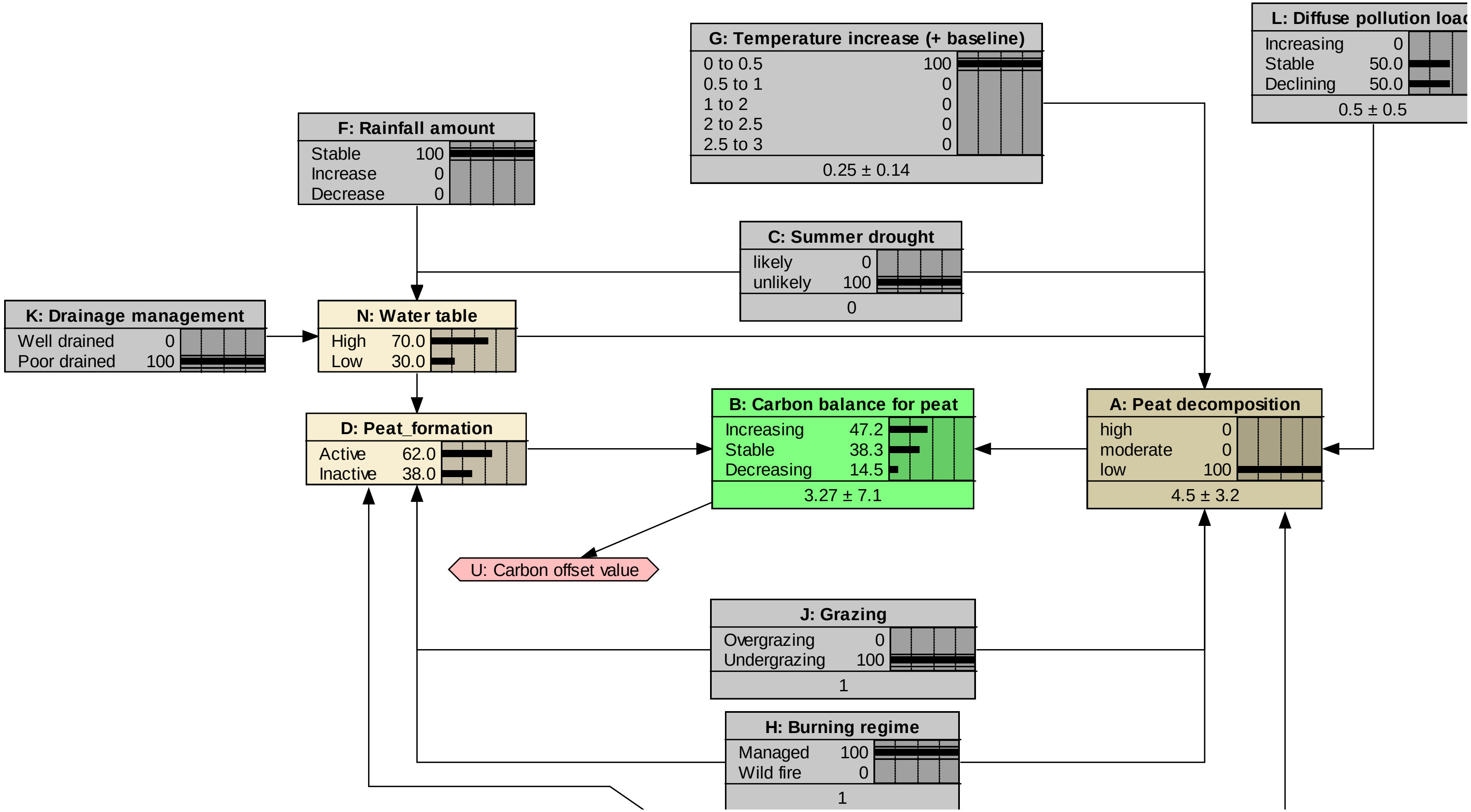


Figure 3.4 Illustration of using BNN to explore effect of mitigating measures (compare with Figure 3.3a)



3.4 Refining the Carbon Network

The simple network for the peatland carbon budget is useful in terms of the kinds of insights that BBN might have for 'conceptual mapping'. Not only is it capable of representing the important influences within a system, it can also operationalise knowledge so that the sorts of outcome implied by different combinations of input factors might be explored and compared. It is important to note, however, that like any model, BBN are by their very nature simplifications of reality. These networks also have a particular quality in that while they can be built using empirical data, they explicitly acknowledge that this may need to be supplemented by expert judgement and stakeholder opinion for them to be made fully operational. The networks should not be thought of as dynamic process-response models, but rather logical models that seek to represent or describe the relationships and associations that have been recognised or detected in a given situation. They are often best suited to situations where knowledge is only approximate and are often best thought of as a kind of 'diagnostic' tool or as an aid to building past and future scenarios.

However, although the network presented above is useful as the basis for discussion, it must be accepted that it is deficient in several respects:

In terms of the calibration, the assignment of probabilities was based on a limited review of the recent literature, and although the directions of the relationships were based on current understandings, the strengths assigned to them were fairly arbitrary. A simple scoring system was used to represent their relative weights. The network has been set up to show these scores, where they have been assigned, at the bottom of each node. , A comparison of Figures 3.2 through 3.4 illustrates how these scores change as the various combinations of input parameters is modified. For the network to be more than an illustrative tool, the weights and the way they impact on the assignment of probabilities would need to be undertaken more systematically and rigorously. Ideally they should be set up to correspond to real quantities.

The scope of the network presented above, in terms of the factors and relationships included within it, is also limited. Even for understanding and representing the factors controlling the carbon budget for peat ecosystems, the network is simplistic. It omits, for example, a number of other land management influences that many be significant in the 'real world'; thus restoration by reseeding eroded peat areas with heather may serve to reduce erosion rates and thus levels of peat loss. Given the aims of this project, the kinds of network required are probably more sophisticated than the one shown here. As indicated above, our preliminary consultations with NE staff and workshop participants suggested that a much wider range of upland issues affecting carbon budgets ought to be considered, beyond those affecting the peat resource.

Thus the development of the initial network was not continued. Instead, a more extensive review of the literature was made in an attempt to identify how the network could be made more comprehensive and where possible, better grounded on empirical data.

In recent years a range of work has been conducted on carbon storage in soils and vegetation, primarily in response to the UK's commitments under the Framework Convention on Climate Change. Estimates on the amount of carbon held in both soils and vegetation vary greatly, according to the assumptions made and methods employed. Bradley et al. (2005) recently estimated that the carbon stored in vegetation in Great Britain was roughly 114 Mt and in soils was 9,838 Mt – these figures suggest that vegetation contributes approximately 1.13% of the total. The proportion may be higher in England, as the figures are dominated by the large proportion of carbon held in Scottish peatlands. On a GB basis, the most important vegetation carbon stores are, in fact, the broadleaf woodlands in Southern England (Milne and Brown, 1997).

Estimates such as those of Bradley et al. (2005) demonstrate the scale and importance of soils as carbon stores. Within England the most important soils for carbon storage are stagnogleys (Milne and Brown, 1997) but these have a limited distribution in the uplands. Nevertheless, peatlands and in the upland context blanket peat, in relative terms provide a major carbon pool.

Studies such as those of Bradley et al. (2005) represent one of the most recent attempts to estimate the size and distribution of soil and vegetation carbon at national scales. An earlier effort was made by Howard et al. (1995), who produced an inventory of the organic carbon content of soils in Great Britain. It was based (in England and Wales) upon representative soil profiles and the National Soil Inventory combined with vegetation data based upon ITE Land Class and land cover groups. The land cover types were grouped into major categories and assigned to 1km squares and cross-tabulated with the organic carbon content of the major soil series. These data were then integrated with bulk density values to transpose carbon content as a percentage by dry weight to carbon weight per unit area; measured values were used where possible and regression models based upon soil characteristics where these were not available.

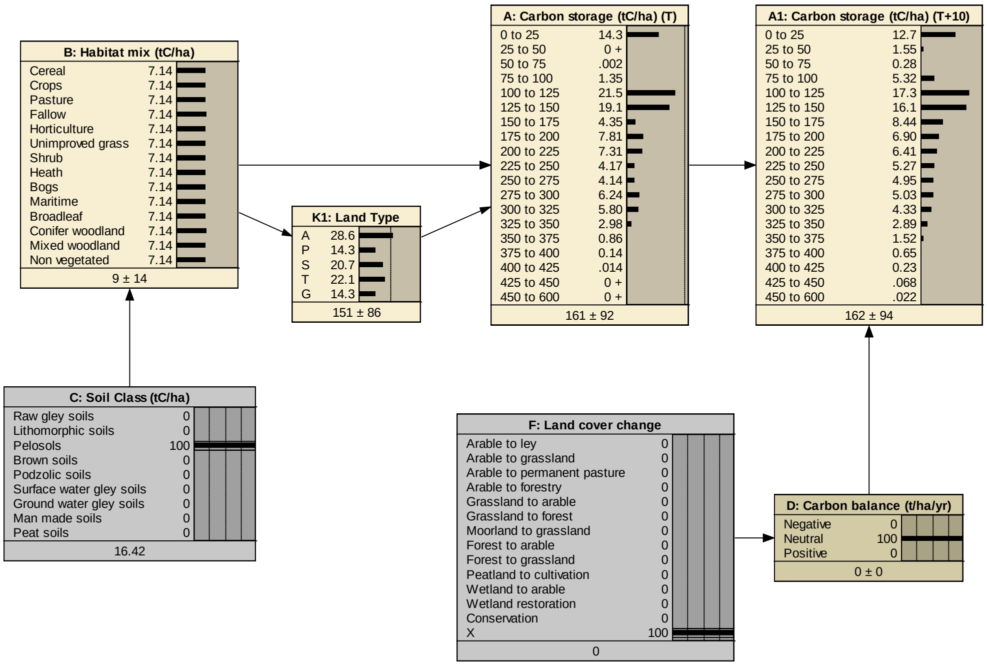
The estimates made by Howard et al. (1995) have, however, been criticised, and subsequently been re-visited by Milne and Brown (1997) and Smith et al. (2000a&b). Both sets of authors questioned the depth of the reference profiles and the figure used for the bulk density of peats (based on English Lowlands) and the discrimination of estimates based upon dominant vegetation cover in ITE Land Classes. Bradley et al. (2005) has gone on to refine estimates, based on the soil carbon and land use database to fulfil requirements under Article 3 of the Kyoto Protocol and for use in RothC – a dynamic simulation model of carbon fluxes (Falloon and Smith, 2003).

The spatial soil database constructed by Bradley et al. (2005) was derived from the 2001 revision of the 1:250,000 National Soil Map (Soil Survey Staff, 1983). This described and mapped 296 soil associations each of which comprised between 1 and 8 soil series characterised by soil and substrate properties. For the database, a 1km x 1km grid square map was developed which integrated the proportion of each soil association with the fraction of the soil series within it. The soil series were classified according to their percentage of soil organic carbon, clay silt and sand content, and bulk density within standard layers (0–30cm and 30–100cm – compatible with the reporting conventions under the United Nations Framework Convention on Climate Change (UNFCC). The depth of the soil profile to rock, or subsoil horizons, was calculated and four major land use types were also recorded: cultivated land, permanent managed grassland, semi-natural vegetation and woodland. The resultant database has been used to estimate soil carbon stocks, and so respond to UNFCC requirements, but as Bradley et al. (2005) suggest, it has the flexibility to meet other requirements.

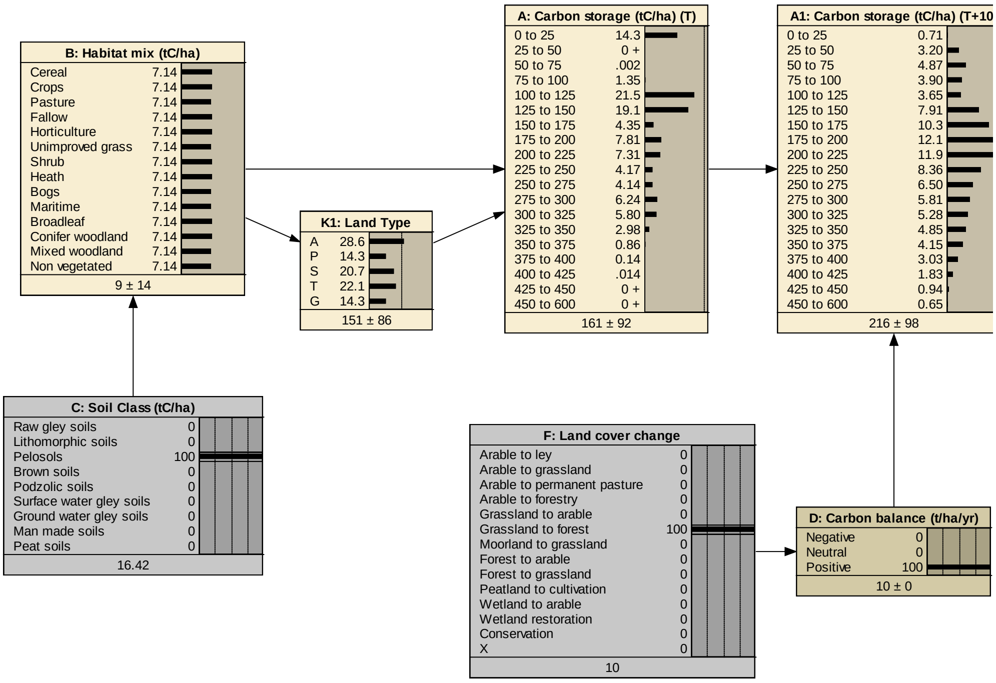
The data found in this series of studies described above which have attempted to estimate the size of the carbon pool for soils and vegetation at national scales, have been used as the starting point for the design of the second BBN for carbon developed in this study (Figure 3.5). In reviewing this revised network and the way it has been designed, it should be noted that it is not intended as some kind of ‘carbon calculator’ that provides estimates of the magnitude of the different carbon stores in different locations and the carbon fluxes associated with them. Rather the utility of the network depends more on the way it represents the general strengths of the different relationship and the relative changes they produce when different parts of the model are manipulated.

Figure 3.5 BBN for carbon sequestration based on data from national carbon budget modelling exercises

a. Base-line- nodes A and A1 show carbon storage at start and end of management period (~50 years)



b. Effects of afforestation on carbon pools after stabilisation (compare A and A1)



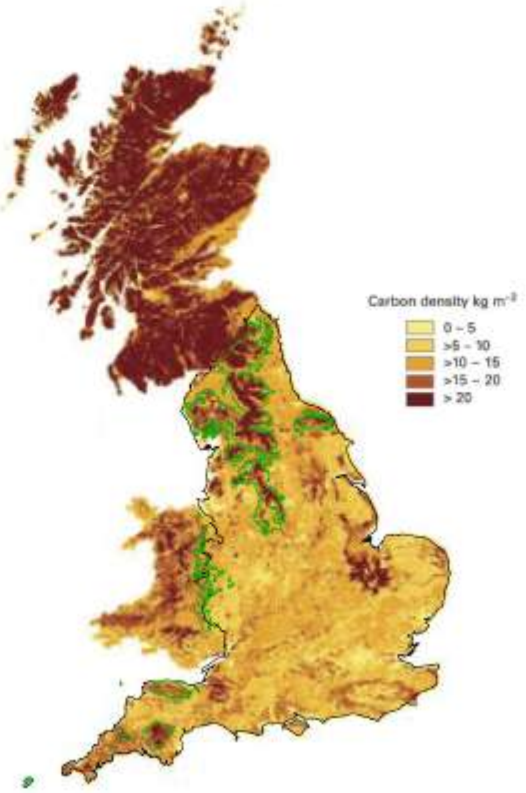
3.5 Spatial Mapping

A second key aim of this study was to examine how ecosystem services might be mapped spatially. This task was seen as being linked to the development of conceptual models, in that the intention was that the maps should, as far as possible, provide insights into the spatial patterns associated with the key nodes in the BNN that either represent the ecosystem service or the sorts of pressures upon it. A further requirement was that the mapping exercise should, wherever possible, draw upon existing data resources to help identify the strengths and weaknesses of the current evidence base.

3.5.1 Mapping Based on National Soil Carbon Map

A key element of the carbon model discussed above was the magnitude of the soil carbon store. While this is not, in itself the ‘service’, the soil carbon sink is nevertheless an important ecological asset and as such is important to map.

Figure 3.8: Soil carbon in 1km x 1km grid squares with upland (Severely Disadvantaged Areas). Source: Bradley et al. (2005)



Advantages:	Adopts standard methods and map already developed to meet other purposes. Interoperable with existing and further work. Should be available via Defra.
Disadvantages:	1 km square basis may be limiting for some applications. Peat depth only available to 1m. Only covers soils.

Figure 3.8 has been derived from the work that has been undertaken for Defra to help meet its obligations under UNFCCC agreements, and has recently been reported by Bradley et al. (2005). As noted above, the analysis resulted in a national estimate of soil carbon taking land use into account. We have taken the national soil carbon map and indicated the location of the uplands. These data show that with the exception of the Fens, the greatest concentrations of soil carbon in England are present in the uplands. Given the 1km x 1km resolution of these data it is clear that within the upland areas, a reasonably fine-scale picture of spatial variations in the resource could be built up.

The strengths and weaknesses of the national soil carbon map are summarised at the foot of Figure 3.8. Its major limitation is that it only covers soils and omits vegetation carbon stores, and the volumes of carbon calculated only relate to depths up to 1m. This depth restriction is the important one in terms of calculating the total amount of carbon stored, because some soils (especially peat) may be far deeper. These calculations are, however, sufficient in terms of potentially calculating carbon flux, and the map may nevertheless give a good indication of the relative differences in the size of the soil carbon store between different areas.

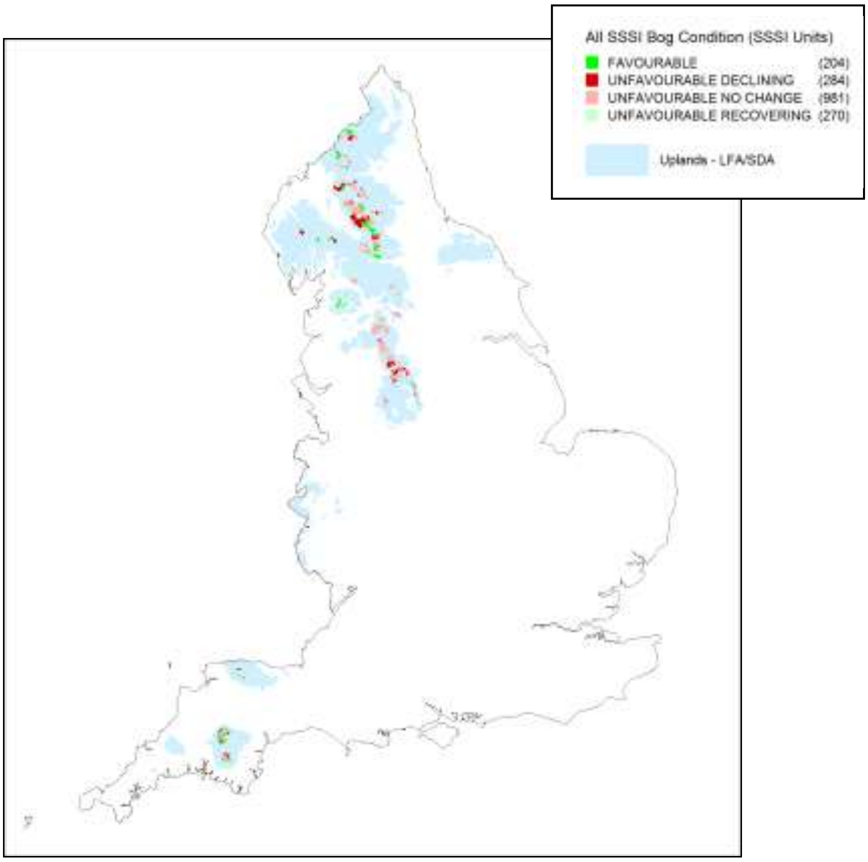
The fact that the vegetation component is not included in the estimates clearly means that the total carbon stock is underestimated. However, as has been widely reported (e.g. Milne and Brown, 1997), the amount of carbon stored above ground is only about 1% of that in the soil, and so the effect on the figure for total storage may be relatively minor. For those more interested in understanding the spatial variations in carbon sinks at more finer spatial scales the contribution that particular types of vegetation can make may be relevant but only comparatively generalised estimates of carbon density by vegetation type exist. However, accurate estimates of land cover are important both because they partly control the density of soil carbon, and because the analysis of transformations in land cover is essential for predicting how the carbon budget may be changing over time.

The study by Bradley et al. (2005) used a coarse breakdown of land cover types to estimate variations in soil carbon density across different soil types. Earlier studies that have sought to map both vegetation and soil carbon have used ITE Land Class-based estimates of land cover derived from Countryside Survey field survey, or Land Cover Map 1990. The Land Cover Map 2000 provides a potentially more accurate source of data than the earlier one, but as this is soon to be superseded by a yet more sophisticated map further possible development should perhaps wait for this to be published. In the meantime, Natural England's habitat inventories could be used to provide a more detailed representation of habitat distribution, but until more detailed carbon density data per vegetation type are available this is unlikely to improve the estimate. There is also the issue of land outside the inventories (i.e. non priority habitat) and how that should be classified. Again the Land Cover Map 2000 or its successor probably provides the only solution.

3.5.2 Mapping Bog/Peat Condition using the Blanket Bog Inventory and SSSI condition

This example uses existing Natural England data to demonstrate how proxy maps could be developed showing blanket bog condition as an indicator for peat condition, and provide information on carbon sequestration and storage trends.

Figure 3.9: Condition of combined blanket bog/bog SSSI units in upland areas.



Source: Natural England SSSI Site Condition Monitoring and Blanket Bog Inventory - dataset is derived from Ordnance Survey and Land Cover Map 2000 data.

Advantages:	Adopts existing standard methods – SSSI condition monitoring. Data already available.
Disadvantages:	Limited to SSSI framework which does not provide an equal geographic spread. Is only a proxy measure for carbon sequestration and storage status. Monitoring data collected over multi-annual time periods. To some extent an ‘end of pipe’ indicator – changes shown in these data indicate longer term and possibly entrenched problems.

The Blanket Bog Inventory provides the distribution of blanket bog. This dataset was intersected with SSSI condition data, which provide areas coded by habitat/feature type and condition. The two data sets had a high level of correspondence but also demonstrated differences in commission and omission – i.e. some SSSI units coded as blanket bog type were not shown in the inventory and not all blanket bog in the inventory is designated as SSSI. After comparison SSSI units with blanket bog habitat (E1 Mire Bog, E161 Mire Blanket Bog, E18 Mire Dry Modified and E11 Mire Blanket Bog) were selected and mapped according to their condition.

Figure 3.9 shows that the majority of the Upland SSSI bog resource is in Unfavourable Condition. The database provides reasons (primary and secondary) supporting the assessments; these are ranked in Table 3.1.

Table 3.1: Reasons provided for unfavourable Bog condition

Count (n)	Primary Reason
313	Overgrazing
294	Moor Burning
218	Lack of Ditch Management or Blocking
184	Air Pollution (NO/SO)
172	Drainage
21	Inappropriate CSS/ESA Prescription
21	Other
11	Forestry and Woodland Management
10	Agriculture Other
4	Inappropriate Stockfeeding

Count (n)	Secondary Reason
550	Overgrazing
115	Moor Burning
74	Other
28	Lack of Ditch Management or Blocking
20	Forestry and Woodland Management
8	Drainage
5	Lack of Scrub Control
4	Lack of Weed Control
3	Air Pollution (NO/SO)
2	Game Management

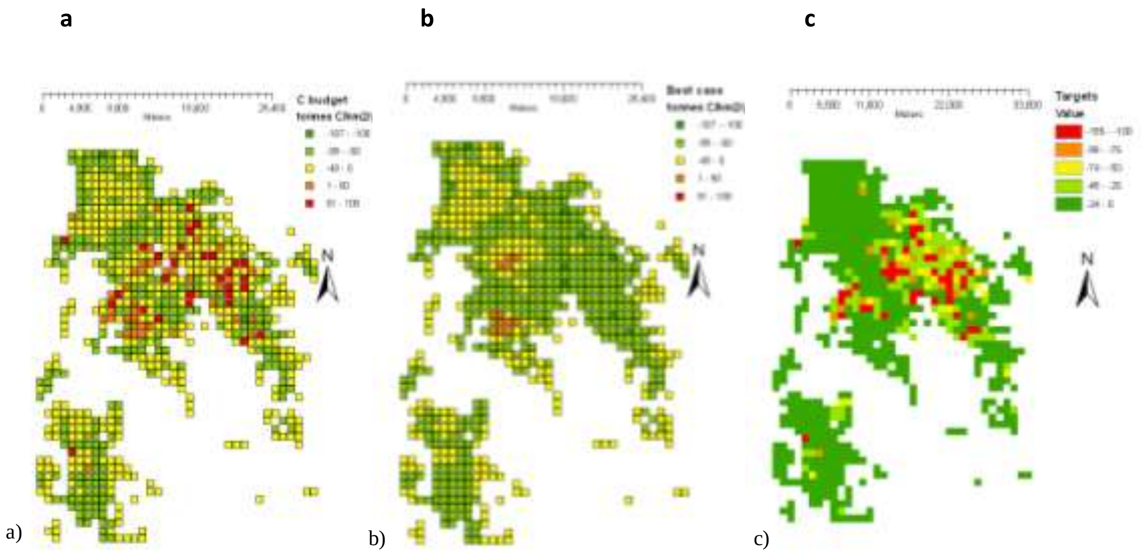
Overgrazing, burning and inappropriate ditch management dominate the reasons for unfavourable Bog condition. These management issues will impact upon the services provided by the habitat in an ecosystem services context and therefore require attention.

The blanket bog inventory was based upon different data sources but the primary components were Land Cover Map 2000, ENSIS records and different individual National Vegetation Classification (NVC) surveys. ‘Ground-truthing’ suggested that the inventory actually provided an underestimate of the resource, which may explain some of the discrepancy with SSSI data. The use of soils data may help improve the inventory and further alignment and integration with SSSI site units and their monitoring may be desirable in the future.

3.5.3 Mapping the impact of land cover change on soil and vegetation carbon budgets

Worrall (pers com – Appendix F[5]) reports that research is currently being undertaken to understand and map the spatial variations in carbon budgets for peat. This is being achieved both through empirical measurement of carbon fluxes and modelling exercises. The work is being undertaken at a variety of spatial scales, and for peat areas in different condition and under different management regimes. An example of the modelled output is given in Figure 3.10. Clearly once such approaches have been refined they could be used to calibrate the models presented here in a more robust way.

Figure 3.10: The modelled carbon budget for the Peak District. a) Carbon budget under current management 1997-2006; b) Carbon budget under ideal management 1997-2006; and c) The difference between maps a) and b) (after Worrall, 2008, pers com – see Appendix F).



The maps show carbon budget for 100m x 100m cells for an area of peat in the Peak District where peat is present

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[5] Appendices A-I are in a separate file and available from Project team or Natural England Project Officer.

3.6 Review conceptual and spatial mapping for Carbon Storage and Sequestration

Our study suggests that it is possible to build and calibrate a BBN that gives a broad indication of the impact of different land management strategies on soil and vegetation carbon budgets in the uplands. The models are, however, relatively coarse in nature, given the nature of the published data that are available which have been prepared mainly for estimating national carbon budgets.

In the next phase of the work there is a good potential of using the detailed Soil Carbon Database, to estimate soil carbon densities under different upland land cover types, by exploiting the new Land Cover 2007 map that will arise from Countryside Survey 2007. There is also the prospect of better estimates of the effects of different land management on carbon budgets for peat from on-going research.

Key messages from Part 3 are as follows:

- The state of the soil and vegetation carbon balance (i.e. whether it is positive or negative over time) has been used to represent the ecosystem service for ‘carbon storage and sequestration’.
- While peat is an important component of the carbon budget of the uplands, a complete picture requires that all soil and vegetation types need to be taken into account.
- Although the modelling of soil and vegetation carbon budgets is complex there is a large body of data that potentially allows the key parameters to be modelled and represented in a BBN.
- In the next phase of the work it is recommended that these methods are developed at a fine scale of thematic resolution that takes particular account of the soil and vegetation combinations found in the uplands.
- It is possible to map soil and vegetation carbon stocks at 1km x 1km spatial resolution.
- In the future it may be possible to develop carbon budget modelling techniques that apply beyond the site and catchment scale so that future policy and management interventions might be explored more fully for the uplands as a whole or for upland blocks such as ‘Dartmoor’.

Part 4: Recreation

4.1 Introduction

Representing recreation as an 'ecosystem service theme' and developing a conceptual model that might be made operational using the BBN approach is a complex undertaking. If we take recreation in rural areas as a whole, for example, there are not only many interrelated drivers and factors, but also there are many uncertainties about how they operate and interact across different spatial and temporal scales. Although outdoor recreation is frequently presented as an important ecosystem service, in a country like England, patterns of recreational activity are often also related to the cultural aspects of landscape with complex links to ecological factors. Thus a good deal of the work that we undertook in the context of the recreation issue involved scoping out exactly what is implied when we refer to it as an 'ecosystem service', and how such a service might be measured with particular reference to the uplands. The work also considered whether the topic was best considered from the 'supply' or 'demand' side[6].

4.2 Scoping the Modelling Exercise

Participation in outdoor recreational activities has many demonstrable benefits. These can be broadly categorised into well-being/health - providing benefits for the participating individual (and the population) and economic benefits which generally accrue near the area visited (i.e. in shops, cafes, hotels) or areas travelled through.

Outdoor recreation including significant exercise can have a range of positive health benefits in relation to cardio-vascular health and obesity. These in turn promote well-being which also includes mental health and more diffuse and less tangible related benefits relating to the overall experience and quality of life. Accessible countryside brings the perception of better quality of life (Defra, 2002). Less tangible and more difficult to quantify are the benefits thought to accrue from outdoor recreation that contribute to good mental health and spiritual well-being.

Economic benefits can accrue when recreational participants spend money on transport, equipment, refreshments, accommodation, entry fees, etc. Recreation and tourism related spending can provide a significant input to rural economies and employment and by using appropriate mechanisms can be used to support management interventions. While other countries have implemented visitor taxes, car park charges or National Park entry fees to support local management, in England these mechanisms are rarely implemented, apart from tax-payers contributions towards agri-environment schemes. Nevertheless indirect benefits of local employment are also likely to benefit land managing communities through infrastructure and opportunities for diversification. However, in the Peak District, upland

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[6] The supply side includes the provision of recreational opportunity as a service, thus it includes the accessible land space and accompanying characteristics. The demand side is concerned with the utilisation of the service by the population - i.e. who is benefiting from the service, where they use it and where benefits may arise.

farmers had been identified as one of the poorest communities in the country (PDRDF, 2004), while overall Peak District residents are above the national average income brackets.

The 2001 foot and mouth outbreak provided an illustration of the value of visitors to the rural economy; visitors have greater economic value than food production. These relative values need to be considered carefully against the context of climate change and changing agricultural policy to assess the relative benefits of different polices and, perhaps, where public money may be most effectively invested.

Curry (2008) argues that the decline in outdoor recreation over the past decades is mainly driven by consumer preferences and leisure lifestyle changes, rather than any particularly strong constraints on participation. Therefore, he put forward the view that, outdoor leisure consumption will not be significantly changed through tinkering with the supply side. This means on the positive side, that even a change in landscape qualities, for example, to provide more biodiversity or ecosystem services will not have a significant affect on the uptake of recreation opportunities.

Thus it may be more important to consider the things that shape demand for recreation. Any potential model would have to reflect the things that affect societal choice such as public values and fashions. The desire for greater fitness and health, as seen by increasing gym memberships, may be one avenue to promote the use of this service. Moreover, it has also been suggested that providing first hand positive outdoor experiences to children and also non-white ethnic communities might also be needed to develop demand/desire and remove non-physical accessibility barriers.

In the workshop we explored a number of these issues and attempted to identify what people thought could be most usefully achieved by the conceptual mapping exercise and thus the scope of the model. The workshop participants were given a preliminary draft model to criticise and change. They were also asked to identify some measurable outputs, mechanisms and drivers related to recreation. The responses are summarised in Table 4.1; Table 4.2 identifies a range of possible data sources that people thought might be useful in providing information about different system components. Given the wide ranging nature of recreation as a topic, the discussion of potential data sources and evidence gaps was particularly valuable as a way of identifying what people thought was important, given their perspective on the issue.

Table 4.1: Outputs, mechanisms and drivers related to recreation.

Service theme	Beneficiary	Measurable output	Underpinning mechanism(s)	Things that can change the level of service output	
				Direct Drivers	**Indirect Drivers**
Recreation	UK population and other recreational users	Well-being (SDC 68 measures)	Access, tranquillity, nature views	Land management (=) maintenance of vernacular architecture barns/walls)	Wind farms
		Quality of experiences	Semi natural habitats	Quality of access Hay meadows Grazing & land management regime maintains habitats/species	
			Enclosed land vernacular structures	Farmers/land managers	Market prices State of tourist economy Affordable housing Maintenance of traditional skills
			View from mountains		
			Geomorphology	Education & information	

In terms of the scope of the model that was to be developed people confirmed that the level of public engagement or overall well-being was an important focus, and that this in some way might be how the level of service output or its value might be assessed. Thus, it was suggested that key indirect and direct drivers were those that influence such things as 'Accessibility & Knowledge' and 'Quality of Visits'. Although well-being was thought to depend on both physical and spiritual components, it is interesting to note that participants placed a strong emphasis on a range of intangible elements, only indirectly linked to the biophysical characteristics of particular places, including learning experience and inspiration. Clearly, such components are difficult to measure.

Table 4.2: Potential data sources to characterise recreation as an ecosystem service

System Component	Data sources
Accessible land i.e. extent available on which to gain well-being or quality experience BUT area extent is not equal to quality of experience	Nat. Park Boundaries/AONB – area-specific, e.g. identities "honey spots" – ENPA – visitor surveys – where people come from FC survey open access land – use open access land (CROW) PROW maps (does not include amount of use) - density Pennine Way use data Cleveland Way use data Curry, Nigel – Bristol Univ. – use of footpaths. No evidence of increasing public demand for open access, although there is political demand through CROW etc.
Health	English Leisure visit survey Sustrans – users of nat. cycle network Quality of Life – Local Authorities data could correlate with where people come from – use data Sport England Active people survey (level of activity where people live) Accessible natural green space standards – could be mapped – proximity to population Tranquillity maps (CPRE/CRE Newcastle) Environmental Stewardship (educational access, physical access – styles/footpaths, etc) National Trust visitor data "Natural Area" profiles (avail on CD) – covered recreation (+ other issues)
	Evidence gaps
	Level of physical and mental health benefits and what the drivers are in context of use of an upland environment (pastoralism might be peaceful!?) Links between geographical location and benefits (health) Reaction to landscape change but lots and lots of contingent evaluation studies to projected change Ethic groups and benefits derived from uplands.

Some output-related statistics were suggested to characterise participation rates - including capturing the post codes of visitors in relation to catchment areas and numbers of: day visits, people, long term visits and visitors no/100 km*yr. It was also observed that in some locations (e.g. in the South Pennines) upland environments were in close enough proximity to significant populations to provide accessible green space and thus help meet NE's ANGST guidelines (Harrison et al., 1995). However, it was also argued that the 'accident of geography and place' should not unduly influence the future vision for the uplands: people make use of whatever environment is available, this suggests that we do not need to fossilise the current use of uplands for recreation but encourage it to evolve and change. Other consultees argued quite the opposite, namely that a Sense of Place is important for community cohesion, and this is tied to the desirability and value of a location (see International Centre for Uplands commissioned reports).

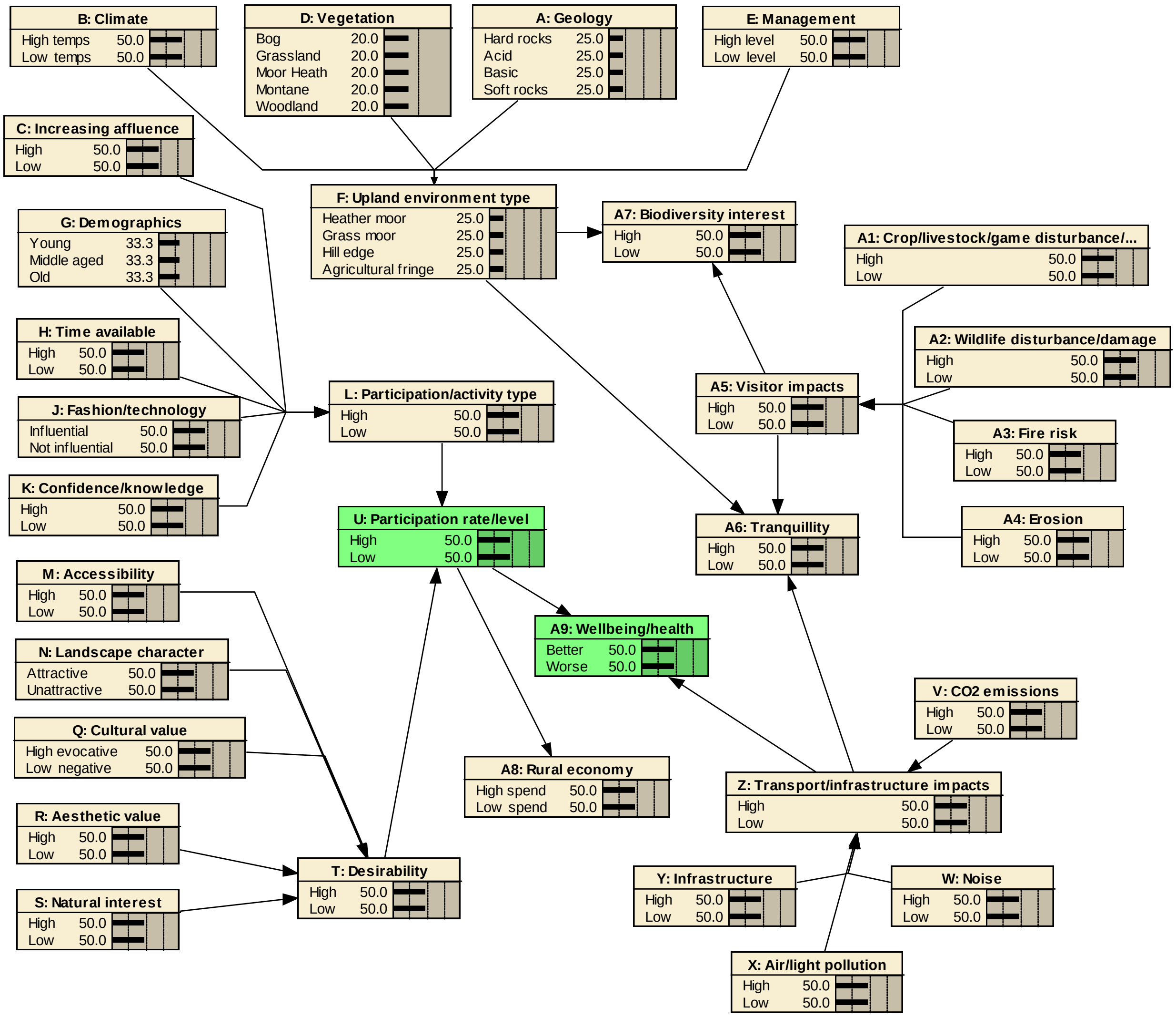
In the workshop, biodiversity was also seen as a significant driver (motivator) for recreation in the uplands (for example in bird/wildlife watching), although, as it was pointed out in a Peak District study less than 10% of visitors cited this as an important reason for their trip.

Of all the service themes considered in this study, recreation was the one that was the most difficult to pin down for the purposes of the modelling exercise. This was due to both the wide ranging nature of recreational activities that take place in the countryside, and the fact that what ever role ‘ecosystems’ play it is only part of a much bigger process, determined as much by socio-economic and behavioural factors as the biophysical characteristics of particular places.

4.3 Developing a Bayesian Belief Network for Recreation

The systems-map that was developed following the workshop (Figure 4.1) is simplified in that it combines different types of recreation that might take place in the uplands into a single variable (Node L). It is also simplified in that it combines the many different land cover elements found in the uplands into only four broad types (heather and grass moor, hill edge and agricultural fringes - Node F). The services modelled are essentially participation rate and well-being (Nodes U and A9). The aim of developing such a general model was to provide more of an overview of the topic, so that the ‘role of ecosystems’ as service providing elements could be seen within a much larger picture. It is intended that the model could be a framework or common structure that could be refined when particular activities are looked at in detail.

Figure 4.1: Systems-map for Recreation



Demand-side issues

In the model shown in Figure 4.1, a number of drivers influence the 'demand' of participants for recreation activities, these include increasing affluence, demographics, available leisure time, fashion and technology and knowledge/confidence.

Increasing affluence

Increasing affluence (as a long-term trend) has resulted in different patterns of leisure activities - of which countryside recreation is one. This also influences the quantity of leisure time, expenditure on transport, visitor spend at a site and participation rates. Visitor levels appear to have been declining in recent years (Natural England, 2006) after significant growth in the 1980s and modest growth in the 1990s.

In general, wealthier people make most leisure visits; the England Leisure Visits survey (Natural England 2006) notes that 17% of all respondents are classified by ACORN[7] as Wealthy Achievers. The proportion of visits made by this group to the countryside, however, was higher (29%). This group also made up 31% of visitors to National Parks and 34% of visitors to open access land.

Affluence is tied to employment conditions and in recent years whilst these have provided increased financial returns they have also, in general, resulted in diminishing leisure time as longer hours have been worked. This has knock-on effects on recreation choices by type and location.

Increasing affluence will increase the demand for recreation; increased demand is likely to boost supply as land owners/managers seek to exploit expanded or new markets. There may also be an increase in willingness to travel and demand for personal transport. As most visits to the countryside are undertaken by car (Natural England, 2006 & Moors for the Future, 2006) ownership of a car seems to be a perceived requirement for many people to visit the uplands. It is also thought that increasing affluence will further segment and differentiate the recreation market, leading to greater specialisation and more niche activities.

Greater affluence may have other wider effects, for example it may lead to more visits abroad and reduce visitor numbers to the uplands. The number of leisure visits abroad more than doubled between 1997 and 2006[8]. Similarly, visitors from abroad may be attracted to English uplands, but visitor numbers may be small. In the Peak District, 5% of visitors did not consider themselves to be white British and over half of these considered themselves to be white Irish or white other (Moors for the Future, 2006). Therefore, the percentage of foreign visitors in this upland area is small.

Greater affluence may also lead to more expensive equipment for intensive outdoor recreation such as motorised sports, including driving with motocross bikes, quad bikes or 4x4 vehicles on public rights of ways and off-road. This is of increasing concern for conservation as well as the well-being of other recreation visitors to uplands, and policies and guidelines are devised to address this (e.g. PDNPA, 2008). Other more expensive recreation activities may include climbing, canoeing and caving.

Finally, affluence is probably not the prime determinant for upland recreation but a covariate. It tends to be linked with social class and cultural background (see below), which have significant influence on leisure patterns and preferences.

Demographics

Demographic factors are represented by Node G. Age, sex, ethnicity, social class and health all provide barriers to participation The increasing ageing of the population is also leading to greater numbers of retired people who participate in outdoor recreation such as hill walking and rambling. It is thought that the increasing urbanisation of our culture may lead to decreased demand for outdoor recreation. However, there is also an apparent counter

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[7] ACORN is a set of postcode-based demographic, economic and lifestyle data used to identify and understand the UK population and the demand for products and services. It is a commercial data set published by CACI Ltd. http://www.caci.co.uk/acorn/whatis.asp

[8] http://www.statistics.gov.uk/default.asp

‘back to nature’ trend as larger numbers of people question prevailing trends and values. Demographics in terms of the numbers and locations of people is also relevant – people make use of locations that are accessible to them, for example, working in the Peak District National Park, Moors for the Future have shown that visitors generally access those parts of the park closest to where they live.

Different demographics also influence user types, for example Smyth (2006) identifies Dudes, Hippies and Cuppas as different user groups with different levels of knowledge, participating in different activities, and in this context they would also gain different types and levels of benefits. A study in Sheffield (Suckall, 2005) found that school children from working class backgrounds found a visit to the Peak District less attractive than children from more affluent middle class background. The children clearly did not relate this to economic constraints, as all said they could go if they wanted to. Personal interest of the middle class children was shaped by prior experience and visits to the uplands and greater knowledge and appreciation of recreational activities. Suckall et al. (2008) concluded that if English uplands are a resource of recreational opportunities to be enjoyed equally by all, different class perceptions of upland landscapes might lead to serious management challenges.

Ethnicity is also an important factor, as the percentage of visitors from non-white British background is much lower than the national average (Moors for the Future, 2006). Leisure patterns and preferences differ, and one aspect often mentioned is the lack of amenities for barbecues or play areas (‘things to do’). Suckall et al. (2008) discuss the issue that models of promoting single landscape values, such as the ‘middle class’ idea of National Parks as a place of wilderness and solitude, can alienate those who do not share this value. In making uplands more inclusive for all of members of society, e.g. through awareness raising, legislation and possibly de-regulation and provision for alternative activities (such as picnic places or barbeque areas, as in Australian or US national parks, or indeed playgrounds), managers may face the challenge of how to incorporate pluralistic views of the uplands without alienating those who already enjoy recreation activities in the uplands. Within the UK, the Mosaic Project works towards creating opportunities for ethnic minority communities to enjoy National Parks[9].

Time available

The amount of time available to a user influences accessibility (Node H), and the type of activity participated in. In recent years increased working hours have reduced leisure time for many people. As one of the main explanations for not making a leisure visit 20% of respondents state that they were ‘too busy’ and many provide work related reasons (Natural England, 2006). However, a large proportion of people also cite ‘no interest’ (9%) or no particular reason (29%) for not going. Therefore, Curry (2008) states that the reasons for the lack of consumption of recreational opportunities are largely related to people’s preferences rather than constraints.

Fashion & Technology

Fashion and technology (Node J) drives changes in activity type and popularity. For example, mountain biking has grown hugely in the last 15 years, creating demand,

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[9] www.mosaicpartnership.org

increased levels of use, and, in some circumstances, conflict with other users. Over the past fifty years the increased ownership of cars has resulted in greater mobility and further access to more remote areas. Nevertheless, there has been no growth in countryside recreation trips since 1977 (Curry & Ravenscroft, 2001; Curry, 2008, Natural England, 2006). In the future, if public policy manages to internalise the external costs of car use, travel-related patterns of use may change. Alternatively, advances in technology may bring different or even increased patterns of personal transport.

Lifestyles are also relevant, the increasingly urban and 'sedentary' lifestyles of many people, and most worryingly of children and young people has been identified as one of the key threats or barriers to outdoor recreation (HenleyCentre HeadlightVision, 2005). Sutherland et al. (2008) even list the Internet and e-technologies as a (future) threat facing UK biodiversity, as they may become a substitute for experiencing real biodiversity and landscapes.

Cultural value

The cultural value of an area (Node Q) often has landscape-related elements. The historical pattern evident in English landscapes has cultural value, as do associations with artistic, literary (e.g. Wordsworth in the Lake District, The Brontës in Haworth), historical, existential and wildlife values, and more recently popular culture. Television series such as All Creatures Great and Small and Heartbeat have brought many visitors to the Yorkshire Dales and North York Moors respectively.

With origins around 150 years ago, the maintenance of grouse moors and field sports have attained cultural value for many. Among some wealthy businessmen, living often far away from the uplands, grouse shooting has become a desirable status symbol and some upland communities perceive shoots as important social events. While grouse moor management may not always be economically profitable, depending on the region, this provides a recreational and cultural service. The management for grouse has shaped English uplands and continues to interact with other ecosystem characteristics such as landscape characteristics, maintenance of wildlife communities and provision of clean water.

Supply-side Issues

Access

Access issues are broadly covered by Node M in Figure 4.1. Having been promoted by a strong access movement, National Parks in the UK were designated with a clear goal, to provide access to the countryside to the public. Open Access has further been increased and between 1990 and the introduction of the Countryside and Rights of Way Act, 2000 (the CROW Act), Curry (2001) estimates that at least 450,000 ha of land and some 20,000 km of linear access were gained in this process. However, the impact of CROW-related access is unclear and levels of use do not seem to have greatly increased.

Physical accessibility is a key issue for recreational visits, especially convenience of travel. The sites visited may not be the preferred one but the most readily accessible in the time available. This is illustrated by the Peak District National Park (PDNP) case study maps derived from postcode analysis, with strong distance decays of distribution of visitors from their homes. Also, more than 40% visitors to the PDNP moorlands and more than 25%

visitors to the whole Peak District state that they have visited because the site is easy to get to or they live locally (PDNPA, 2006; Davies, 2006). As, at least in the Peak District, the majority of visits are made by car and most common walking distances are below a 10 mile walk (PDNPA, 2006; Davies, 2006), day visits are often made near to home and roads and car parks determine visitor patterns. Patterns are likely to differ for other uplands, with longer stay visitors attracted from more distant locations.

Access constraints are not necessarily physical. Knowledge is an important component of accessibility; people need to know about the existence of areas for recreation, about modes of transport and how to get there and about characteristics of the environment, landscape and available facilities. The importance of knowledge is supported by the fact that over half of the visitors to the Peak District state, that they have come because they have visited before (PDNPA, 2006). This has also been illustrated by the study of Suckall (2005) for children and the Peak District. Awareness raising has also been highlighted as a key component of the research for the Natural England recreation strategy (Henley Centre, 2005) and by the MOSAIC Partnership.

Climate

The tourism industry in the uplands may experience costs and benefits with climate change (Bonn et al., 2008). Since the weather mainly impacts upon short term visiting decisions, numbers of visits might be affected in the long term through climate change (Node B). However, since summer seasons may also be extended overall higher numbers of visitors may be expected so that recreation from both short and long-term visits might increase. Health-related visits to the uplands may also become more popular to escape hotter city climates. Potentially, price rises in aviation fuel may lead to less visits abroad and higher visitor pressures in local uplands.

Rising visitor numbers and drier warmer weather periods may result in increased wildfire risks (McEvoy et al., 2006; McMorrow et al., 2008). With climate change we are likely to see changed visitor patterns that will impose increased stress on ecosystems and biodiversity if not managed in sustainable ways.

Landscape character[10]

Landscape character (Node N) is a product of the pattern of elements that occur in a particular landscape. Variations in geology and soils, landform, land use and vegetation, field boundaries, settlement patterns and building styles, give rise to different landscapes each with its own distinctive character and unique sense of place. Landscape character can change as different features change, through succession, management intervention, different land uses and development. The landscape also provides related aesthetic value and associations. People gain value from different areas, features and views and action has been taken to codify and protect this through the designation of areas as National Parks and Areas of Outstanding Natural Beauty.

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[10] See www.cqc.org.uk for definition and mapping issues.

Use-related factors

In addition to those elements of the model that deal with demand and supply side issues, there are a number of others that cover associated impacts of recreation. These can be divided into two broad categories, those that arise from and during travel to, and at, an area for recreation (travel and infrastructure) and those that arise from visitor activity.

Transport and associated infrastructure and related energy usage produce impacts through noise, air and light pollution and CO_2 emissions (Node Z). These impacts are not simply environmental in that they also have negative health impacts – although these impacts will accrue en route as well as at the destination.

The impacts arising from visitors/users can include disturbance of crops/livestock/game, disturbance of wildlife, increased fire risk and increased levels of erosion on paths and hill tops (Node A5). These impacts/risks are increased by greater participation rates and can have a negative affect on the overall visitor experience and satisfaction.

Service Outputs

The upland environment provides a number of key services in the context of recreation. These include:

Desirability

The desirability of a site or area as a location for recreation varies greatly and is influenced by a range of factors. The type of activity is important, as is the ‘pull’ of specific areas that bring people in from wider areas because of their characteristics such as natural and scenic beauty, landscape character, wildlife, historic and cultural value and associations. Within the Peak District almost all of the visitors noted scenery as one of the main reasons for visits (PDNPA, 2006). The Countryside Agency’s Predicted Pattern and Levels of Use (PPLU) model is therefore mainly based on topography and access routes.

Areas that are considered desirable for a range of characteristics will draw visitors from further afield and will attract large numbers of visitors. However, locations effectively have both physical and perceptual carrying capacities and the user experience and desirability of an area can be diminished is it is considered too busy or overcrowded. The desirability of an area will contribute to the participation rate and hence influences the quantity of benefit.

Habitats/upland environment

The environment provides the location, space and opportunity for recreational use. The different geology, landform and vegetation, as influenced by land use, management and climate provides a spectrum of opportunities and experiences.

Biodiversity is a benefit provided by habitats/environment and itself acts as a driver for some recreational pursuits, for example wildlife watching, photography, field sports and angling. The environment and biodiversity provide the pull for these recreational activities. However, these activities and other recreational activities can also negatively affect the target species or other aspects of biodiversity through disturbance and the active management for providing these pursuits (e.g. burning of grouse moors, legal predator control or illegal persecution).

Tranquillity

Tranquillity is a quality sought by many recreational users, particularly for quiet pastimes such as walking. As a generality it is a function provided by the natural environment in the absence of other intruding factors (MacFarlane et al., 2004). It will result in greater visitor satisfaction but can be negatively associated with accessibility. It can contribute to natural beauty and to well-being as an outcome.

Within the Peak District, about 50% of all visitors stated they came to enjoy the peace and tranquillity (PDNPA, 2006). Nevertheless, hotspots of visitor activities (see maps for case study) are not located in the most remote and tranquil areas within the Peak District (such as the very North), but the Peak District in particular, offers an island of tranquillity surrounded by major conurbations, as do other uplands visited. This means that tranquillity is seen as relative to local areas at home, and not necessarily within the upland area. Therefore a relatively broad scale can be used for mapping across English uplands, and there may be little congruency between fine scale analyses of visitor patterns and tranquillity measures such as light pollution. This has also positive implications for visitor management, as tranquillity seems more related to view sheds and the absence of development, than necessarily absolute remoteness and absence of other visitors.

4.4 Model implementation

If the two main ecosystem benefits from recreation are health/well-being and the local economy a number of evidential elements are required. We need to know:

1. How many people are visiting the uplands for recreation and how often;
2. Where they come from; (and thus where the health/well-being benefit accrues);
3. Where they are going; (and thus where the economic benefit accrues);
4. What is the economic impact;
5. Certainty about the link between recreational activities and health/well-being benefits;
6. The motivations and predilections of visitors and how these are affected by landscape and other changes;
7. The true impact of transport-related (and other) impacts - and the magnitude of these in relation to the apparent health/well-being and economic benefits; and,
8. How behaviour (and hence benefit rates) may change under different management scenarios.

In each of these areas considerable uncertainties or gaps in the evidence base exist, and as a result it is extremely difficult to operationalise the recreation model, as we have done for the other topics. We briefly consider the major gaps in the current evidence base.

A number of the elements contained in the model shown in Figure 4.1 can be quantified and it may be possible to a certain extent to scale findings. However, it appears very difficult to generalise between areas. For example, it is not very clear how to infer usage for an area based on visitor data collected elsewhere because of the complex contingent factors that influence the desirability and popularity of a location. For example, the work conducted with the PDNP by Moors for the Future, suggests how visitor numbers may be estimated in broad categories and mapped. It is possible that this approach could be used in other National Parks if they have sufficient ranger or other staff resources. However, it is unlikely that most AONBs would have the staff to commit to such an exercise and there are many upland areas with a lower level of management supervision and input - or certainly with a lower level of central co-ordination. On the other hand, the economic benefits of visitors are probably easier to quantify by combining accurate visitor data (where available) with information on average day and visit spends from other surveys.

Similar problems arise when we think of making predictions over time. Although the uplands are subject to change it is unclear how people will react to it, in terms of how it may influence the desirability/suitability of an area for recreation. The current upland landscape is strongly shaped by the influence of grazing and livestock systems. If, for example, a more market-driven system was adopted hill sheep farming could decline rapidly and in the absence of other grazing or management intervention previously open hill sides may scrub over. Would this affect visitor enjoyment and appreciation - or simply change it? How would it change the balance of a case for management interventions?

One of the key, problematic issues relating to the model presented here is that the beneficiary group is too wide and too differing in impacts to be considered *en bloc*. It was suggested that the beneficiary group be split along functional lines (perhaps into dudes, hippies and cuppas, *sensu* Smyth, 2006) and considered relative to each other in defined study areas. This issue is an issue of thematic scale, which should be explored more fully in future work.

The beneficiaries will include a great many people not resident in the uplands (and will include other nationalities). Well-being can be described according to SDC measures, although described these cannot all be quantified. It is also necessary to try and make the quantifiable link between residents and benefit arising (spatially). A further understanding of causal links is also required to quantify the relationship between well-being measures and contribution provided by upland recreation-related activity; i.e. what is the contribution made by monthly weekend hill walking to reduction in cardio-vascular-related morbidity and mortality? Or perhaps more difficult still, what is the contribution made by scenic views and tranquillity to mental health?

At a more detailed level differential activity groups and types (e.g. walkers, cyclists etc.) could be considered and it is possible that with further work this would help differentiate impacts and provide better information for assessing trade-offs and informing management. Some of the tangential impacts (such as transport) generally remain in common to different activity groups. However, differentiating different users would require a level of complexity greater than is possible in this feasibility study. The same applies to sub-dividing the upland environment into constituent habitats (and identifying different capacities and impacts) to allow comparison with other ecosystem services. While this is clearly an ambition that should be worked towards, there is currently insufficient information and evidence to allow this level of analysis on an England wide basis. Separating different activities is unlikely to be feasible from available data and may lead to double counting. Similarly, the impact of wind farms on recreational was considered, and it was noted that while there may be the some people who find the turbines intrusive, others may not be so concerned. It was noted that such polarisation of view may make it difficult to model the implications of developments in a simple way.

In an attempt to operationalise some part of the model at least, we tried the strategy of identifying more specifically particular, target beneficiary groups – and looking at what might be done to model participation and potential health benefits. The results of the exercise are shown in Figure 4.2.

The model focuses on two groups, cyclists (Node R1) and walkers (Node R), both of which have partially different requirements for a satisfying visit. The former benefit by a higher frequency of quiet roads and tracks (node N) and good access (Node C), where as the latter, along with access, are more highly influenced by tranquillity (Node H) and associated landscape characteristics (Nodes F1, Q and J). Other factors considered to contribute to the recreational experience include travel satisfaction (Node M) and costs (Node L). The conditional probabilities were assigned entirely on the basis of 'expert judgement', drawing upon our reading of the material reviewed above and the workshop discussions.

Figure 4.3 and 4.4 shows some of the effect of manipulating the state of some of the nodes. For example, in Figure 4.3, the designation node (Node J) has been set to show we are only dealing with the areas outside National Parks and AONBs. With the network in this overall configuration we can compare the relative levels for the key outputs (Nodes, T, S and A) both with the initial pattern shown in Figure 4.2, and with the situation where we set the goal of at least achieving moderate health benefits; this is done by switching moderate health benefit to 100%. The network suggests that if we want to move from a situation where it is more likely that benefits are moderate to low, then the number of day as opposed to half day visits would have to increase.

In Figure 4.4, the preconditions needed to achieve 'moderate health benefits' outside the designated areas are identified by using the network to 'backcast' from this target state.

Figure 4.2: Recreational sub-model for walkers and cyclists

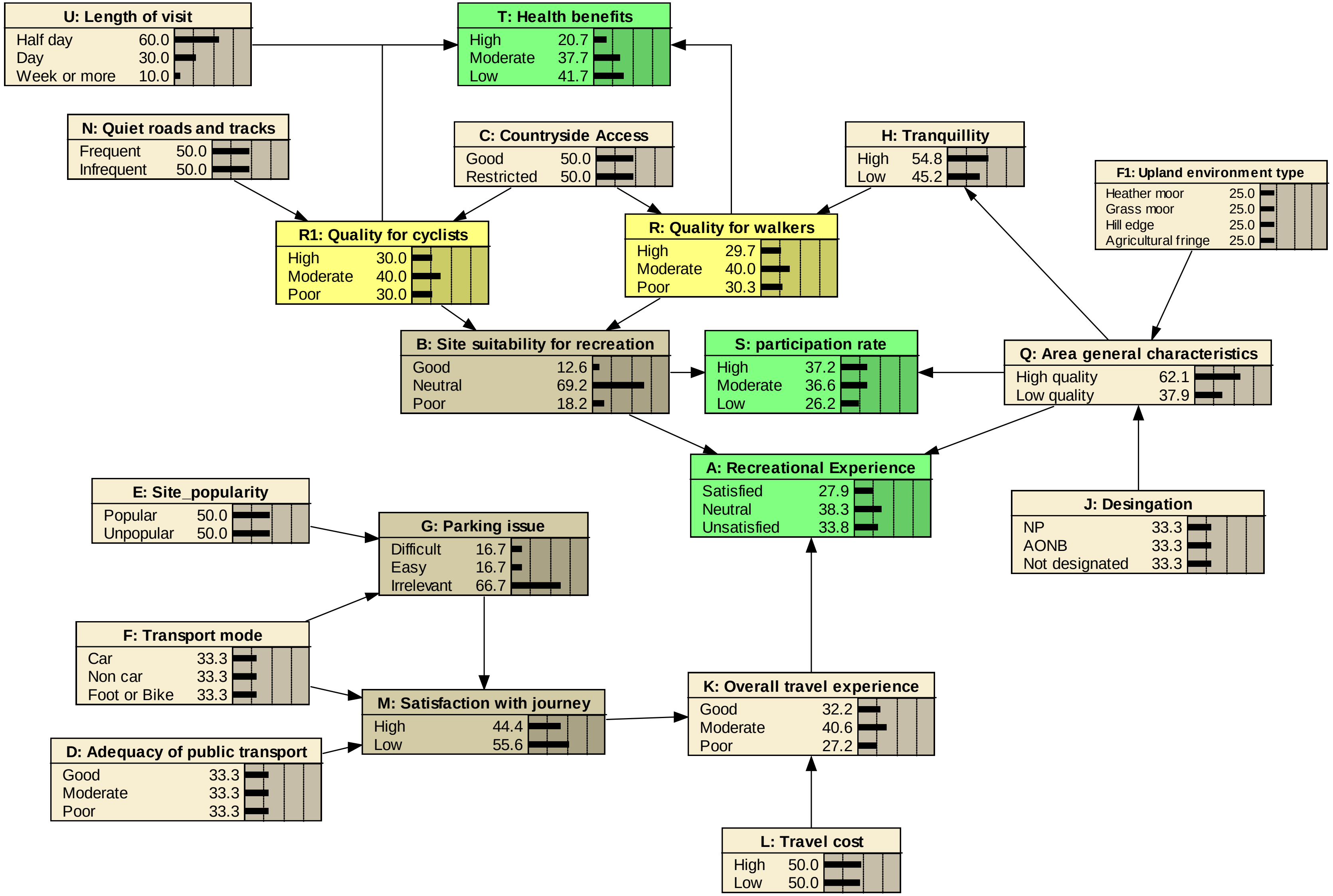


Figure 4.3: Exploring the factors that promote potential health benefits in the wider countryside

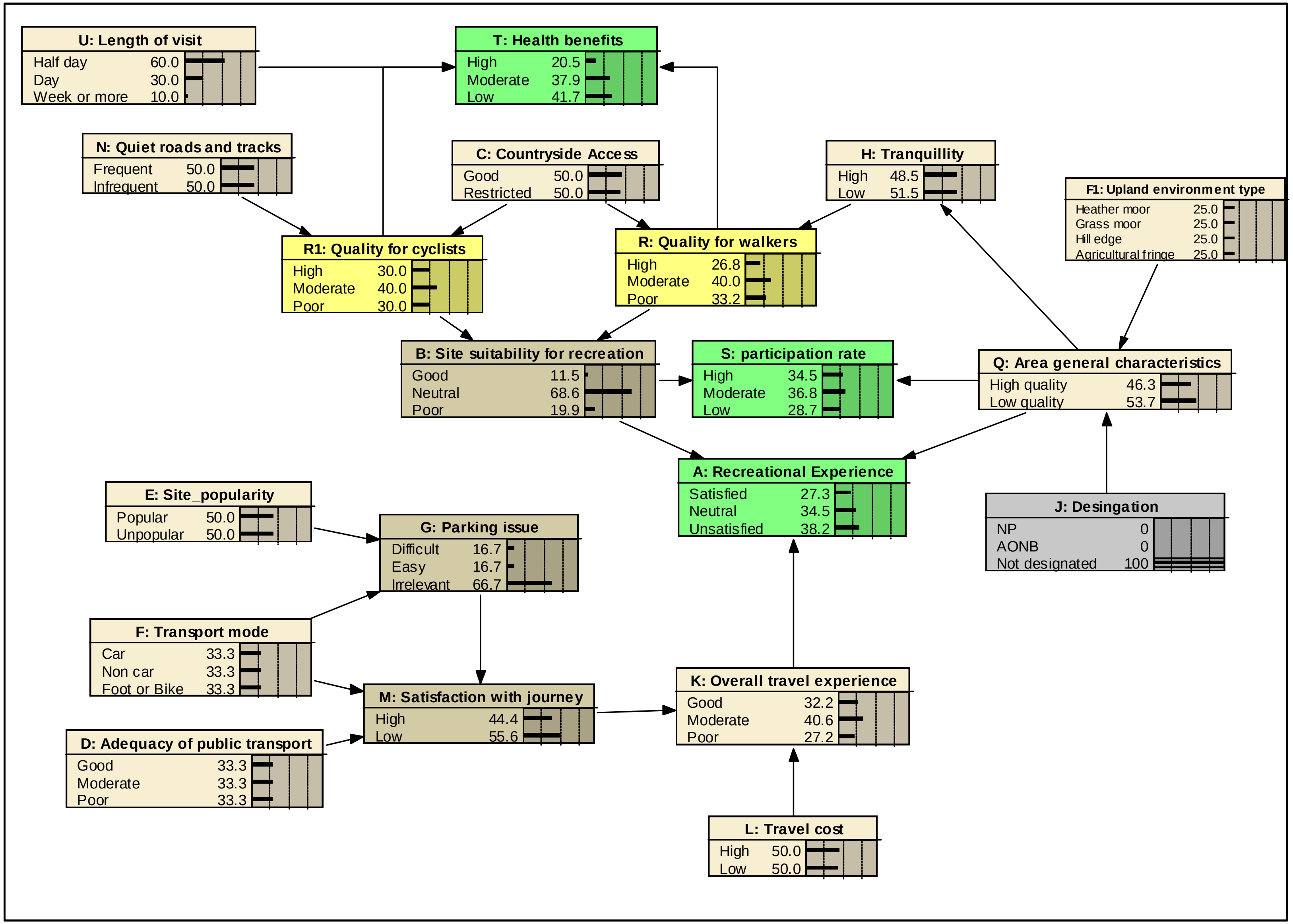
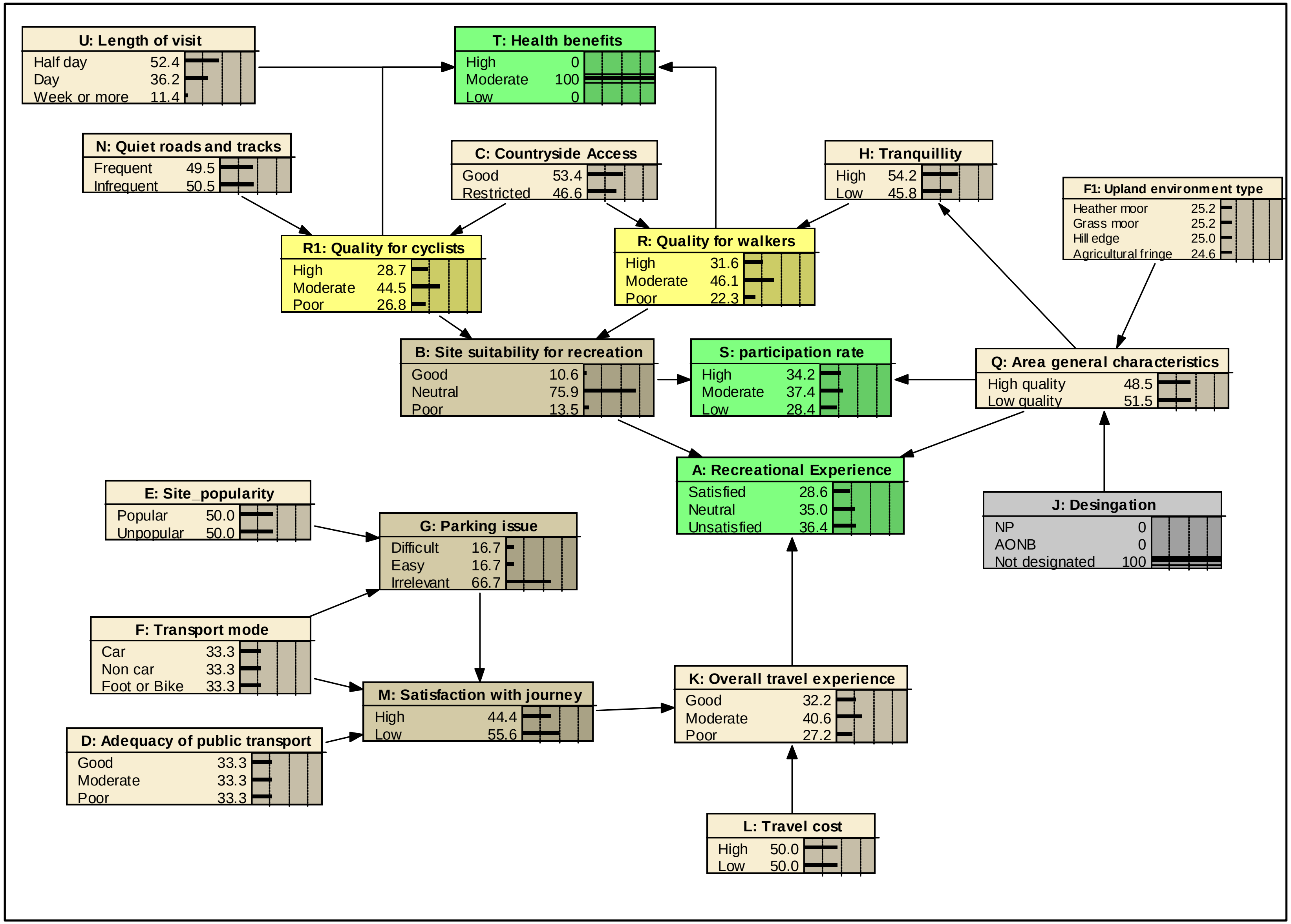
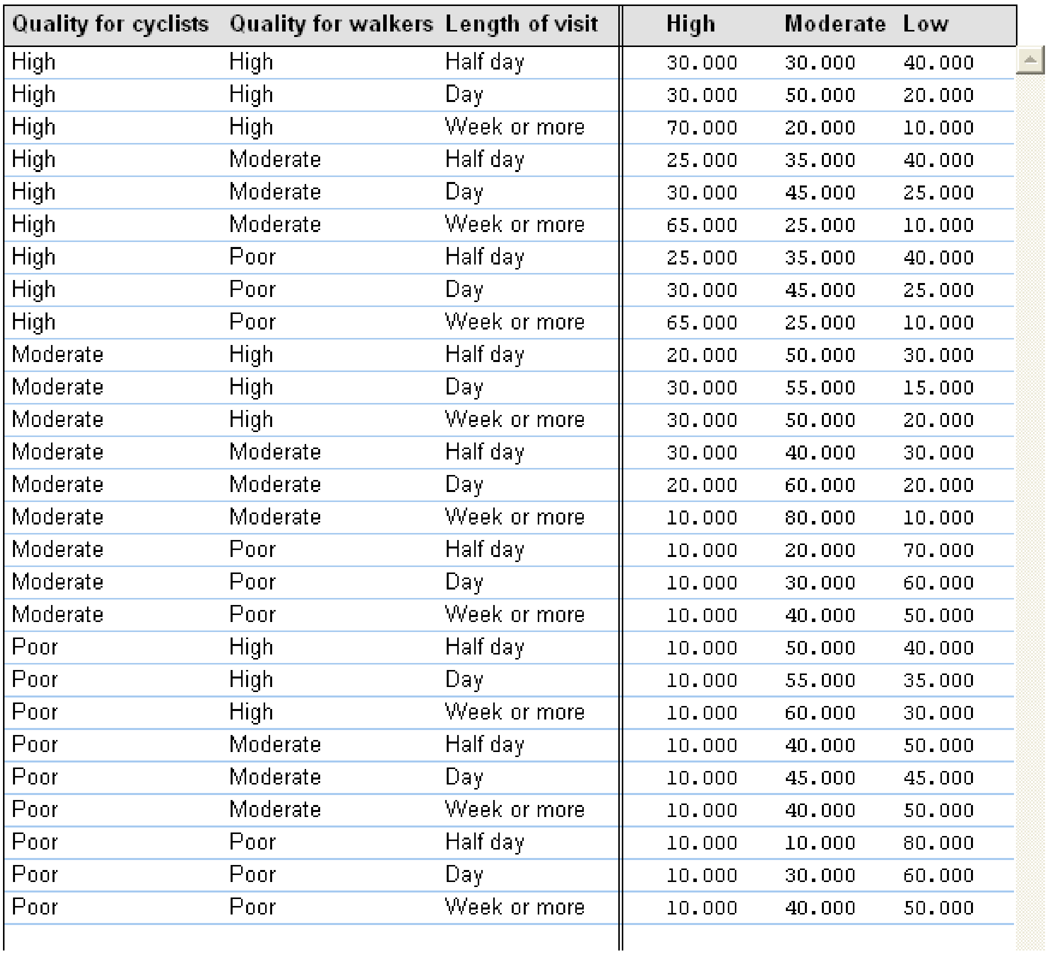


Figure 4.4: Exploring the factors that promote potential health benefit



It should be noted that while we have no information about the relative health benefits of a half or single day recreational visit, we might assume since it is accepted that longer activity periods lead to higher levels of fitness, that a whole day visit is more worthwhile. Similarly a week long period of activity is more beneficial than a whole day. Such an assumption has been expressed in the way the conditional probabilities have been set for node T, as shown in Table 4.3. As yet, however, this model has not been tried with a wider group of experts and the probabilities for all the nodes need to be further refined.

Table 4.3 Conditional probability table for health benefits (Node T) showing relative strengths of the influence of environmental quality for cyclists and walkers.



Quality for cyclists	Quality for walkers	Length of visit	High	Moderate	Low
High	High	Half day	30.000	30.000	40.000
High	High	Day	30.000	50.000	20.000
High	High	Week or more	70.000	20.000	10.000
High	Moderate	Half day	25.000	35.000	40.000
High	Moderate	Day	30.000	45.000	25.000
High	Moderate	Week or more	65.000	25.000	10.000
High	Poor	Half day	25.000	35.000	40.000
High	Poor	Day	30.000	45.000	25.000
High	Poor	Week or more	65.000	25.000	10.000
Moderate	High	Half day	20.000	50.000	30.000
Moderate	High	Day	30.000	55.000	15.000
Moderate	High	Week or more	30.000	50.000	20.000
Moderate	Moderate	Half day	30.000	40.000	30.000
Moderate	Moderate	Day	20.000	60.000	20.000
Moderate	Moderate	Week or more	10.000	80.000	10.000
Moderate	Poor	Half day	10.000	20.000	70.000
Moderate	Poor	Day	10.000	30.000	60.000
Moderate	Poor	Week or more	10.000	40.000	50.000
Poor	High	Half day	10.000	50.000	40.000
Poor	High	Day	10.000	55.000	35.000
Poor	High	Week or more	10.000	60.000	30.000
Poor	Moderate	Half day	10.000	40.000	50.000
Poor	Moderate	Day	10.000	45.000	45.000
Poor	Moderate	Week or more	10.000	40.000	50.000
Poor	Poor	Half day	10.000	10.000	80.000
Poor	Poor	Day	10.000	30.000	60.000
Poor	Poor	Week or more	10.000	40.000	50.000

4.5 Spatial Mapping

To this point we have considered schematic or system 'maps' that provide models of how ecosystem services may be generated and what services and benefits they may provide. In order to quantify and to better understand them it's necessary to map them spatially. This is not straightforward, geographies and scales may vary when looking at different components of the schematic networks such as service provision, benefits and where they accrue. In attempting to map services it is again useful to consider the ecosystem services ‘cascade’ (see Fig 1.1):

Structures > Function > Service > Benefits

For different services, it may be possible to map each or some of these levels but there are also likely to be very different geographies for different services and evidence and data to support them will vary.

Taking carbon as an example, carbon storage is provided in the uplands primarily by soil and vegetation. If carbon storage rates are known for different soil and vegetation types, then these can be mapped and quantified using soils and vegetation data sources. It is likely that nearly all of the upland area will provide some level of service. However, deciding where the benefit accrues is more difficult and tends to move the domain from a physical functional one to a political/administrative realm. Therefore, the carbon storage benefit provided may be attributed to a region, England, the UK or world wide. However, management, to prevent loss and to support sequestration, may manipulate the carbon store, and this is more likely to be directed on a more local basis.

The recreation system map produced for this study (Figure 4.1) provides a more complicated example. The recreation service is provided by the accessible parts of the uplands. This proportion may be changed by different policy and management regimes and is also likely to comprise elements of both physical and perceptual access (i.e. in the latter knowledge of accessible areas and how to access them). Different interventions can be made to alter the physical access (habitat management, access agreements, infrastructure etc.) and the perceived access (education, information, marketing, activities etc). The service is inherently provided and located within the uplands.

The benefits are provided in two main forms, as health/well-being improvements to those who participate in recreational activities and in the rural economy (and any other en route) at/supporting the destination, or those visited *en route*. Both groups of beneficiaries may reside outside the uplands.

Recreational participants, for example, are most likely to live within easy travelling distance of the location visited but are also drawn from across regions and much farther a field (UK Day Visits). The predominant mode of transport to upland areas is the car, so it would be possible to combine visitor survey, population and road network data to model and map visitors by place of residence. This will have a distance decay function, the numbers decreasing as distance increases away from the location visited. However, given the low levels of population in the uplands and their attractiveness as recreation destinations, the majority of health and well-being benefits will accrue to visitors outside the upland areas.

The geography of economic impacts will be different from those of health and well-being. The rural economy will benefit from increased numbers of visitors according to the numbers of visitors, their length of stay and their average spend, which is related to activity and visitor behaviour and type. For those taking longer journeys, there will also be some economic benefits within transport corridors en route to popular destinations.

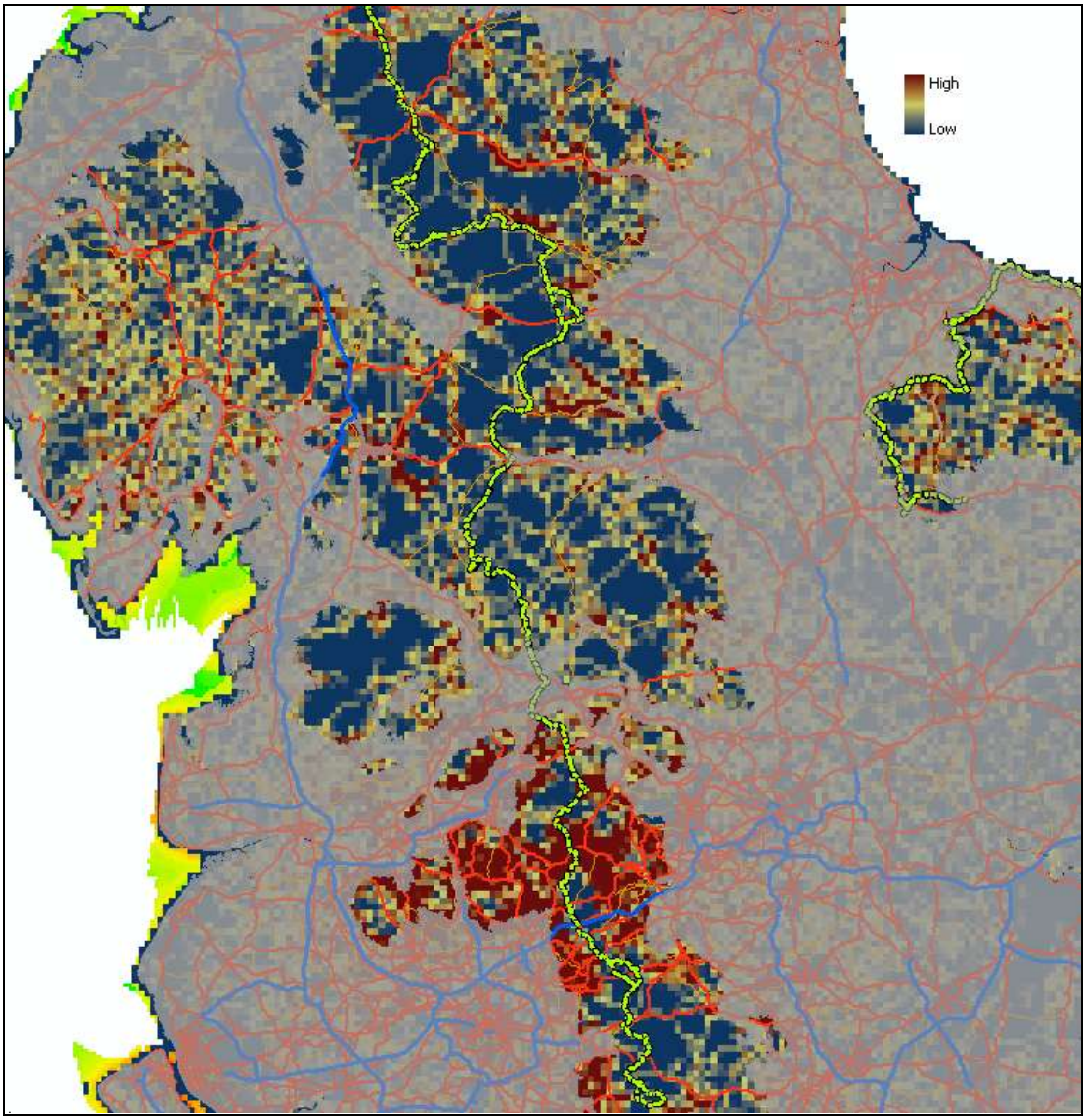
Evaluating trade-offs between different kinds of benefit adds to the spatial complexity as visitor impacts also accrue in different places. Transport-related impacts will occur between the visitor’s residence and the location visited – producing scattered impacts far away from the destination and spatially converging impacts closer to the destination location. There will be different levels and patterns of visitor impacts at the destination, some of which may reduce the utility and value of the service and related benefits.

Together these characteristics produce a complex and contingent matrix of factors that operate at different scales and are difficult to correlate. In sustainability terms, policy and management should seek to optimise the system by maximising use and participation from more local users, thereby providing benefit to the population while reducing transport-related impacts.

Mapping approaches

In order to map the systems maps spatially we must consider what elements should be quantified and what evidence is available to support this process. Two major approaches are available; to consider either the supply side of the service/benefit or to look at the demand side.

Figure 4.5: Footpath densities in the uplands



The value of each approach will vary according to the theme under consideration but may also be influenced by the type and quality of available data.

If we consider again the ecosystem services 'cascade':

Structures > Function > Service > Benefits

It may be appropriate/possible to quantify and map (spatially) any or each of the elements in the cascade. A supply-side approach would tend to focus on the (bio/physical) structures and a demand-based approach might focus more upon the service or benefit elements. Functions are generally more related to process and therefore less appropriate/useful to map.

A supply-side approach would be useful in the case of carbon, it would be most useful to focus upon structures that produce the service and perhaps interventions that impacts upon the level of service – so that policy/management scenarios can be explored. As mentioned previously, it makes less sense to map direct benefits as they may accrue to the whole population. However, for example, there will be indirect benefits of management for peat consolidation and conservation in other themes such as the reduction of sediment loads and these can be mapped as benefits in downstream catchments.

Recreation may require different approaches. The supply side is extremely complex but could be mapped through combining different information sources, perhaps to create a resource 'surface' related to supply. This might comprise an indicator based upon land suitability, access characteristics (open access land, linear access etc) and tranquillity. Some examples of mapping more supply side factors are shown in Figure 4.5 and 4.6, both mapped on a 1km x 1km grid square basis.

Figure 4.6: Variations in tranquillity in the uplands

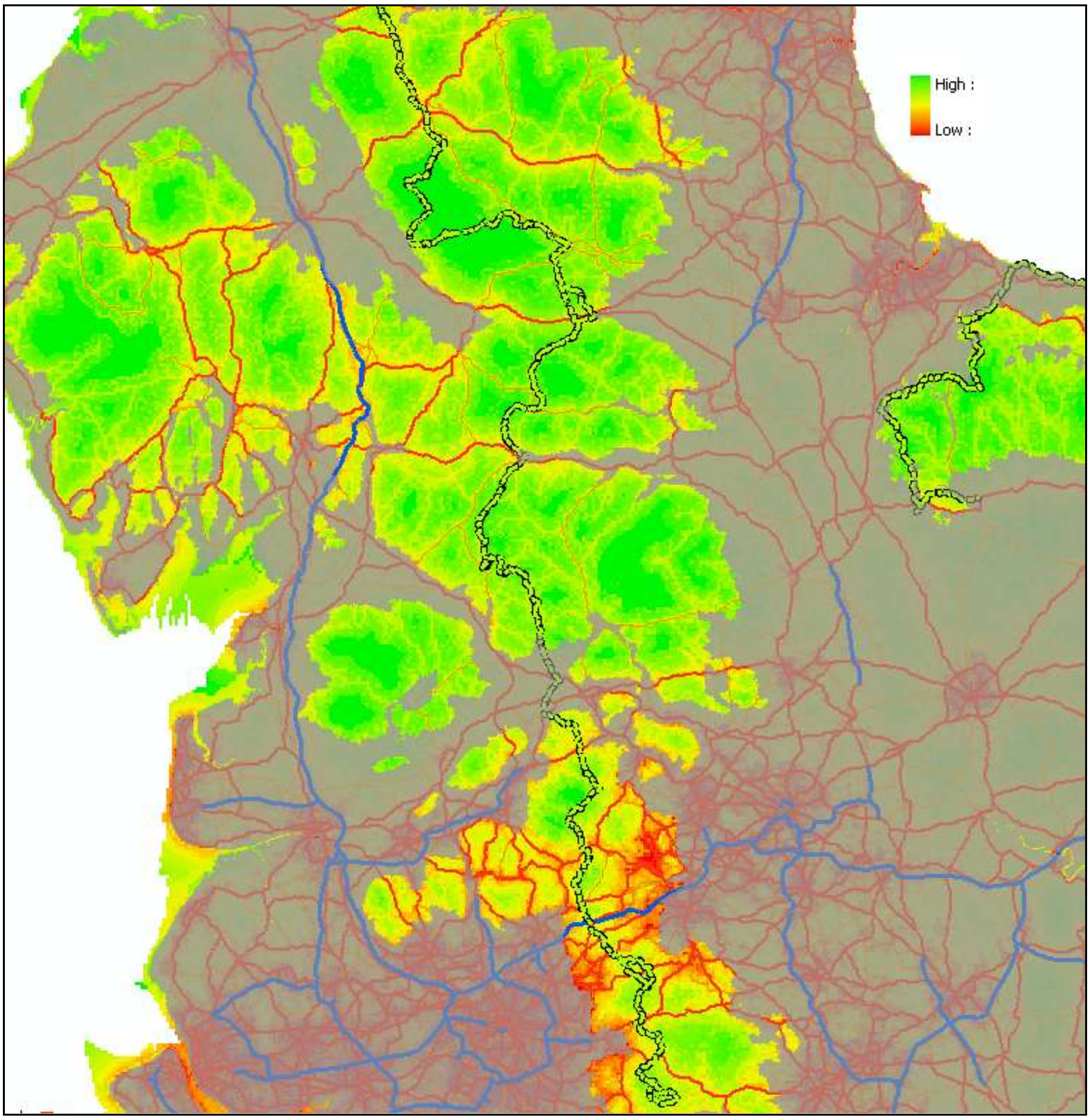
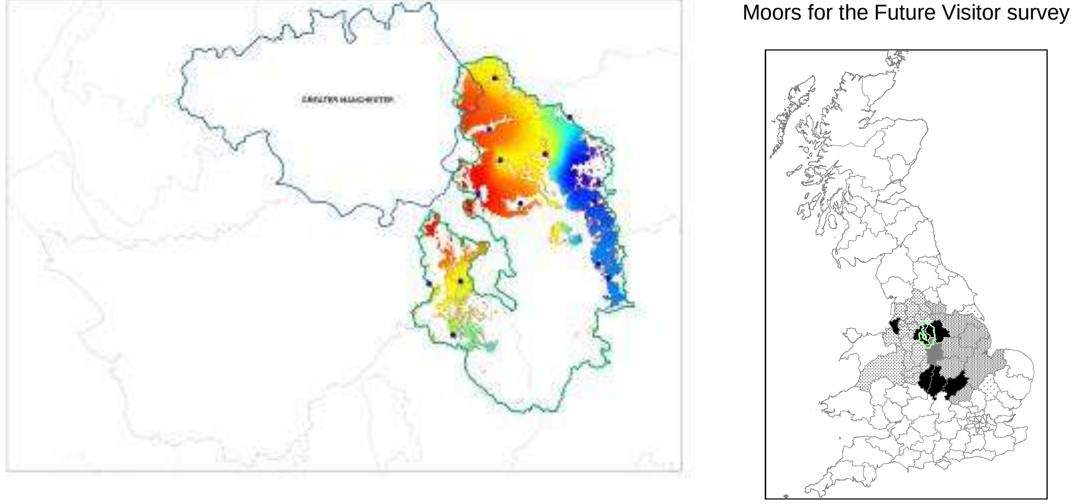


Figure 4.5 shows variations in footpath density. If we can assume that access is an important component for some aspects of recreation in the countryside then this maps would form part of some overall potential surface. Similarly if we assume that tranquillity has a role, then Figure 4.6 might be used to show where areas of high quality exist. Taking the two maps together, the contrast between the Peak District and the uplands of Northern

England are quite striking. Whereas the Peak District is highly accessible its tranquillity scores are lower – whereas the Lake District is more tranquil but access remains good.

Theoretically, for recreation the demand side is almost limitless. The proportion of the population that participates in outdoor recreation is very low. Population (census) data could be used together with access and proximity algorithms to model a potential demand surface calibrated with available visitor survey data. Some example data are shown in Figure 4.7. However, like the supply side scenario this may provide little insight into functional relationships and it is those that largely determine behaviour. Suitable data may exist to allow the mapping of these elements, or proxies may need to be sought where data are either not available or the variable is currently too complex or poorly understood to be mapped. Further work is required to examine public attitudes and values and the ways these shape use of the countryside for recreational purposes.

Figure 4.7: Use of Peak District moorlands by residents of Greater Manchester (after Moors for the Future, 2008 – see Appendix G)



County	% of visitors to the PD moorlands
Greater Manchest	12.0 (600,000)
Cheshire	10.9 (545,000)
Lancashire	0.6 (30,000)
Merseyside	0.5 (25,000)
Cumbria	0.3 (15,000)

4.6 Review of Conceptual and Spatial Mapping for Recreation

The key messages from Part 4 are as follows:

- Recreation is a complex theme that transcends simple analysis as a single ecosystem service.
- The major task is to find ways of identifying the role or contribution that those aspects of the ‘countryside’ that are within NE’s remit play in this range of activities.
- This requires a general understanding or conceptualisation of the issues – and more specific operational models that might be used to examine specific activity sectors and influences.
- The work needs to be grounded in more thorough analysis of recreational activities and public attitude to make the BBN operational.

Part 5: Renewable Energy

5.1 Introduction

Given the brief for this study, the extent to which 'renewable energy' can be regarded as an ecosystem service was a question that we examined carefully in order to scope our work. Clearly, as a locale that may provide conditions which are suitable for the generation of renewable forms of energy the upland environments are potentially valuable – but the processes from which that energy is derived are diverse and clearly differ in their dependence upon some underlying set of ecological processes or some component of *biodiversity.* Thus while renewable forms of energy that are derived from some form of biomass may be regarded as an ecosystem service in the strict sense of the term and might legitimately be considered here, energy derived from wind or hydro are mainly dependent on the *physical* characteristics of the uplands so probably fall outside this definition. Although the terms 'environmental service' or 'landscape service' are less commonly used in the literature, they are probably more useful as a label to cover the types of benefit that nature provides that are only weakly dependent on living organisms but which are clearly related to the abiotic characteristics of particular places.

It was decided that for the purposes of this scoping study both types of service ought to be considered in order to explore the way in which they might be handled in future work. Thus, in the context of renewable energy, five specific sources were considered, that spanned this division between ecosystem and environmental services, namely:

- Energy from existing woodlands;
- Energy from new crops;
- Energy from biogas;
- Wind; and,
- Hydro-power.

As noted in the general introduction to this report (Part 1) renewable energy was one of the topics considered in a less detailed way, and as a result the system networks we present are mainly conceptual, and mapping issues are considered at a more general level.

5.2 Energy from existing woodlands

The Forestry Commission's (2007) *Woodfuel Strategy for England* sets out how the Government's target for utilising an additional 2 million tonnes of wood for energy production can be achieved by focussing on under-utilised woodland and on 'forestry arisings' that are not currently harvested in commercial forestry operations. Since a high proportion of commercial conifer plantations occur in the uplands (overall 16% of England's woodland occurs in the Severely Disadvantaged Areas (SDA) and a further 6% in the Disadvantaged Areas (DA)), the uplands may make a potentially significant contribution to

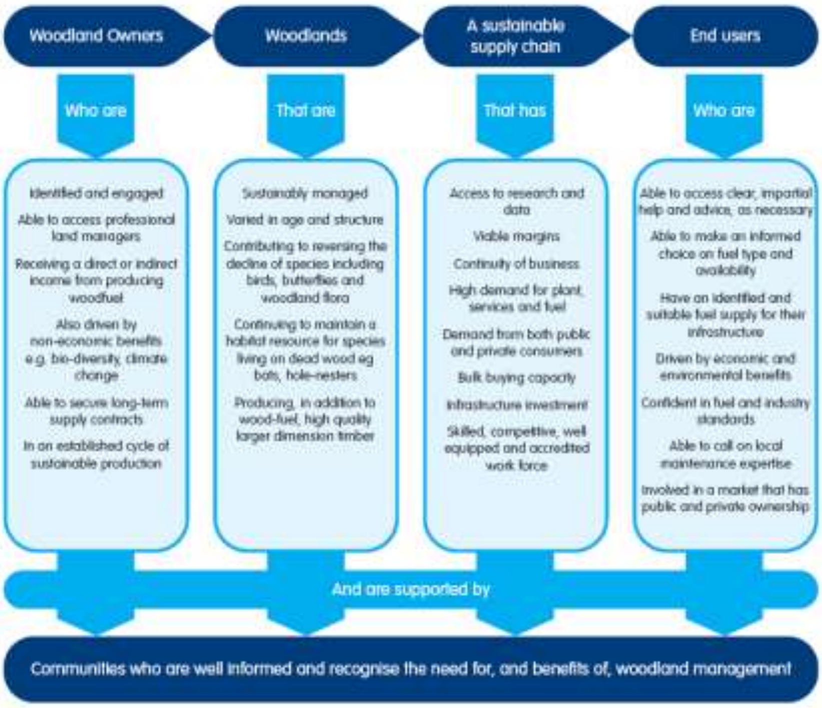


Figure 5.1: Wood fuel supply chain (after Forestry Commission, 2007)

the overall output. Woodfuel can be used to create heat alone (for instance to heat individual domestic properties in open fires and boilers), it can be used to create both heat and electricity in dedicated 'combined heat and power' (CHP) plants and it can be used to create electricity in conventional coal-powered power stations by 'co-firing' with coal. All these are potential markets for wood from the uplands.

As the strategy notes, however, there are a number of barriers to the use of the renewable energy potential that woodlands might provide. These include limited awareness of the value of woodfuel systems and difficulty of accessing appropriate technical help and assistance. In woodlands that have not been managed for a number of years, disinterest, and lack of knowledge to access grants and licenses have been identified as a further barriers to progress. Perhaps, the most significant factor preventing the exploitation of this resource is the complexity of what the *Strategy* calls the 'supply chain' (see Figure 5.1), that is the series of steps that connects the producer of the 'feedstock' to the end user. The *Strategy* argues that in putting all the elements of the supply chain in place, "The challenge is to advance all of them together." It recommends, "A concentrated sub-regional approach rather than a general support mechanism is the key to joining these up".

Distance to market is also likely to be a further factor constraining the production and use of woodfuel. Woodfuel is heavy and uneconomic to transport over long distances. Defra tend to apply a limit of 25km from source to processing where public grant aid is available for biomass schemes.

In addition to the energy benefits, there are also other strong potential environmental benefits that can arise from bringing woodland back into traditional forms of management. These include the reintroduction of coppicing, and removing conifer plantations from ancient woodland and heathland sites. Clearly such woodlands may have increased biodiversity and recreational values as well as their value for energy. However, there are also environmental sensitivities about the impact of removing the brash and other material that was previously left on-site in forestry operations. For example, a balance needs to be struck between the removal of woody material and the needs to leave sufficient deadwood in the system to sustain all the different elements of the woodland biota.

5.2.1 Systems-Map

Figure 5.2 summarised the major demand and supply side issues related to the production of energy from existing woodlands, and some of the interventions that might be required to overcome the barriers identified above.

The concept map shows three main sources of material entering the woodfuel supply chain:

- The volume of woodfuel products arising directly from forest operations and forest waste (node O), which include the ‘arisings’ that result from forest management (thinning, felling, pruning etc.);
- The co-products or by-products from wood industries (Node E); and,
- Aboricultural arisings resulting from the management of trees in urban areas and along roads (Node F), much of which is presently sent to land-fill.

The volume of fuel wood derived directly from forests is clearly the element of the supply chain that is most relevant in the context of this study, and is dependant on a number of factors that influence the size of the unutilised resource. It has been estimated in the *Strategy* that for England, only about 40% of the annual increment is harvested, and that there are about 4Mt potentially available for use each year. The *Strategy* suggests that making allowance for difficulties associated with accessing this material, a target of 50% of this (2 Mt) is probably a realistic one.

The systems-map shows two factors mainly responsible for influencing the volume of woodfuel arising from forests that are generally relevant, but particularly so in the uplands. First is the awareness issue, which is addressed by the advice and incentives node (H), and the second site access node (U). Awareness is a key influence affecting the proportion of private woodlands that are managed appropriately.

For this scoping study there has been no attempt to calibrate the network for woodfuel, although some estimates for wood volumes are readily available at regional and forest district levels via the *Woodfuel Resource* Website[11]. More location specific estimates could be made by working in partnership with the Forestry Commission for England using woodland survey data. The National Inventory of Woodlands and Trees (NIWT), coupled with the English Woodland Grant Information can be used to make estimates of the proportion of unmanaged woodland, the proportions of different woodland types in an area, and its status with respect to ownership, conservation status and management objectives.

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[11] http://www.eforestry.gov.uk/woodfuel/

Two key outputs are shown in the systems map, namely the energy produced and the environmental impacts. Given the more specific focus of this study on ecosystem services, possibly the most important ‘intermediate’ element is the Forestry Fuel Wood Volume (Node O) or the size of the unutilised resource (Node C), both of which can, in principle, be estimated and tracked over time at reasonably high spatial resolutions. Further work is required in relation to gauging the environmental impact of woodfuel production, which as Table 5.1 suggests is highly context specific.

Figure 5.2: Systems-map for production of woodfuel

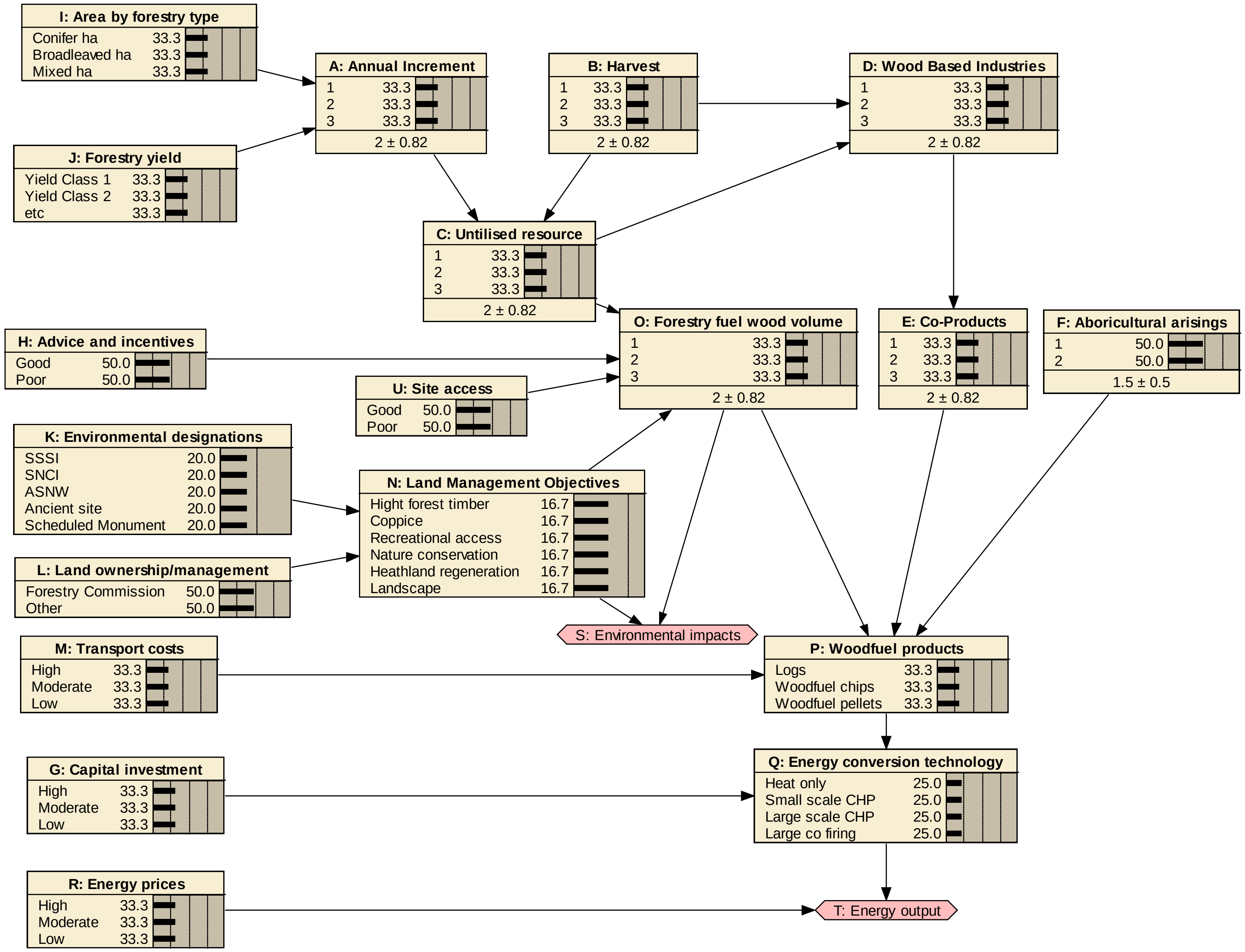
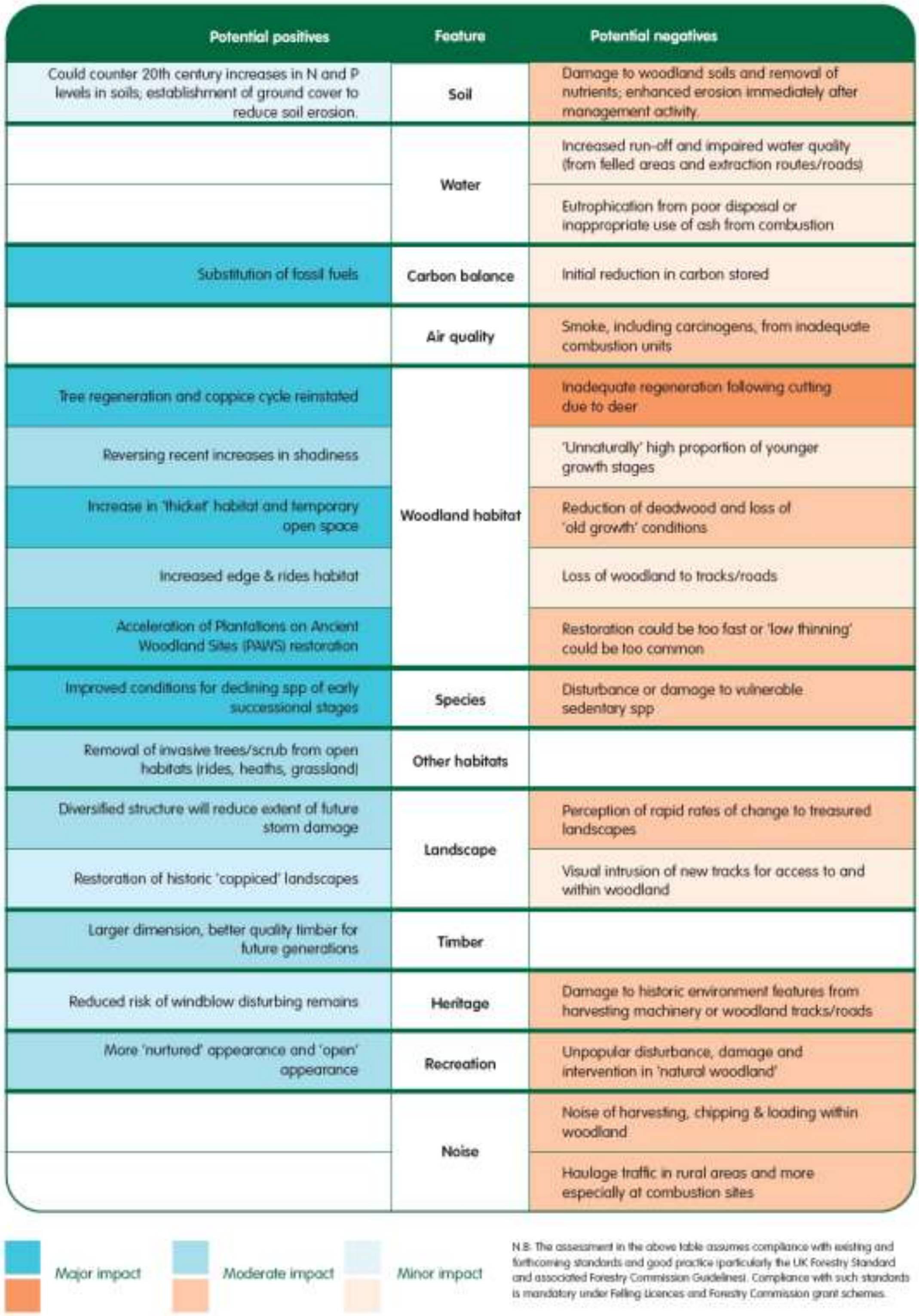


Table 5.1: Potential environmental impacts of implementing a woodfuel strategy (after Forestry Commission, 2007)



Potential positives	Feature	Potential negatives
Could counter 20th century increases in N and P levels in soils; establishment of ground cover to reduce soil erosion.	Soil	Damage to woodland soils and removal of nutrients; enhanced erosion immediately after management activity.
	Water	Increased run-off and impaired water quality (from felled areas and extraction routes/roads)
		Eutrophication from poor disposal or inappropriate use of ash from combustion
Substitution of fossil fuels	Carbon balance	Initial reduction in carbon stored
	Air quality	Smoke, including carcinogens, from inadequate combustion units
Tree regeneration and coppice cycle reinstated	Woodland habitat	Inadequate regeneration following cutting due to deer
Reversing recent increases in shadiness		'Unnaturally' high proportion of younger growth stages
Increase in 'thicket' habitat and temporary open space		Reduction of deadwood and loss of 'old growth' conditions
Increased edge & rides habitat		Loss of woodland to tracks/roads
Acceleration of Plantations on Ancient Woodland Sites (PAWS) restoration		Restoration could be too fast or 'low thinning' could be too common
Improved conditions for declining spp of early successional stages	Species	Disturbance or damage to vulnerable sedentary spp
Removal of invasive trees/scrub from open habitats (rides, heaths, grassland)	Other habitats	
Diversified structure will reduce extent of future storm damage	Landscape	Perception of rapid rates of change to treasured landscapes
Restoration of historic 'coppiced' landscapes		Visual intrusion of new tracks for access to and within woodland
Larger dimension, better quality timber for future generations	Timber	
Reduced risk of windblow disturbing remains	Heritage	Damage to historic environment features from harvesting machinery or woodland tracks/roads
More 'nurtured' appearance and 'open' appearance	Recreation	Unpopular disturbance, damage and intervention in 'natural woodland'
	Noise	Noise of harvesting, chipping & loading within woodland
		Haulage traffic in rural areas and more especially at combustion sites

Major impact

Moderate impact

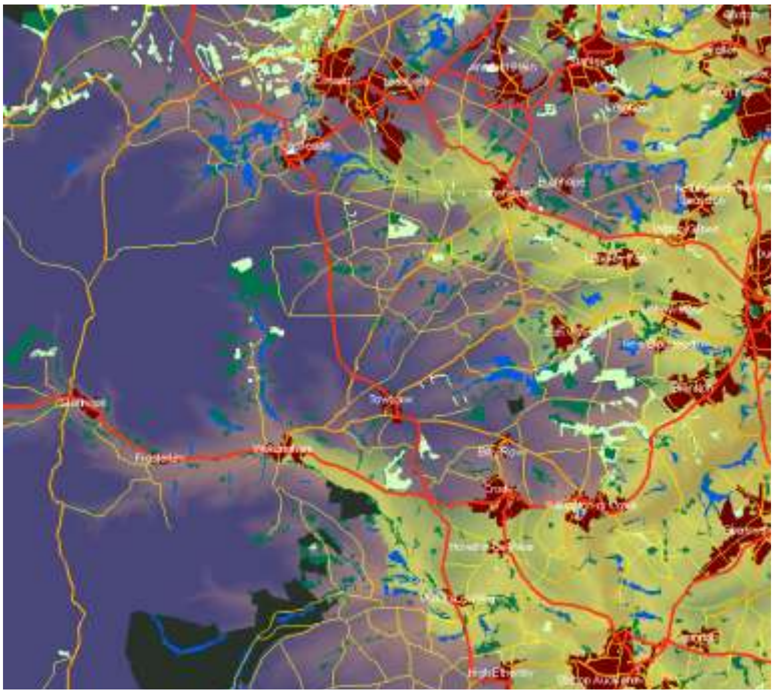
Minor impact

N.B. The assessment in the above table assumes compliance with existing and forthcoming standards and good practice (particularly the UK Forestry Standard and associated Forestry Commission Guidelines). Compliance with such standards is mandatory under Felling Licences and Forestry Commission grant schemes.

5.2.2 Spatial mapping

Given the mapping data that are presently available, various key elements of the systems-diagram shown in Figure 5.2 can be represented spatially. As Figure 5.3 suggests both the distribution of woodlands, their management and conservation status can be mapped, and given addition of further data on the location of roads and tracks, an estimate of potential site accessibility might be added. While the NIWT data does not directly link to the forest survey data from which estimates of timber volume and the size of the unutilised resource can be made, it would seem worthwhile in future work to explore how modelled estimates might be made for woodland parcels.

Figure 5.3: Mapping of sites for potential woodfuel production



The map shows the extent of the SDA area on a terrain model, together with the distribution of woodland for an area east of Durham. Woodland parcels are derived form NIWT and have been colour coded according to whether they are within the 2003 FC legal boundary (black), covered by a WGS agreement in 2003 (light green) or ancient woodland (blue). Woodland parcels without any of these assignments are shown in green. Map shows extent of potentially under-managed resource and location of resource in terms of road network and population. Parcels could be scored for potential woodfuel production and 'catchment areas defined' using such mapped data.

Since the policy makes no specific reference to the uplands, and since upland woodlands would be only one part of the resource available, it would seem sensible to extend the analysis into the lowlands, if only to show what contribution the uplands might make overall. In any case, because many of the potential beneficiaries of the woodfuel resource would be locate in the lower areas, it would seem necessary to make this wider analysis in order to identify catchment areas, linking the supply and demand side of the service.

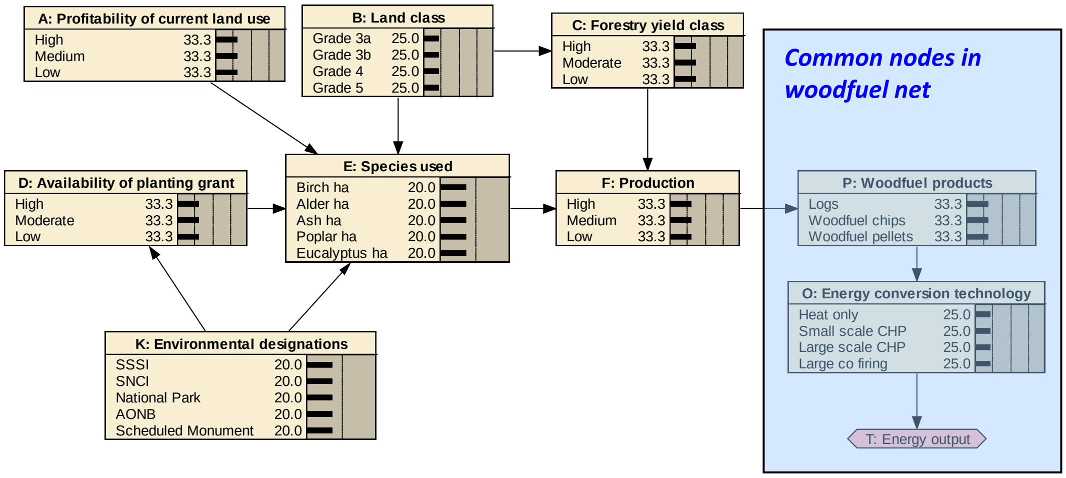
5.3 Energy from new crops

Government supports the planting of new high yielding biomass crops such as Short Rotation Coppice (SRC) and *Miscanthus* on farmland through schemes such as the Energy Crops Scheme and Energy Aid Payment and the Forestry Commission has researched the opportunities from Short Rotation Forestry (SRF). SRC and *Miscanthus* are unsuited to most upland sites (due to the relatively short growing season and poor soils) but SRF offers more potential in these areas, even though relatively little has been planted to date. The area of SRF that is likely to be established in the SDA is likely to be small because of the high proportion of the area that is within the moorland line or under existing forestry. In addition, many SDA farms also include significant areas in the wider belt of Disadvantaged Land, so that practical decisions over the establishment of these crops will tend to be made over management units that cover both DA and SDA. As a result, as with woodfuel, enlarging the area under consideration for this option to include wider geographical areas would seem necessary.

5.3.1 Systems-Map

The systems map for the production of energy from new crops is in general terms similar to that shown Figure 5.2, in that the same market and incentive factors would influence output. The biomass would feed into the woodfuel supply chain, and so the two sub-topics might best be dealt with in an integrated way in a single systems map. Figure 5.4 shows the additional nodes that would be required, and how they would link to the woodfuel model.

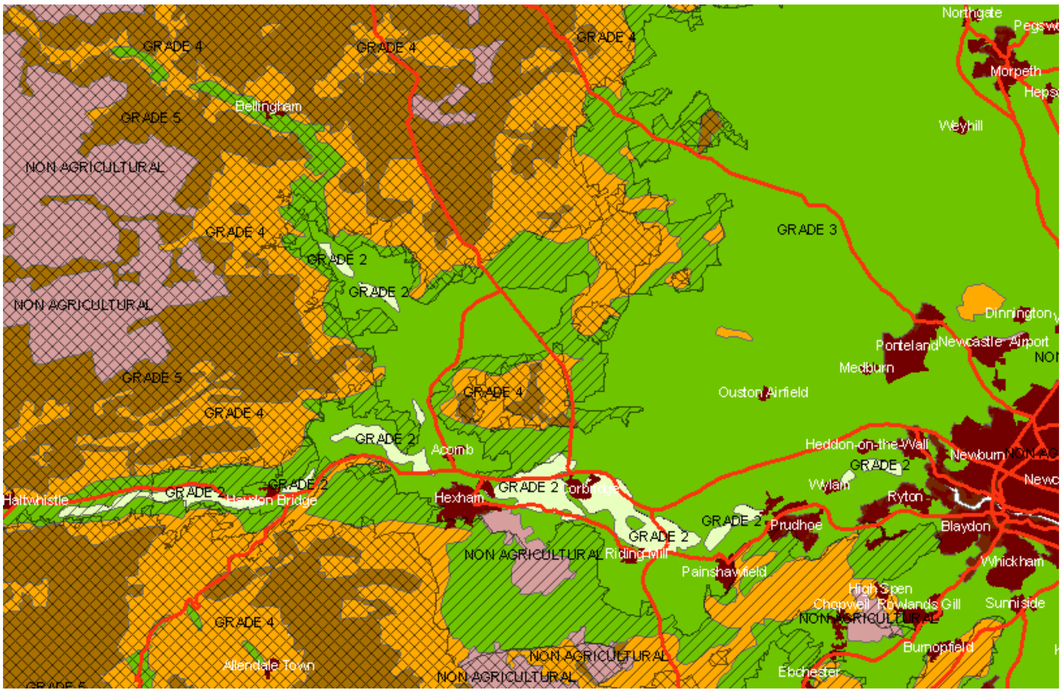
Figure 5.4: Supplementary nodes for new energy crop modelling



In terms of the calibration of the nodes shown in Figure 5.4 to cover the upland situation, the main problem is that sources of yield data largely assume lowland situations and deeper, more fertile soils compared to those of the uplands.

Although the energy crop sub-model could in principle be linked to the one for woodfuel production, in terms of developing an analysis for the uplands it is unclear what the benefits of doing so would be. It is likely that decisions on the uptake of energy crops would be taken on a farm by farm basis, and such crops would be confined to lower situations on better soils, largely outside the definition of uplands used here. As Figure 5.5 illustrates, only small pockets of land categorised as Grade 3 on the Agricultural Land Classification are to be found within the SDA boundary; the bulk of the SDA area is classified as Grades 4 & 5 or non-agricultural. The consequences for the uplands would mainly be in terms of either what new energy crops did to support incomes on farms, which included land in these higher areas, or the stimulus their general growth brought to the market and supply for biomass energy.

Figure 5.5: Relationship between Agricultural Land Classes and SDA Boundary



The map shows that the SDA boundary closely follows the distribution of land categories for Grades 4 and 5 according to the Agricultural Land Classification, although some Grade 3 does fall within the wider SD area. The lower, better quality land would probably be the location where energy crops were taken up if upland farms that included such land considered this management option. The area shown is east of Newcastle upon Tyne.

5.3.2 Spatial Mapping

As in the case of woodfuel, it would seem worthwhile to explore the potential distribution of energy crops at a national scale, and use these data to examine the contribution that the uplands could make, and more specifically the type of location where such crops might be located in such areas. Potentially such information could be combined with the ‘catchment area’ approach described above to identify areas where local biomass energy markets might be viable.

5.4 Biogas from organic wastes and crops

New technologies for converting organic material into processed fuels such as methane have been under development in recent years. For example, methane for electricity generation has increasingly been collected from landfill sites while anaerobic digesters taking organic waste from domestic and industrial sources are in use in some large towns and cities. Agricultural sources of organic material that are suitable for anaerobic digesters include cattle and pig slurry, poultry litter and grass. The contribution made by on-farm anaerobic digesters is currently small but could develop.

5.4.1 Systems-map

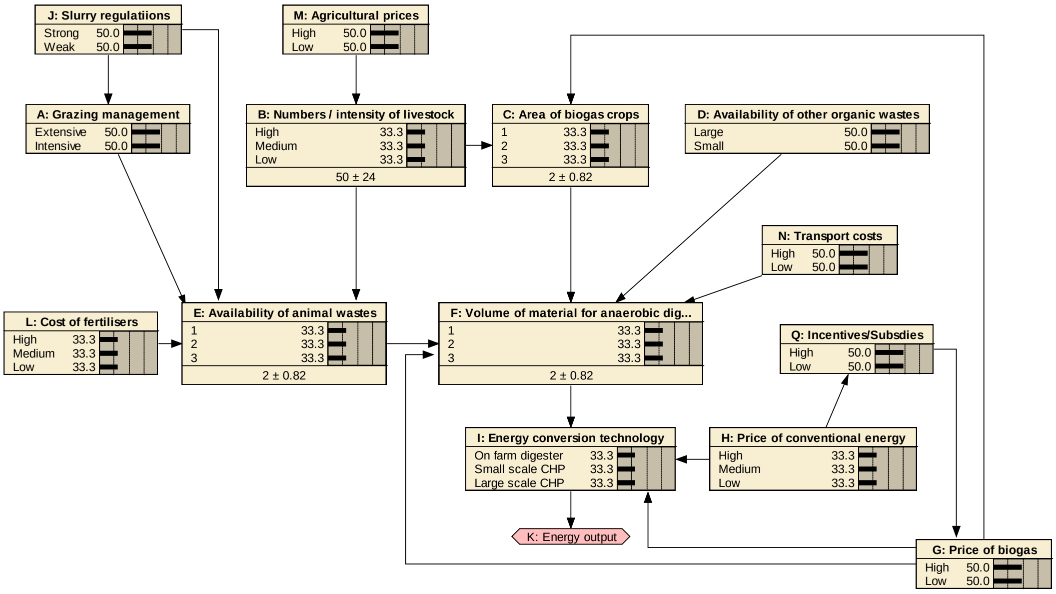
A simple systems map for the production of biogas is shown in Figure 5.6. Three principle sources of material are identified, namely livestock, biogas crops and the availability of other organic materials (largely from domestic waste).

Animal manures for anaerobic digesters come from housed livestock that produce a liquid or highly concentrated slurry, and so the production of biogas is partly controlled by the distribution of dairy cows, pigs and poultry. There are many dairy cows in the uplands (most of which are housed in the winter) but relatively few pigs or poultry. A rise in the intensity of dairy farming will normally tend to produce more slurry during the winter and, potentially reduce the amount of grass that could be supplied directly as a feedstock for anaerobic digestion. However, dairy cows that are farmed more extensively or are grazed outside for most of the year (under a ‘New Zealand’ grazing system) produce less recoverable slurry. Pollution regulations (node J) are encouraging farmers to reduce the amount of slurry that needs to be stored, particularly in high rainfall areas like the uplands, and so may encourage the search for alternatives means of dealing with such materials, such a biogas production.

As in the case of energy crops, it is likely that many of the decisions affecting the production of biogas will be made on a farm by farm basis, and which are probably affected by factors that go beyond the SDA boundary. Unlike the issues related to the location of new energy crops, however, it is possible that some of the land within the upland might be used to produce biogas crops.

Using current technologies, plant material suitable for anaerobic digestion needs to be both high in nitrogen and low in woody material. Productive grassland, of the kind used to grow silage in the uplands and its fringes is therefore potentially suitable as a source of material (hence node C). However, grassland in the uplands is only likely to be used for biogas where it is not needed for livestock production. Thus it may only be an option where livestock numbers have fallen either due to the influence of agricultural markets, or where the production for anaerobic digestion is more profitable than livestock farming; thus the link between nodes B and C.

Figure 5.6: Systems map for production of biogas

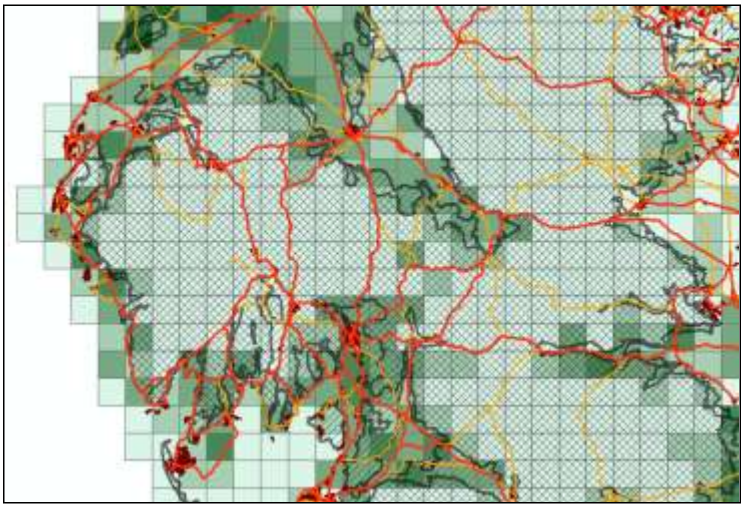


The cost of fertiliser (node A) has been included in the systems-map, because high fertiliser prices (which are highly dependent on global energy costs) will tend to reduce the intensity of livestock farming and increase the value of livestock slurry to the farmer as a source of plant nutrients. This may serve to reduce the amount of slurry available for biogas production. However, the solid digestate produced as a by product of anaerobic digestion has a value as a fertiliser and soil conditioner, offsetting, to some degree, the farmer's loss of the fertiliser value of the raw slurry.

5.4.2 Spatial Mapping

Given the farm-based nature of many of the factors that might contribute to biogas production, much of the data that might be used to build up 'a geography' of this ecosystem resource would come from the June Agricultural Survey[12] . Some of these data have been used in Figure 5.7 to show how the density of dairy farms tends to be higher on the lowland fringes of the uplands. Such data on farm type, along with animal numbers and grassland area could be used to model areas where clusters of farm units suitable for biogas production might be located, particularly when looked at in association with the distribution of population. These data suggest, however, that there would be some merit in including areas outside the SDA boundary, since their involvement in such enterprises are likely to be a stimulus to the local energy markets which may also benefit farms in higher elevations.

Figure 5.7: Distribution of dairy farms in relation to upland areas in Cumbria



The map shows the density of dairy farms in 2003 on a 5km x 5km grid basis for window on the uplands of Cumbria. The darker the green tone, the more farms have been assigned to the dairy category (the data have not been standardised to take account of number of farms in each grid square). The boundaries of the SDA and DA areas are shown. The data were derived from the June Agricultural survey.

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[12] http://www.defra.gov.uk/esg/work_htm/publications/cs/farmstats_web/default.htm

5.5 Wind power

Although not technically an ecosystem service the uplands clearly have considerable potential for the generation of wind power, and its development may be a factor in shaping future land management decisions and the strength of the rural economy. Hence it is a factor that must be considered in any consideration of upland environments and their links to human well-being.

National and regional government policy is leading to significant private sector investment in wind turbines, the size and efficiency of which has been increasing in recent years. There is currently over 700 MW of installed operational wind capacity in England (sufficient to power around 400,000 homes), with a further 350 MW of capacity under construction[13]. Many of the land-based wind farms are situated in the uplands[14]. Concerns about the environmental impacts of wind farms has led to national and regional planning policy which focuses on small-scale wind turbine development (i.e. discouraging large-scale) within protected landscapes. Nevertheless, larger scale developments may occur outside such areas where less restrictive planning restrictions apply.

5.5.1 Systems-map

A simplified systems map describing the key factors that influence the suitability of sites for wind power and ultimately energy output is shown in Figure 5.8. It is simplified in the sense that the wider environmental impacts have not been considered, but assumed in the node relating to planning restrictions (node I). The framework within which planning applications for wind energy developments are assessed influences the number of schemes that are approved or refused.

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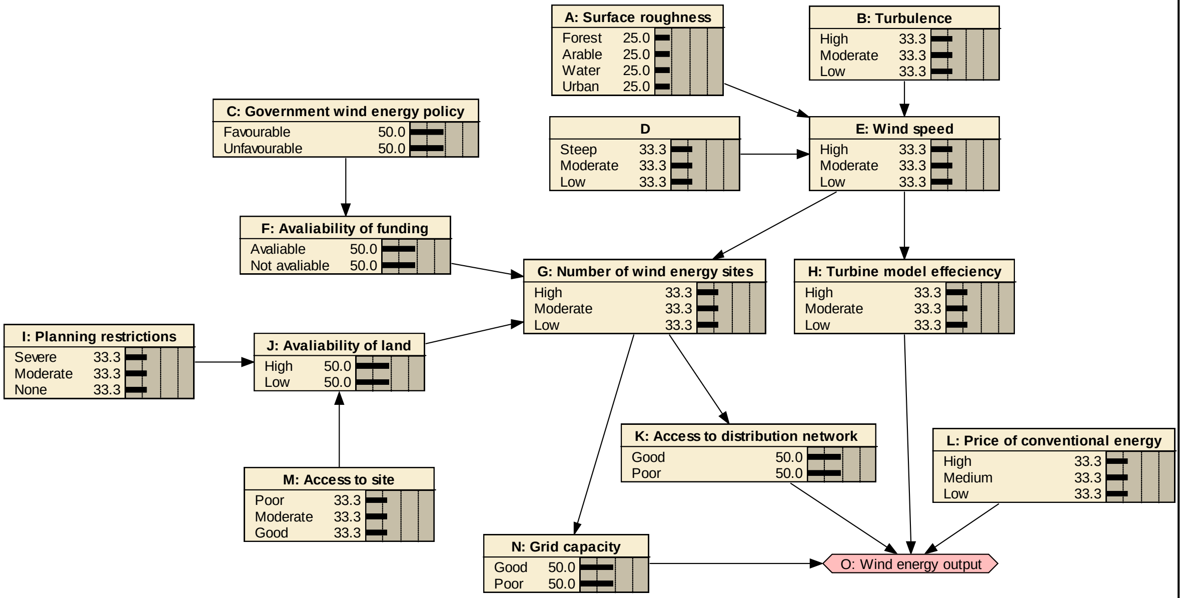
[13] Source: British Wind Energy Association

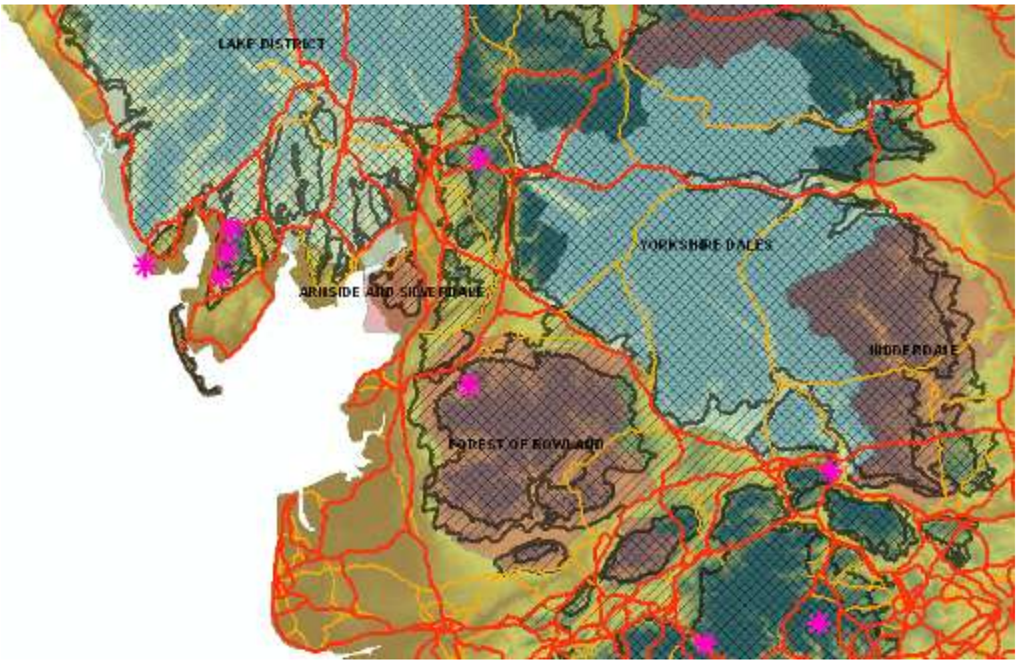
[14] Taking account of off-shore wind, the LFAs account for 18% of the total operating capacity currently installed or under construction (LUC, pers, comm., 2008).

Figure 5.8: Systems-map for wind power



Wind turbines are projects which are listed under Schedule 2.3(i) to the Environmental Impact Assessment Regulations. Local planning authorities are required to screen applications for the need for EIA where the development involves the installation of more than 2 turbines or the hub height of any turbine or height of any other structure exceeds 15 metres. If a proposed wind energy development is sited within an area that has been designated for nature conservation or landscape value, and the development could have a significant impact then planning permission will be more difficult to secure. National Parks, for example, are not presently considered appropriate areas for the development of wind power, which clearly limits the number of potential sites available in the uplands. However, some development has occurred in some Areas of Outstanding Natural Beauty that lie within the SDA boundary. As Figure 5.9 suggests, such limitations tend to lead to developments clustering around the boundaries of designated areas.

Figure 5.9: Distribution of wind power sites across the uplands in northern England, and their relationship to designated areas.



The map shows the location of major wind power sites in 2003 as recorded by the BWEA in relation to protected area boundaries, and the boundaries of the SDA in North West England.

Further restrictions arise in relation to the proximity of the development to housing and its relationship to radar installations. The availability of sites is also determined by ease of access (node M), since it will have to be able to accommodate abnormal loads for delivery of the turbine components. Wind turbine blades have to be delivered in one piece and can extend to 40m in length. The hub of the turbine can also be extremely heavy so access to the site (including bridges etc) will need to be able to accommodate heavy loads. Moreover, access to the electric grid and its capacity will also be key factors (nodes K and N). The distance from the proposed wind energy development to the National Grid can influence the viability of the scheme in terms of cost and scale of environmental impacts. Installation costs will increase with distance between the potential wind power site and the connection point to the grid. Many environmental concerns associated with such developments concern the landscape and visual impacts of the grid connection, although in many locations cables can be run underground. The capacity of the existing grid to accommodate new schemes is a further key factor which can influence the number of sites available for wind energy development. If there is no capacity in the grid, the grid will need to be upgraded which has associated cost implications which may prevent schemes from being taken forward.

5.5.2 Spatial Mapping

Given the physical and planning restrictions that determine site availability, there is a good prospect of using available data to map wind power potential for upland areas in England. Modelled wind speed data are available on a 1km x 1km grid square basis for 10m, 25m and 45m above the ground from the Department for Business Enterprises and Regulatory Reform (BERR)[15], which can be used to refine mapping further.

5.6 Hydro-power

The high rainfall and varied topography of the uplands makes them well-suited to impounding water for hydroelectricity generation. A national programme of hydropower development and water storage for human supply in the 1950s and 1960s created reservoirs in many of the most suitable upland valleys. Future development is likely to be on a reduced scale (micro-hydro up to 100 kW power and small-scale up to 5MW), with latest technologies making grid-connected plants based around a low impact 'run-of-river' design (i.e. not involving the impounding of water) feasible. In this study we have focussed on these smaller scale technologies. While small-scale hydro-generation is currently one of the most cost effective and carbon-efficient sources of renewable energy, it nevertheless can have environmental impacts on the migration and other movement of aquatic species (such as the salmon and otter).

5.6.1 Systems-Map

A systems map describing the major factors thought to influence the development of small- and micro-hydro is shown in Figure 5.11. The energy produced by smaller scale hydro schemes is directly proportional to the volume of water and the vertical distance it falls (the head). Thus a similar amount of energy could be produced form a small volume of water falling over a long vertical distance as from a larger amount of water falling over a much shorter distance (thus nodes H and J). It is assumed that at a regional scale, the average head and discharge will vary, and that in the longer term climate change may affect flow characteristics (hence nodes R and Q).

The total energy output is assumed to be dependent on the average site power (node A), turbine efficiency (node D) and the number of potential sites in the area (node B). The latter is perhaps the most complex node suggested in the model, since it is likely to vary in relation to the average site power (presumably the higher the average the more potential sites), the efficiency of the technology and the number of restrictions on sites, either in terms of the environmental and recreational characteristics of the area, or proximity to the consumer. Small scale hydro schemes are often linked to the premises of the end user and/or the distribution network. The financial viability of the scheme will be influenced by the distance to the end user or grid (hence node G).

In terms of environmental impacts, water abstraction has the potential to have a negative impact on fish stocks and fish spawning grounds. However, this risk can be minimised by careful design and adjustment of the seasonal operating schedule of the plant. On the

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[15] http://www.berr.gov.uk/energy/sources/renewables/explained/wind/windspeed-database/page27328.html

positive side, small scale hydro could lead to the creation of weirs and pools which could have a positive impact on fisheries. Some types of turbine (such as low to medium head cross-flow designs) can oxygenate the river water and may thereby benefit the fish population. The Environment Agency has stringent controls on water abstraction, particularly where nature conservation interests are evident.

5.6.2 Spatial Mapping

The network shown in Figure 5.10 could be used to calculate service output, say in terms of 'average site power', either on a small catchment or reach basis, and the total capacity or potential in an area estimated by taking the other influencing factors shown in the conceptual model into account.

In terms of data that are already available, a key resource is the national assessment of the potential for small-scale hydro developments in the UK was Small *Scale Hydroelectric Generation Potential in the UK* (ETSU 1989). It considered every river within the UK and major reservoirs, and identified potential sites with hydraulic heads of greater than 3m (or 2m where weirs already exist). Sites with smaller heads were not considered to be economically viable given the technology available at the time. The assessment also took some account of planning and environmental constraints. Although this work is now nearly 20 years old, it has been used as a starting point for more recent work, such as that used to provide the mapped data shown in Figure 5.11. These data are derived from the *Lancashire and Yorkshire Renewable Energy Planning Study*, published in 1998[16]. The sites identified by the original ETSU study were added to information derived from subsequent feasibility studies made in the region. Altogether 73 viable sites were identified. Parts of these data are mapped in Figure 5.12, with sites represented both in terms of head and capacity. The proximity in relation to the boundary of the SDA and DA is also shown.

A number of such studies exist for other parts of England, which could potentially be used to identify potential sites for micro-hydro generation. These data could also be used to calibrate and test modelling procedures that might be used to extend this approach and ultimately link it to other data on the potential for renewable energy generation from a wider range of sources.

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[16] ETSU & Terrence Rourke PLC (1998)

Figure 5.10: Systems-Map for Hydro-Power

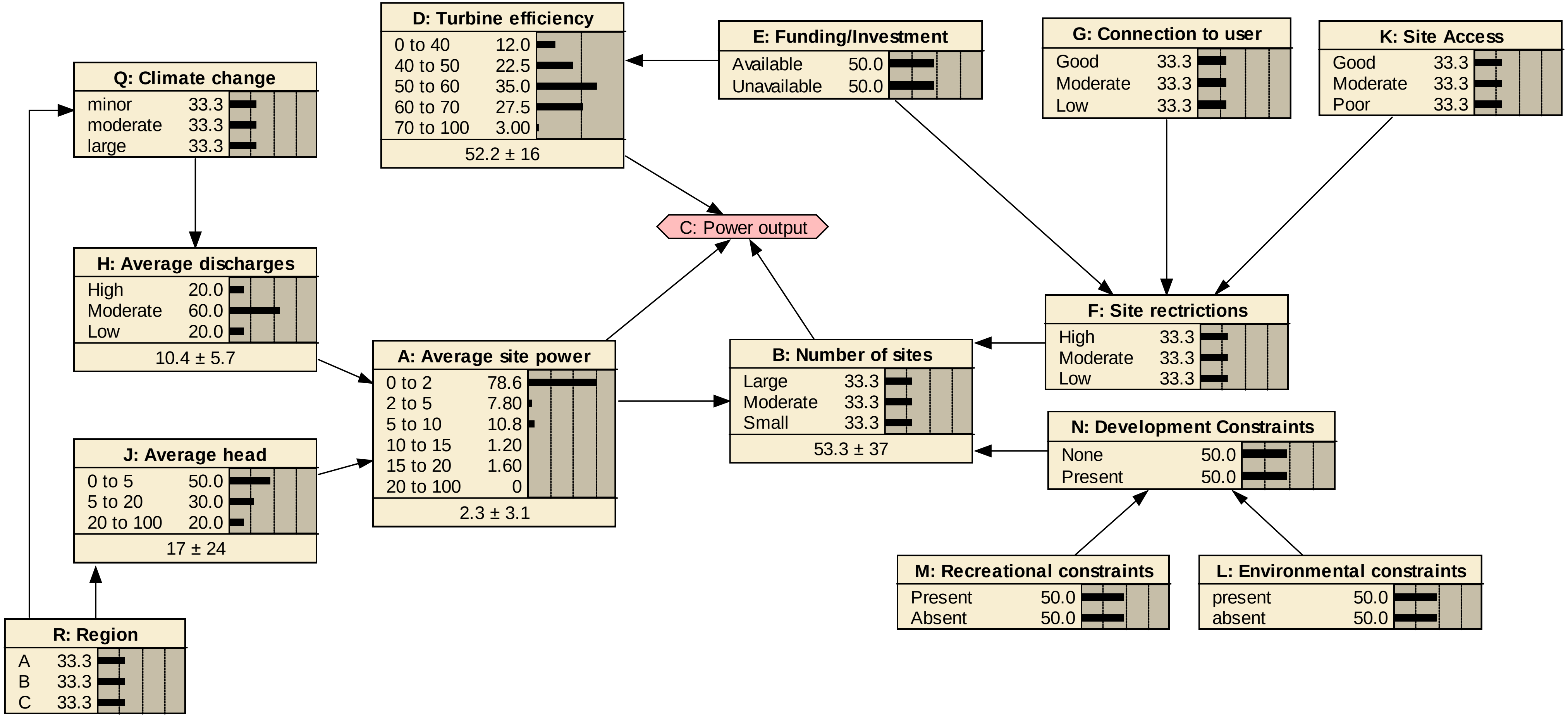
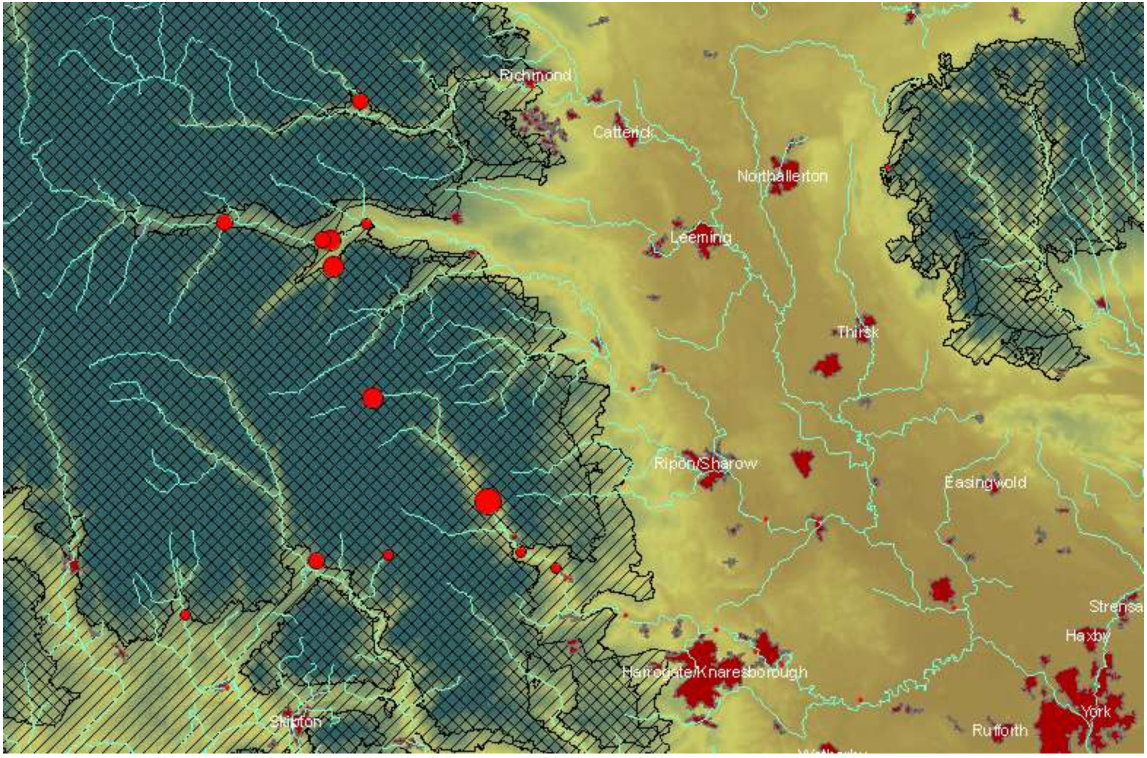
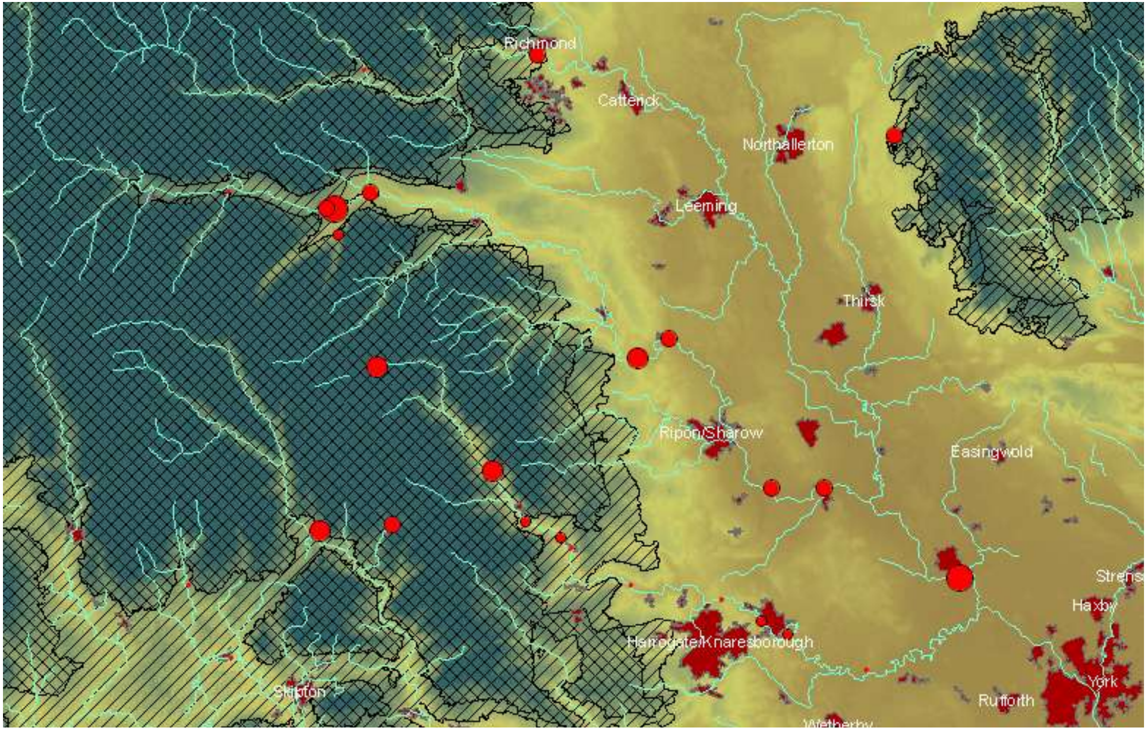


Figure 5.11: Potential small-scale hydro sites in Northern England (based on data from the *Lancashire and Yorkshire Renewable Energy Planning Study)*

a. Variation of hydraulic head (m) by site



b. V*ariation of capacity (kW inst.) by site*



5.7 Review of conceptual and spatial mapping for renewable energy in the uplands

The key messages form Part five are:

- It seems feasible to construct separate concept maps for each of the main renewable sources that might be important in the uplands.
- It is difficult to separate the factors influencing these services from those affecting energy markets outside the uplands.
- Possibly such studies should be looked at nationally, so that the contribution that the uplands make can be fully contextualised.
- All of the technologies considered have strong links to land management issues, and need to be considered both, in terms of the constraints that conditions in the upland place upon the development of these energy sources, and the benefits these developments might have for the rural economy.
- The synergies between the technologies in terms of stimulating local energy markets needs to be considered.
- The integration of renewable energy technologies into farm business models needs to be considered in order to make reliable predictions about the consequences of such developments for land management.

Part 6: Water Provisioning and Flood regulation

6.1 Introduction

The uplands of England have a significant role in the provision and regulation of water quantity and quality. Upland catchments have often been modified through the construction of reservoirs, to increase their capacity to store water, and the vegetation and soils of the surrounding land is an important asset, in terms of securing the supply of waters of high chemical and biological quality, both as surface runoff and ground water recharge. Moreover the hydrological characteristics of upland catchments are often significant in the control of river discharges at lower altitudes, and thus the regulation of flooding. As a result, understanding of the water provisioning and regulation services associated with upland ecosystems is one of the most important steps towards identifying the benefits that these areas provide for society.

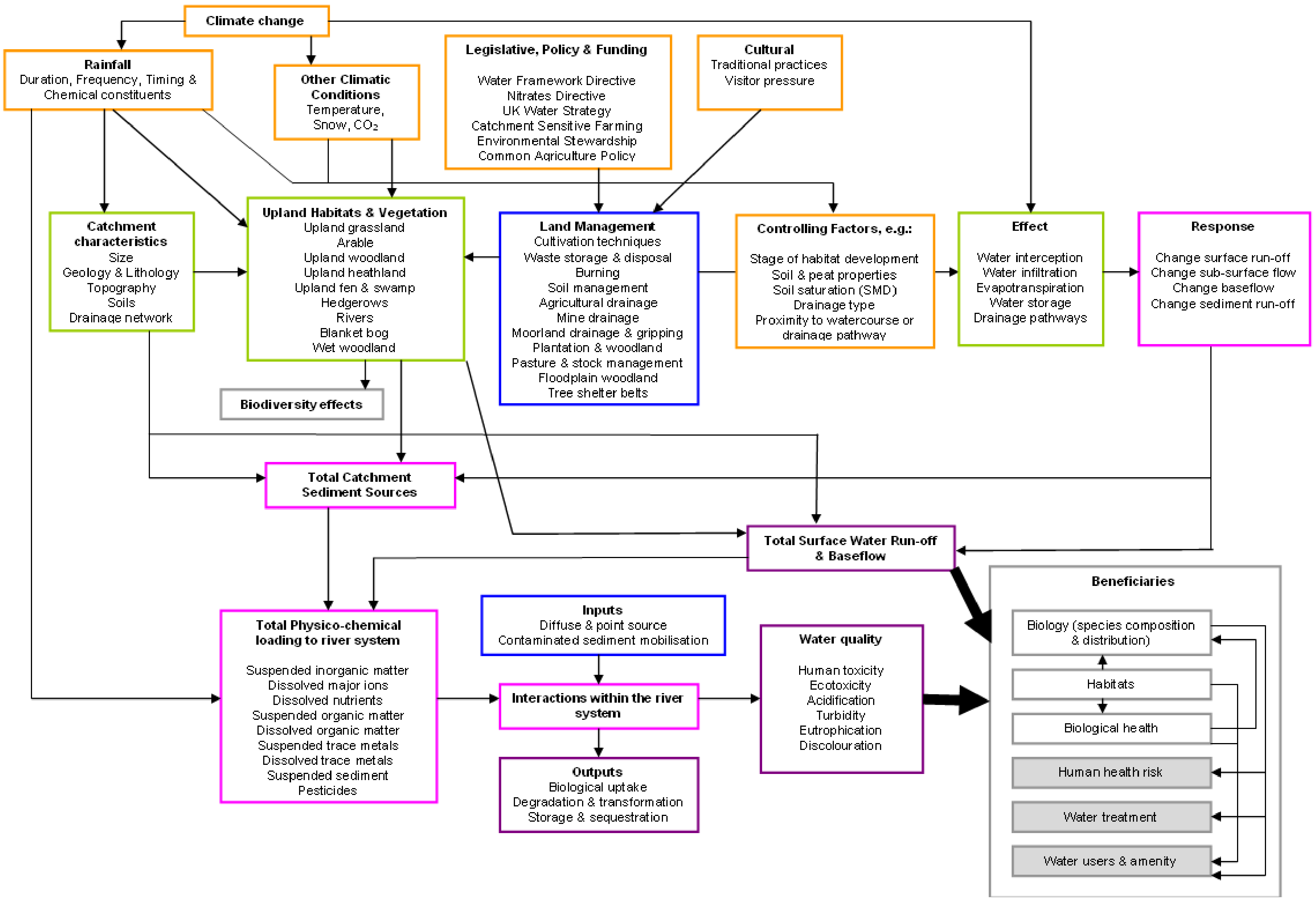
Given the limited time available for this study, we have sought to scope out the issues surrounding the influence that upland ecosystems have on water quantity and quality, rather than attempting to model the hydrological and hydrodynamic processes in detail. These are inherently complex issues and merit a separate more extensive and detailed study at a later stage. Instead, in this section of the report we seek to explore the nature of the ecosystem services provided by the uplands in relation to the provision and regulation of water supply. As in the case of renewable energy, the issues are far from clear. The *ecological* structures and processes which influence both the quantity and quality of water in the uplands are part of, and interact with, a much broader hydrological system, and it is often difficult to disentangle those elements that depend on biodiversity from abotic factors. If we want to understand the benefits that the uplands provide to society in terms of influence on water quantity and quality, the physical characteristics of these areas are probably as important as their ecological properties.

In order to develop a clear focus for the work on water, we consulted with a number of experts within NE to determine how ‘they saw’ the issues. This resulted in the construction of two conceptual maps, one dealing with the general topic of ‘provisioning’ (involving issues relating to both quantity and quality) and a second dealing more specifically with flood regulation. In this Part of the report, we describe each of these models and how elements of them might be represented as an ecosystem service, using where appropriate the BBN methodology. This Part concludes with a review of spatial mapping issues.

6.2 Scoping the conceptual maps for water provisioning and flood regulation

Figure 6.1 shows the general conceptual model for the ‘water provisioning’ issue that we developed through our consultation. Even though it only deals with surface runoff, the broad scope of the model is clear. The complex ways that ecological structures and processes are conceived as being embedded in a wider hydrological system involving many other, independent physical elements is apparent. The boxes have been colour coded, according to Figure 1.1, to identify the direct and indirect drivers, the ecological structures and processes, functions, services and potential benefits. However, a clear distinction between ecosystem services *sensu stricto* and more general ‘environmental’ or wider ‘landscape’ services is difficult to make given the general nature of the model.

Figure 6.1: Conceptual model for the factors influencing 'water provisioning' in the uplands



Two 'outputs' are identified in the provisioning model, namely 'total surface water runoff and baseflow', and 'water quality', which provide a number of potentially beneficial uses. Although these outputs could be described as 'services' in the most general sense, it is clear that they are not wholly dependent on ecological structures, processes and functions, since they are also controlled by a number of other physio-chemical factors.

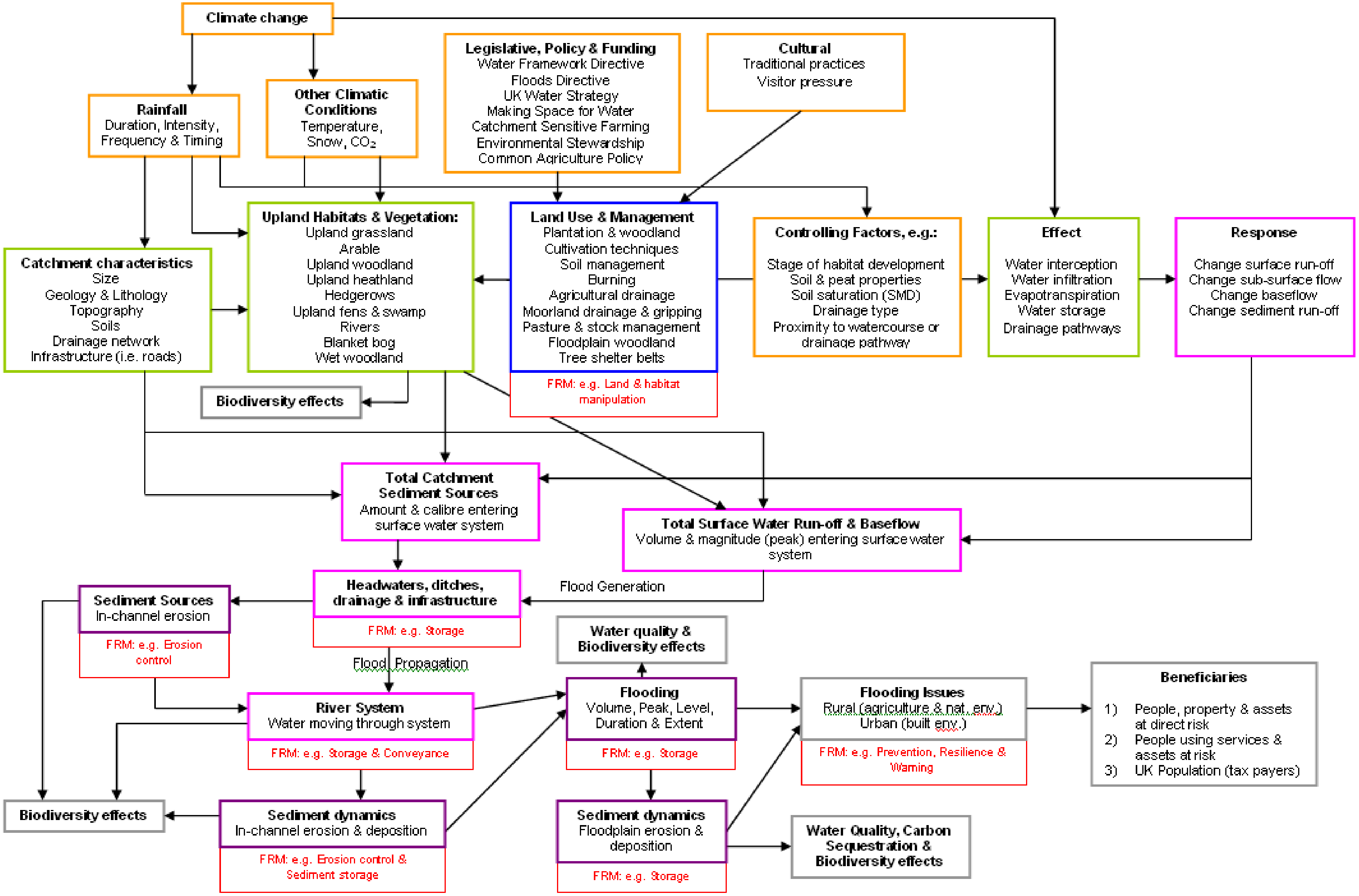
For example, the major indirect driver of both water output and the quality of those waters is precipitation input, in terms of the magnitude, frequency and seasonal distribution of precipitation events, as well as precipitation chemistry. The way these inputs result in a specific set of hydrological responses depends on the physical characteristics of the catchment (size, geology, topography, drainage pattern, management activities) as well as the cover of vegetation and soils. The extent to which these ecological systems provide an identifiable 'ecosystem service' in relation to water quantity and quality depends on the extent to which they modify the flow of water through the hydrological system, or its composition, in ways that have tangible benefits for society.

As the conceptual model shown in Figure 6.1 suggests, these 'services' can take a number of different forms. They range from the role of specific types of vegetation cover in the interception of precipitation inputs, the role that specific vegetation types have on slowing of the passage of water through the hydrological system, the role of ecological processes in controlling sediment run-off, or run-off chemistry, and the importance of in-stream biological processes on water quality and discharge. The scale of their importance is, however, difficult to judge. Natural climatic variability is probably the dominant factor in influencing the frequency and magnitude of flood events, and it would appear that land use management effects are of second order importance (Atkins, 2007). The extent to which 'in-catchment' ecological processes are less important for water quality than the chemistry of atmospheric input, is less clear.

In view of the multiple 'services' that ecological systems potentially provide in relation to the flow of water and its chemical and biological quality, a more specific exercise was undertaken that looked specifically at the issue of 'flood control'. Figure 6.2 shows the resulting conceptual model that has been worked up through discussions with experts and policy advisors in NE. It has the same broad structure as Figure 6.1, in terms of direct and indirect drivers and 'outputs', but the processes influencing flood risk have been expanded. In addition to the impact that different types of vegetation cover have on the magnitude and intensity of runoff events, ecological systems also influence the risk of flooding through the control they may have on sediment sources. The amount and calibre of sediment entering headwaters and ditches, for example, will strongly influence the speed of water moving through the system as well as the risk of erosion. A number of specific influences have been identified in relation to the role of ecological ecosystems and 'flood mitigation' in upland environments:

The conceptual models shown in Figures 6.1 and 6.2 are clearly complex in structure, and would require considerable effort to convert into a fully calibrated BBN. We have, however, extracted some of the key relationships identified in these two schemas, and represented them in network format in order to provide a platform for future development. Since there are a number of common factors influencing water quantity and quality it was decided to include them in the same model. However, in view of the wide scope of the elements suggested in Figure 6.1 and 6.2, the resulting networks have been highly simplified.

Figure 6.2: Conceptual model for the factors influencing 'flood regulation' in the uplands



6.3 A preliminary BBN for water provisioning and flood regulation

Network structure

A preliminary BBN covering the issues related to water provisioning and flood protection is shown in Figure 6.3. The assumption is that it operates at the catchment scale. The principle ecological driver is vegetation cover and related land management factors such as grazing pressure, land drainage and liming. Other drivers include climatic variables covering rainfall amount and intensity, atmospheric chemistry, and a topographic factor ‘average basin slope’, together with factors influencing the sensitivity of soils to acidification. The service outputs are discharge volume, flood risk, and water quality.

In Figure 6.3, vegetation cover is assumed to influence both discharge volumes, through its interception potential (node E) and erosion potential (node E2). In the model the vegetation types are clearly highly simplified, but its structure does illustrate how different cover types can influence these two key elements differently (Table 6.1). Nodes E and E1 allow each vegetation type to be given a different weight, expressing its capacity to influence both the interception and erosion potential. In the UK, woodlands are generally thought to be less susceptible to run-off than other types of land cover such as pasture and agricultural crops (Armstrong et al., 1990). Woodland tends to increase interception and evapo-transpiration, increase infiltration and increase impediment to flow leading to a decrease in run-off (yield and peak). In terms of regulating flows, woodland is generally considered to reduce low flows but has a more limited potential to reduce peak flows. Thus in Table 6.1, woodlands are given a larger weight than the other cover types in terms of their impact on discharge volume.

Tale 6.1 Weights used to model sensitivities of interception and erosion potentials to vegetation type

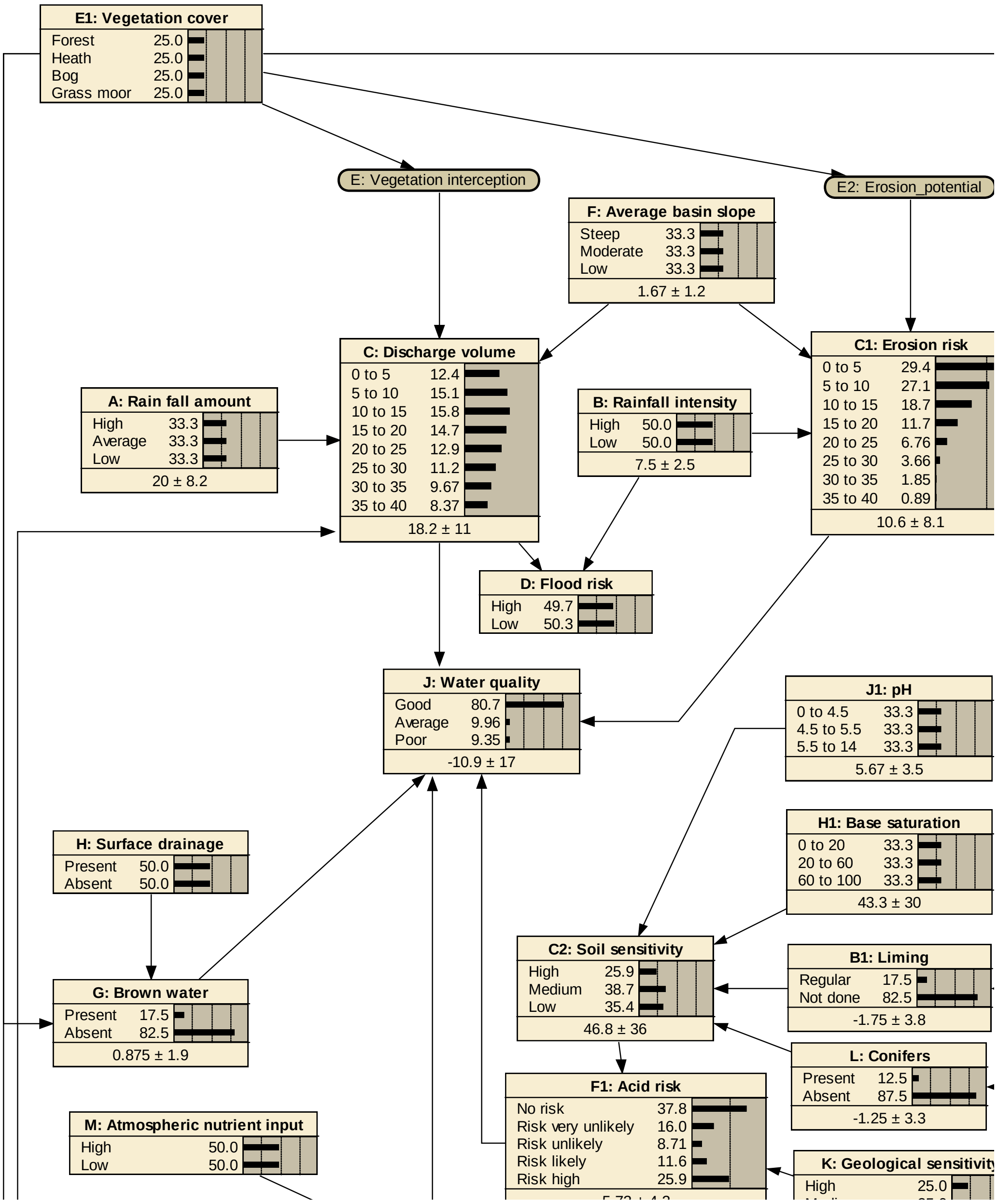
Vegetation type	Interception potential	Erosion potential
Forest	**3**	**1**
Heath	**2**	**2**
Bog	**2**	**3**
Grass moor	**1**	**1**

Note:

- *For interception the greater the weight the greater the capacity of the vegetation type to reduce surface discharges.*
- *For erosion potential, the greater the weight the greater the susceptibility of the soils associated with the vegetation type to erosion.*

It is generally assumed that pasture (particularly permanent pasture and rough grazing) can increase infiltration and reduce run-off. Thus it is given one of the lowest weights for its influence on discharge volume. However, intensification of grazing (stocking density and length of grazing period) can lead to increased compaction and increased run-off. Appropriate pasture management can influence run-off at local scale although probably a large extent change is needed to reduce or delay downstream flood peaks. Sensitive grazing management can also reduce sediment inputs. These effects are expressed in the model in terms of the node for grazing pressure (node N) and its links to discharge volume (node C) and erosion risk (node C1).

Figure 6.3: BBN for water provisioning and flood mitigation



In terms of erosion potential, bog has been assigned the highest weight, followed by heath, indicating that these have the greatest influence on erosion potential; for this factor, forest is assigned the lowest weight. The assumptions used here largely follow the studies of the MAFF sponsored work on *The Quantification and Causes of Upland Erosion*[17] and McHugh (2000), which suggested, on the basis of field measurements, that mean erosion rates were

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[17] http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=6503#RelatedDocuments

lowest under bracken and highest on heather, mixed heather/bog and bog vegetation. These studies suggested that the association was possibly more to do with the characteristics of the soils on which these plant communities are found, than any direct relationship to the vegetation themselves.. The sensitivity of peat soils was partly attributed to their vulnerability when their hydrology was disrupted by artificial drainage. As it stands, however, given the lack of information available, the model shown in Figure 6.3 is unable to express the combinations of soil and vegetation types that might be found in the uplands

Soil drainage has been undertaken widely in upland areas in England, to alleviate surface water problems mainly to improve agricultural productivity (Robinson and Armstrong, 1988). The effects on water flow and water quality varies with context, depending on soil properties, topography and soil wetness. However, drainage has been particularly problematic in relation to peat soils. Worrell et al. (2007) note that in the UK efforts to drain upland peat areas reached a climax in the 1970s. It was undertaken mainly to increase grazing for sheep and improve habitat conditions for grouse. As noted in Part 3, the creation of grips and drains have not only impacted on the ability of peat soils to sequester carbon, but also significantly increased the rates of runoff in such areas, as well as water quality. The removal of discolouration in water and dissolved organic matter in waters through draining eroding peat soils can impose significant treatment costs upon water companies (Worrell et al., 2007). The blocking grips can slow the rate of water flow and increase the height of the water table, thereby reducing day-to-day run-off as well as improving water quality (Worrell et al. 2007). The protection of permanently waterlogged soils and the halting of any new land drainage schemes or modification to existing drainage infrastructure that would increase run-off are now conditions of the England ELS scheme for flood risk management.

The model shown in Figure 6.3 attempts to take the issues relating to peat erosion and water quality into account by including nodes for ‘brown water’ and the presence of surface drainage (nodes G and H). If surface drainage is ‘present’ and vegetation is either bog or heath, then the risk of ‘brown water is increased. In the model, the impact on risk is set to be greater for bog vegetation than heath.

In terms of the influence of vegetation and land management upon discharge volume and water quality, the model shown in Figure 6.3 omits a number of potentially important local factors. In the uplands, preparation measures prior to woodland planting, such as the installation of drainage and haulage roads, can increase run-off and peak flows, although the effect ameliorates over time (O’Connell, 2004). The planting of tree shelter belts can also increase infiltration and reduce run-off volumes and sediment inputs. The effect is most apparent for non-saturated soils, and so shelter belts may be most effective in terms of mitigating the effects of short duration, high intensity rainfall events. Flood plain woodlands are also considered to have beneficial effects in terms of controlling the intensity and duration of flood events by modifying downstream discharges. Their effect is probably most marked on the narrow floodplains in middle and upper reaches of a catchment. It is thought that compared to other land cover types, woodland on flood plains delays flood peak times and peak flows by increasing roughness. However, by slowing the passage of water downstream, such woodland may increase the chances of flooding up stream, and may trap sediments and debris that could later be flushed from the system at times of extreme events (O'Connell, et al. 2004, Thorne et al., 1997). At this stage it is difficult to see how such factors could be built into the BBN shown in Figure 6.3.

Turning to water quality, the model shown in Figure 6.3 attempts to develop an aggregate measure that takes account of the influence of sediment input (arising from soil erosion), water discolouration (peat oxidation), acidification and diffuse pollution (nitrogen and phosphorous). The factors controlling sediment load and water discolouration have been described above. The structure of the nodes for acidification have been based on the accounts of Hornung et al. (1995) and the EA[18], which suggest that acidification risk (node F1) is mainly dependent on soil pH (node J1) and base saturation (H1). Acidification risk has been found to be reduced by liming (node B1), but may be exacerbated by the presence of coniferous plantations on vulnerable soils (node L). Both effects have been included in the model.

The risk of diffuse pollution is assumed mainly to be due to the input of phosphorus and nitrogen into water courses. The model assumes that atmospheric input is a key source, but the risk may also be increased by high animal numbers. The effects of point sources have not been included in the model.

Activating the water net

Figure 6.4 shows the effects of changing some of the key nodes in the water net. For example, while the network was initiated with all the vegetation types having equal abundance (Figure 6.3), we can use it to show the potential differences in a catchment with complete cover of bog, under conditions of high atmospheric nutrient input, with and without management of surface drainage. The average catchment slope has been set to low, to reflect the fact that such vegetation cover is more likely to be associated with low angle slopes. A comparison of the outputs suggests that the improvement in water quality brought about by drain blocking (surface drainage absent) is proportionally larger under conditions of high atmospheric nutrient input than when such inputs are lower.

A further manipulation of the net is shown in Figure 6.5. This set of graphs allows a comparison between the proportional effects of the probability of different levels of rainfall intensity on the erosion risk associated with each vegetation type. The model suggests that the differences between vegetation covers, in terms of their effect of reducing erosion potential, is least under conditions of high rainfall intensity.

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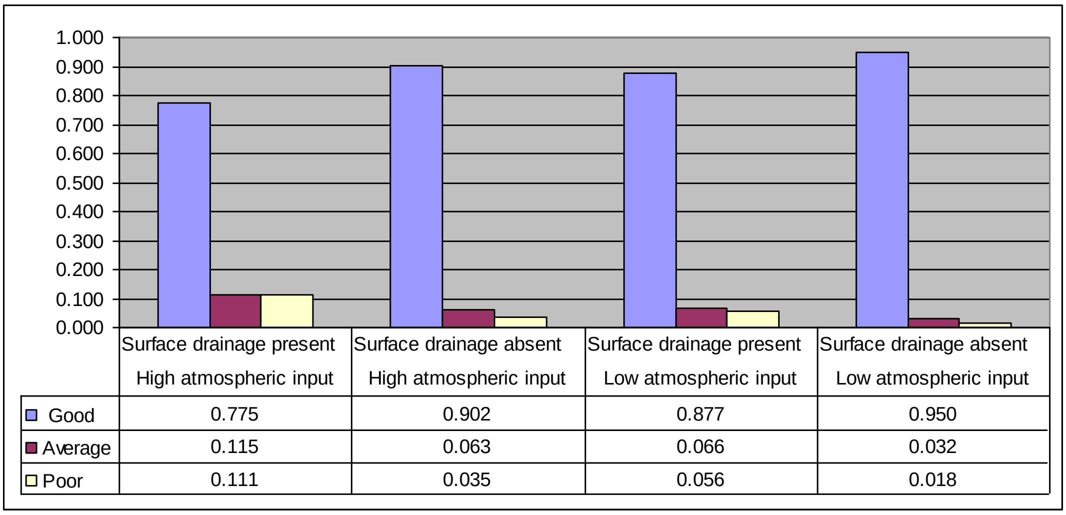
[18] http://www.environment-agency.gov.uk/commondata/acrobat/r_acidification_t_v2_1781436.pdf

Figure 6.4: Effect of removal of surface drainage on water quality for bog vegetation under conditions of high and low atmospheric nutrient input.

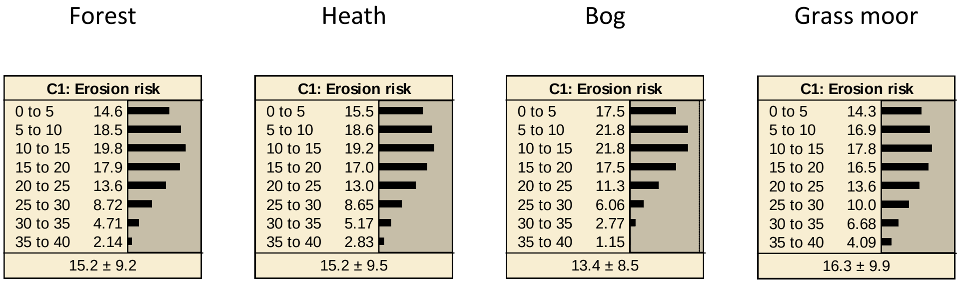


	Surface drainage present High atmospheric input	Surface drainage absent High atmospheric input	Surface drainage present Low atmospheric input	Surface drainage absent Low atmospheric input
▢ Good	0.775	0.902	0.877	0.950
■ Average	0.115	0.063	0.066	0.032
▢ Poor	0.111	0.035	0.056	0.018

The bar charts show the probability of achieving good, average and poor water quality under the different combinations of conditions for surface drainage and atmospheric nutrient input when vegetation type is set to bog, and slope angle is set to low.

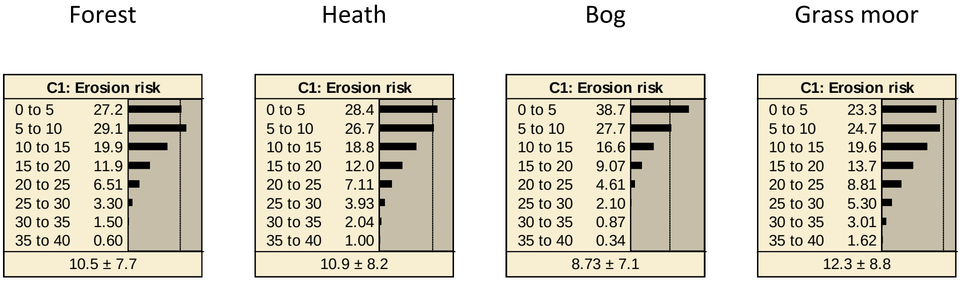
Figure 6.5: Effect of catchments with different land covers on erosion risk

High rainfall intensity



C1: Erosion risk	Forest	Heath	Bog	Grass moor
0 to 5	14.6	15.5	17.5	14.3
5 to 10	18.5	18.6	21.8	16.9
10 to 15	19.8	19.2	21.8	17.8
15 to 20	17.9	17.0	17.5	16.5
20 to 25	13.6	13.0	11.3	13.6
25 to 30	8.72	8.65	6.06	10.0
30 to 35	4.71	5.17	2.77	6.68
35 to 40	2.14	2.83	1.15	4.09
	15.2 ± 9.2	15.2 ± 9.5	13.4 ± 8.5	16.3 ± 9.9

High and low rainfall intensity equally likely



C1: Erosion risk	Forest	Heath	Bog	Grass moor
0 to 5	27.2	28.4	38.7	23.3
5 to 10	29.1	26.7	27.7	24.7
10 to 15	19.9	18.8	16.6	19.6
15 to 20	11.9	12.0	9.07	13.7
20 to 25	6.51	7.11	4.61	8.81
25 to 30	3.30	3.93	2.10	5.30
30 to 35	1.50	2.04	0.87	3.01
35 to 40	0.60	1.00	0.34	1.62
	10.5 ± 7.7	10.9 ± 8.2	8.73 ± 7.1	12.3 ± 8.8

Note: In each case the node A, vegetation cover has been set to 100% for each type with rainfall intensity set either to ‘high’, or to ‘high’ and ‘low’ with equal probability (base-line conditions)

Evaluation of the BBN

Since water provisioning and flood risk was one of the topics that was to be considered in a less detailed way by the present study (see page 2), further refinement and exploration of the network shown in Figure 6.3 was not undertaken. Nevertheless the exercise did succeed in identifying a number of issues, particularly how one might frame ideas in relation to how we define ecosystem services in relation to water provisioning and flooding. The main point illustrated by the model is how difficult it is to define exactly what constitutes such services in terms of some measurable parameter, since so many factors potentially influence water quantity and quality. It seems to be the case that in relation to these service themes, ecological systems play more of an intermediate role in the delivery of the overall outputs, and that they are best assessed by looking at the *marginal effects* they have on final outputs such as discharge volume, and erosion risk.

The nature of these marginal effects is, in fact illustrated by the analysis presented in Figures 6.4 and 6.5. If the network had been calibrated more rigorously, and the effects predicted really do occur ‘on the ground’, then the network could be used as the basis for making an economic valuation of the marginal benefits of different land management decisions under different conditions. Moreover, it also seems possible that the network could be used in the context of a benefit transfer exercise. Thus, in the case of the management of surface drainage, if the marginal costs and benefits of the different management strategies had been determined, say, for present conditions, then a fully calibrated network has the potential to test whether the differences seen are maintained under other sets of circumstances.

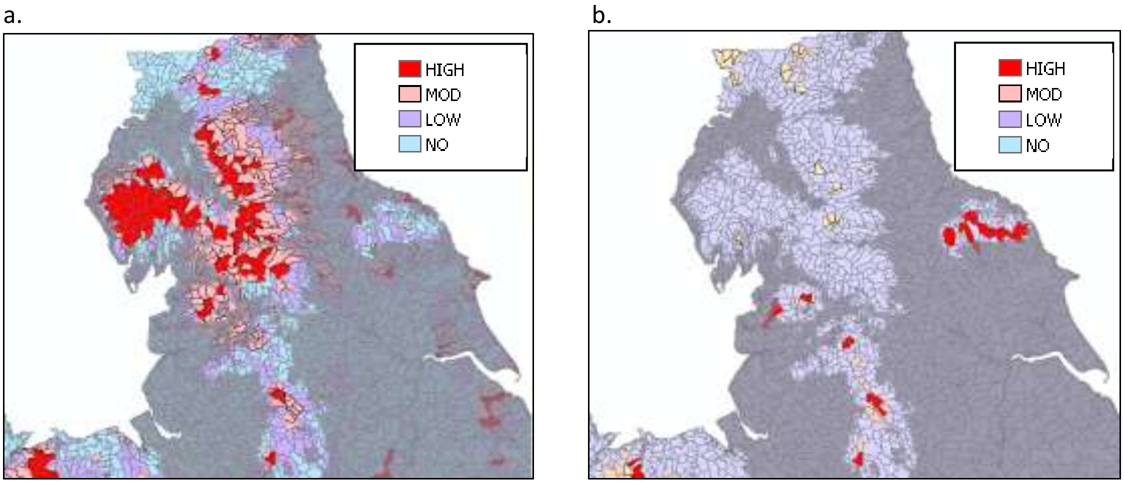
Nevertheless, before further development of the BBN is discussed, a number of fundamental issues must be considered. Most especially, the nature of the spatial unit modelled by the BBN should, perhaps, be more clearly specified. It has been assumed that the model applies to catchments, but this could be more explicitly recognised if the network included more of the parameters used in basin characterisation exercises, such as those being led by the Environment Agency (Environment Agency, 2006; see also Defra 2007). This work, which has been developed in response to the requirements of the *Water Framework Directive* (WFD), seeks to better understand the pressures, risks and impacts on water bodies in general. The work on ecosystem services related to water provisioning and flood risk alleviation could be taken forward using this framework, by focussing on how ecological systems mitigate or protect from specific pressures or risks, or help buffer people against specific kinds of impacts in different types of location. Some of the data that these characterisation exercises have generated are discussed below in the context of how spatial maps of ecosystem services might be constructed.

6.4 Spatial mapping for water provisioning and flood regulation

Compared to many of the other service themes considered by this study, there is an extensive body of easily accessible data available relating to water quality which can give some insight into how ecosystem services related to the water theme might be mapped spatially; examples for the risks associated with sediment and acidification risk are shown in Figure 6.6 a & b.

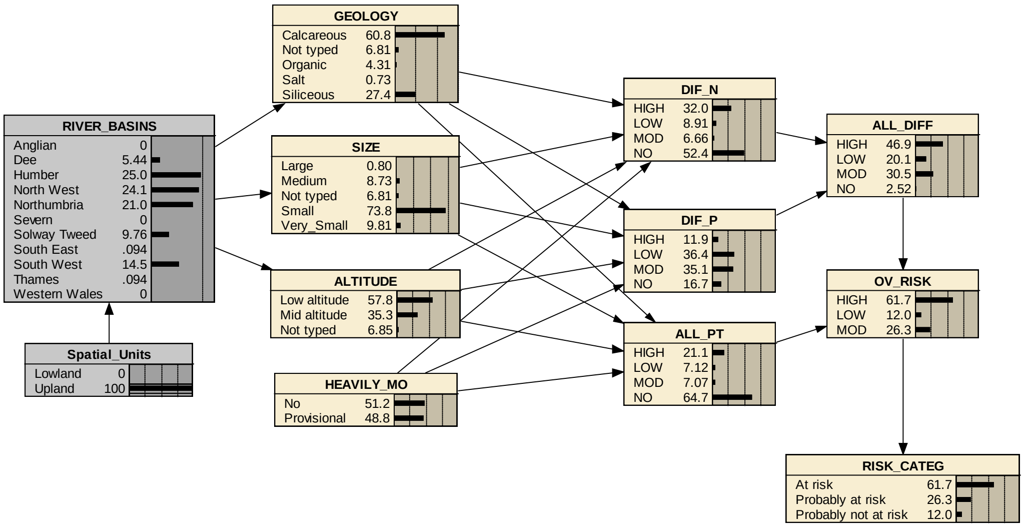
These sediment and acidification data arise from the WFD river basin characterisation work undertaken by the EA, which aims to establish the extent of the diffuse pollution problem and to identify those water bodies where nutrient, sediment and pathogen inputs were compromising WFD objectives. Detailed mapping is available for river catchments as well as lakes and groundwater sources. This mapping, together with other information on the extent of flood risk and biological and chemical water quality offer a good foundation on which to build an analysis of those locations which are potentially at high risk or in poor condition, where the 'intermediate' services provided by ecological systems might make a significant contribution in risk reduction. These data can also be used to help calibrate BBNs, which describe the relationships more fully, as is illustrated in Figure 6.7.

Figure 6.6: Spatial variation in sediment and acid risk at catchment level scale



In each case the maps have been overlain by a mask showing the area within the severely disadvantaged areas. Note also these data are from the first (2005) basic characterisation exercise, and have been recently modified in a second-round study (2008). The data from this second study are not currently available to the project team.

Figure 6.7: BBN for point and diffuse pollution risk in England, based on data arising from the first round of river basin characterisation undertaken by the EA in 2005.



The BBN shown in Figure 6.7 was constructed using the data for each of the 7817 river basins in England and Wales to calibrate the probability tables. The basins were already assigned to River Basin areas, but have also been tagged using the mask for the Severely Disadvantaged Areas to show which are in the uplands. In reviewing the net it is important to note that not all the risk factors have been included, although the aggregated risk assessment (Ov_Risk) and the combined measure for diffuse pollution (All_diff) are included, together with the risk category assigned to the basin by the EA. The BBN shown selects those basins which are uplands, and within England. The network suggests that the majority of basins in the uplands (62%) have been assigned a to a high risk category as a result of the combination of individual factors, and that there is roughly a 46% chance that this assignment reflects risks associated with diffuse pollution. The chances are that it is more likely to be due to nitrogen input than phosphorus.

It should be noted that these data are from the first river basin characterisation exercise undertaken by the EA, and the probabilities are likely to be different using the revised characterisation methodologies used in the second round. Nevertheless, they indicate what kinds of approach might be developed by combining the spatial mapping data with BBN techniques. Future work could take each basin in each risk category and investigate the contribution which particular ecological structures and process make either in terms of mitigating the risk or in terms of offering opportunities, though management interventions, of reducing that risk. In this way the ‘marginal’ benefits of ecosystem services for water quality or flood risk, say, might be determined.

6.5 Review of conceptual and spatial mapping of water provisioning and flood regulation

The key conclusions from Part 6 are:

- It is difficult to separate the role of ecological structures and processes from the other variables that control water quantity and quality and so identify clear ecosystem services in relation to this topic area.
- The most promising way forward would be to look at the extent to which ecological structures and processes affect the risks to water quality and flooding at the catchment scale.
- A large body of potentially useful information exists for England, and further work should attempt to characterise catchments in terms of the ecological structure in a more detailed way, and to link this with future basin assessments made in relation to managing land resources within the context of the Water Framework Directive.

Part 7: Developing a Unified Approach to Conceptual Mapping

7.1 Introduction

It became apparent during the project that there were a number of common direct and indirect drivers or controlling factors represented in the different conceptual maps. Although not part of the brief for this study, it was suggested that further consideration of these shared elements might provide the opportunity to link up the separate topic areas into a more unified picture. Such a strategy might also reduce the time required to operationalise each of them. We focus our discussion on three main topic areas, namely those relating to scale and location, biophysical drivers and the rural economy. The aim is to identify how these common elements might be framed, rather than to build a unified model at this stage. We will use the conclusions to suggest possible future development strategies should the conceptual models presented here be developed further.

7.2 Scale and Location

A recurring issue across all the conceptual models is the spatial scale at which they should be designed to operate, and what types of 'locations' the models should specify, or whether a nest approach to the scaling issue should be adopted. In order to provide some commonality across the models it would seem useful, initially at least, to attempt to design them to deal with issues at roughly the same spatial scales, and in this study we have attempted to do this by trying to look at the uplands as a whole. The problem that this poses is that the uplands are, of course, a very diverse set of landscapes, and it is difficult to describe explicitly the key differences that we find between them.

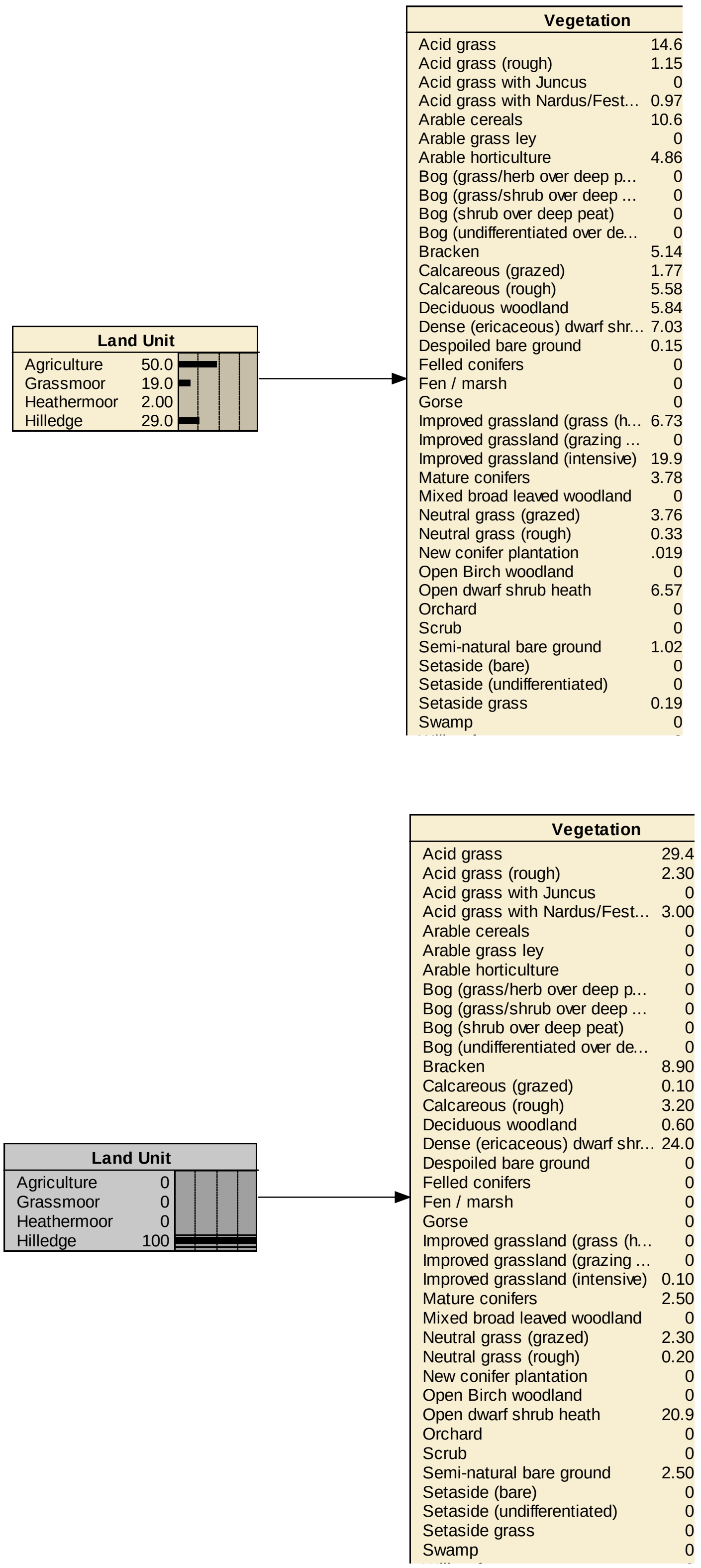
To some extent differences between upland areas can be taken into account by the design of some of the controlling nodes. Two strategies are possible:

- Where a node shows proportional vegetation cover as in Figure 7.1, a 'locational switch' can be included that allows the different frequencies in different locations to be represented. The diagram shows how the proportions of the key cover types vary between two landscape units. Note that when neither area is selected the average of the two is provided. These data were derived from the Review of Hill-edge Habitats in the uplands of England and Wales study by Milsom et al. (2002), which provided information on the proportions of cover types recorded by Land Cover Map 2000, in different topographic situations in the different upland blocks found at national scales.

Where a set of areas have different characteristics, each area can be represented as a record in a database, and the network used to look at them on a 'case by case' basis. If we assume the carbon model described in Part 3 is applied to a set of 1km x 1km grid squares, for example, the conditions found in each, say relating to afforestation, peat restoration and gully blocking, can be read in ‘record by record’ so that the consequences for different locations can be observed.

Use of a cases file, containing records of specific combinations of node states observed at different locations, is also valuable as a way of calibrating a network. A possible future research strategy might be to identify a set of locations across the uplands (e.g. grid squares, catchments or farm units), and record for each the expression of the different characteristics associated with them, and then use these data to assign probabilities to the nodes.

Figure 7.1: The probability of different vegetation types in different land units expressed in a BBN.



Land Unit	
Agriculture	50.0
Grassmoor	19.0
Heathermoor	2.00
Hilledge	29.0

Vegetation	
Acid grass	14.6
Acid grass (rough)	1.15
Acid grass with Juncus	0
Acid grass with Nardus/Fest...	0.97
Arable cereals	10.6
Arable grass ley	0
Arable horticulture	4.86
Bog (grass/herb over deep p...	0
Bog (grass/shrub over deep ...	0
Bog (shrub over deep peat)	0
Bog (undifferentiated over de...	0
Bracken	5.14
Calcareous (grazed)	1.77
Calcareous (rough)	5.58
Deciduous woodland	5.84
Dense (ericaceous) dwarf shr...	7.03
Despoiled bare ground	0.15
Felled conifers	0
Fen / marsh	0
Gorse	0
Improved grassland (grass (h...	6.73
Improved grassland (grazing ...	0
Improved grassland (intensive)	19.9
Mature conifers	3.78
Mixed broad leaved woodland	0
Neutral grass (grazed)	3.76
Neutral grass (rough)	0.33
New conifer plantation	.019
Open Birch woodland	0
Open dwarf shrub heath	6.57
Orchard	0
Scrub	0
Semi-natural bare ground	1.02
Setaside (bare)	0
Setaside (undifferentiated)	0
Setaside grass	0.19
Swamp	0

Land Unit	
Agriculture	0
Grassmoor	0
Heathermoor	0
Hilledge	100

Vegetation	
Acid grass	29.4
Acid grass (rough)	2.30
Acid grass with Juncus	0
Acid grass with Nardus/Fest...	3.00
Arable cereals	0
Arable grass ley	0
Arable horticulture	0
Bog (grass/herb over deep p...	0
Bog (grass/shrub over deep ...	0
Bog (shrub over deep peat)	0
Bog (undifferentiated over de...	0
Bracken	8.90
Calcareous (grazed)	0.10
Calcareous (rough)	3.20
Deciduous woodland	0.60
Dense (ericaceous) dwarf shr...	24.0
Despoiled bare ground	0
Felled conifers	0
Fen / marsh	0
Gorse	0
Improved grassland (grass (h...	0
Improved grassland (grazing ...	0
Improved grassland (intensive)	0.10
Mature conifers	2.50
Mixed broad leaved woodland	0
Neutral grass (grazed)	2.30
Neutral grass (rough)	0.20
New conifer plantation	0
Open Birch woodland	0
Open dwarf shrub heath	20.9
Orchard	0
Scrub	0
Semi-natural bare ground	2.50
Setaside (bare)	0
Setaside (undifferentiated)	0
Setaside grass	0
Swamp	0

A further set of test locations could be used to examine how accurate the network was in suggesting the types of characteristics that might be found in these additional locations. **We recommend that before further work is undertaken, NE consider what types of location they would like to consider when using networks to examine future scenarios, and that a calibration exercise either using empirical data and/or expert judgement and stakeholder opinion is undertaken.**

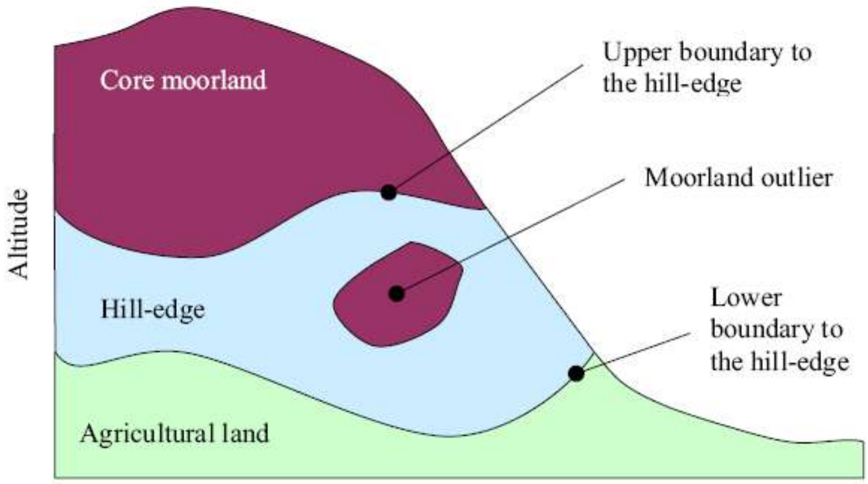
7.3 Biophysical drivers

Since the purpose of designing the networks presented here was to explore the mechanisms underpinning ecosystem services it would seem likely that some set of biophysical characteristics might be common to them. The way these might be included in each of the networks is suggested above; the key conceptual question is what precisely should these biophysical characteristics be? The following recommendations seem appropriate on the basis of the investigations made here.

Land Cover: Most commentators agree that land cover typologies are best handled in a nested way, broad classes split into finer thematic detail as and when required. Such a strategy is one that recommends itself for the construction of BBN, since it helps cope with the fact that sources often have different data structures. **We suggest that Countryside Survey and particularly the satellite derived land cover mapping that is associated with it forms an appropriate nested framework for future work, not least because its class structure has (and is) been used as a framework for national scale carbon budget estimates. It is also a framework in which major changes in land cover and use can be represented.**

Topographic Context: The sensitivity of upland systems to both biophysical and socio-economic drivers clearly varies by topographic location; the contrasts between open, unenclosed moor and in-bye land, for example, are particularly stark and represent a boundary that has moved historically. The probability of finding different habitats in different locations is also partly dependent on topographic context (plateau top, valley side, valley bottom, etc.). At the most general level the distinction between core moor (split between heather and grass moor types), hill-edge and agricultural areas suggested by Milsom et al. (2002) is a useful one (Figure 7.2). A second and more detailed typology of topographic units is provided by the draft national landscape typology at level 1, or level 2 where it is available. We recommend that the three-fold distinction of Milsom and his co-workers is a useful staring point, and that in any future development of conceptual maps the relationship of these units, to those of these other more detailed typologies, are investigated, so that a nested approach to topographic context might be built into them.

Figure 7.2: The position of moor, hill-edge and agricultural landscape components in the uplands (after Milsom et al., 2002).



Climate Change: The need to include the effects of climate change in the networks was a common element in the feedback we gained in each of the topic areas explored with our stakeholders. Information about alternative and plausible climate futures are now readily available, and as the network presented for carbon shows these can readily be built into a BBN; possible changes can be indicated on a probabilistic basis (e.g. see Figure 3.2, Node G, temperature) or in a more deterministic way (e.g. see Figure 3.2, Nodes C and F, summer drought and rainfall).

The problem that we face in taking such work forward is that we need to understand the sensitivities of particular locations to these broad-scale changes in climate, so that their effects can be built into future modelling exercises. **We recommend that as part of any future modelling exercise, a common climate change model is developed and that some attempt is made to consider how the effects of change will be expressed in different types of location (e.g. by altitude, aspect, region etc.).**

7.4 The Rural Economy

Upland rural economies are diverse and complex open systems shaped by a range of economic, political and social drivers operating on many scales: global to national, to regional, to local, to individual. While there are a considerable number of sources describing these drivers for the wider rural context or for particular discreet habitat types, there are few that deal specifically with the upland sub-set in its entirety. A key area of focus is to determine how many of the forces observed in the wider rural context can be carried over to the uplands; are they magnified, minimized or equally significant? What are the special characteristics of the upland setting when considering the impact of these drivers on landscape and land use? Do these factors apply equally in all upland areas? It should also be remembered that the use of the term ‘uplands’ indicates some commonalities shared between these areas, but as discussed above, each locality has its own identity so the ‘uplands’ are far from homogeneous (as the specific habitat studies show).

As part of this study we commissioned a short review of how some of the key indirect drivers might impact on land management decisions and the structure and prosperity of rural communities (Appendix I)[19]. The most important issues that ought to be taken into account in any future modelling exercise are as follows:

- **Demographics**: The most frequent observation regarding the demographics of upland and rural areas are the changes in population structure. Lowe and Ward (2007) report on the wider rural scene and characterise the current situation as one "of growing counter-urbanisation" (p.308). Rural England has an increasing population of more than 100,000 per year, although it is unclear how this increase is split between upland and lowland areas.

  In terms of change in population structure, Holden et al. (2007) noted evidence to suggest that younger unskilled workers are moving to urban areas due to the scarce opportunities for financially rewarding employment. The same age group is also being priced out of the local housing market due to increasingly affluent commuter populations and an influx of second home owners. The remaining population with an interest in traditional employment opportunities is often older, causing shortages of suitable labour for traditional land management practices. Midmore et al. (1998) citing Alcock (1992), for example, reports the significant decline in the extent and quality of hedges in the uplands due to the lack of skills, as mechanised flailing and heavy browsing results in poor hedge structure and impoverished ground flora (also leading to relatively low wildlife value). The counter-urban incomers appear to be those with young families and the middle aged (less than 10% are retired). This flow boosts local demand for services and swells the pool of those who might start up in business or self employment. However, these trends suggest that the population in the uplands may be ageing at a faster rate than the urban population. This is coupled with pockets of poor pay (average wages are 10% lower compared to urban areas) since the bulk of unskilled employment is related to farming and tourism (Defra, 2005). Together this presents an interesting set of challenges to the rural economy in the uplands which are likely to be important components of any scenario study. **Thus we recommend that as part of any future modelling exercises, a demographic component is included, covering as a minimum population size, age and social structure, labour force and employment patterns.**
- **Rural Businesses**: Lowe and Ward (2007) describe four sectors that account for 80% of employment in rural areas; distribution and retailing, business and financial services, public administration (including education, training and health), and manufacturing. Farming constitutes just 2.6% of the rural employment despite using 75% of the land surface. Once again it is unclear how these split across upland and lowland areas, but it is plausible to assume that the proportion in agriculture probably rises in the lowlands. Although farming adds little in terms of overall

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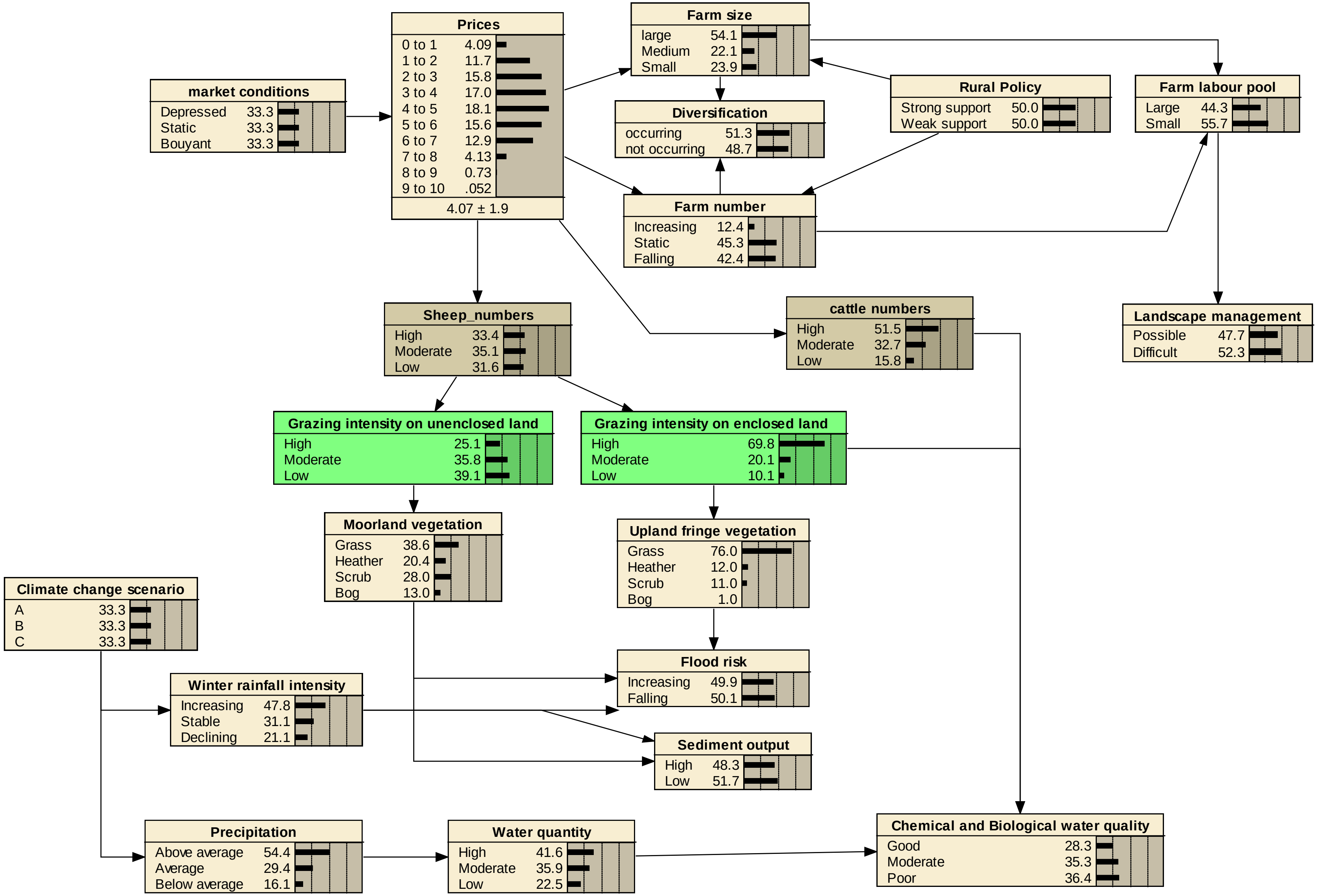
[19] Appendix A-I are in a separate document available from the Project manager or Natural England's Officer for the project.

employment it remains important to isolated rural economies for the ecological services that it provides and the landscapes that it maintains. These in turn attract tourists, in-migrants, businesses and conservation/environmental activities to upland areas. **The structure and profitability of the farming sector in upland areas is an important component in any future modelling exercise, and we recommend that it forms a key component of future work.**

- Figure 7.3 indicates how such factors may begin to be integrated and described. The BBN builds on the simple model discussed in Part 2, and seeks to trace through the effect of changes in grazing intensity and the balance between different types of livestock on vegetation condition and outputs such as sediment loads, flood risk and biological and chemical water quality. The network also attempts to include the supposed effects of different climate scenarios (say IPCC scenarios) and their influence on rainfall amount and intensity. Although we have activated this network, the assignment of probabilities has been based only on our judgement, and it is intended mainly for illustrative purposes. Nevertheless it could form a basis for a more refined approach to linking the influence of the farm sector across all the networks presented here.

Figure 7.3: Prototype integrated model for land management factors in the uplands



Although it is important to examine the effects of the agricultural sector on land management decisions it should also be noted that there are other business drivers that are important in rural areas. It has been suggested, for example, that in addition to the growing counter urbanisation driver discussed above, the other business economic drivers are: the relocation of firms and the growth and diversification of existing small rural firms. Relocation is principally from professional services or manufacturing enterprises to converted barns and estate yards or to large purpose built warehousing and industrial sites close to major infrastructure networks. The way these drivers impact on the economy of the uplands and associated land management decisions is difficult to judge, and we have not as yet attempted to include them in the structure of the conceptual network shown in Figure 7.4. **A critical consideration of their importance would seem to be an important element of any future study.**

- **Policy**: In recent years there have been frequent policy changes affecting the uplands. During the 1990s, for example, one of the main mechanisms was the Hill Livestock Compensatory Allowance (HLCA) part of the Less Favoured Area (LFA) scheme, which was based on compensating hill farmers on a per head basis for their animals. It is widely recognised that this led to; overstocking and thus overgrazing (Dwyer and Baldock, 2000; LUC, 2002; Winter et al., 1998; Drew Associates and The Agricultural Economics Unit, 1997; Firbank et al., 2000; Hughes and Jenkins 1990), also a switch from hay to silage (LUC, 2002), the use of native woodlands for grazing (preventing natural regeneration) and a growing imbalance in the mix of grazing animals towards sheep. It was then replaced with area based Hill Farm Allowances (HFA) and the problem of overgrazing in the English uplands was somewhat reduced, but is still considered to be a significant problem.

  Given the obvious sensitivity of upland areas to policy change, it would seem worthwhile to develop a ‘policy’ sub-network that could also be linked across the topic areas. The work could draw upon the range of review material already in the literature and aim, for example to represent some of the implications of the reform of the Common Agricultural Policy (CAP). A key focus should be how this may change the use of land while maintaining sustainability and the support of conservation and environmental interests – particularly in the face of changing conditions such as climate change, fuel price inflation and potential worldwide food shortages and price increases. Conservation of the landscape and wildlife has been financially supported through the European Union’s Agenda 2000 proposals, which see farmers as custodians of the countryside. While the policy model cannot predict precisely what the outcomes will be, the network could be set up to examine the implications of varying levels of policy success, and the minimum amounts of support that might be needed under different biophysical or demographic scenarios. It would be useful to distinguish the different types of schemes (SFP, ELS, HLS EWGS) in such work. It could also be extended to include the potential impact of different regulatory regimes, relating to pollution control and potential payments for ecosystem services.

7.5 Review

Although linking models across topic areas would make for a large and complex structure, it is important to note that in terms of 'integration', the different elements need not physically be connected.

The integration we suggest here can initially be achieved by adopting a common structure for the direct and indirect drivers, and ways of representing 'locational' characteristics. Users can then examine the topic separately, but be able to explore the consequences of the same sets of assumptions across the different topic areas. Clearly there may be some feedback or interactions between the different services, and ultimately a more physically integrated structure may be necessary. However, for the sake of transparency, we suggest, the more modest aim of developing a common framework of assumptions and constrains across the models would be a good staring point. A further advantage of such a framework would be that other ecosystem services models could also exploit it, thus speeding up the development process.

The key messages from the Part 7 are as follows:

- A unified approach will help simplify some of the complexity inherent in conceptual maps.
- The inherent complexity suggests that first efforts should concentrate on common elements rather than a single unified model – which is unlikely to be obtainable or useful.
- Seeking common spatial scales on which to base networks is useful for clarity and comparability but it is important to retain focus on the functional scales within networks. The 'uplands' are not necessarily a functional unit for different ecosystem services themes, or they intersect with functional units at different scales.
- To some degree conceptual networks can be fitted to different spatial scales by manipulating the content and function of controlling nodes – but it must be remembered there are implications for detail versus generalisation in doing so.
- Different evidence and 'cases' from different locations can be used to apply networks in different places and at different scales.
- The importance of biophysical characteristics to different ecosystem service themes is variable. Common elements such as land cover and topographic typologies are relevant to most/all applications. These should be adopted and applied in nested hierarchies to allow for the resolution of greater detail.
- Climate change acts as a driver, constraint and impact upon ecosystem services cross-cutting all themes. A common approach and model for climate change and how it should be considered and expressed in different applications should be developed.
- The rural economy provides a good example of a cross-cutting issue where there are clear impacts in the uplands but the related geography is complex and extends far beyond the specific uplands area. Upland areas are undergoing demographic and economic changes driven by wider structural changes and world markets.

- Despite the fact that farming is only a minority component in the economy of the uplands, it has disproportionate importance for the fabric of the landscape and local communities.
- Policy also has a disproportionate influence upon the uplands owing to the large proportion (historically) of price support and intervention in these areas. There is a case for greater integration and alignment of policy instruments.

Part 8: A typology of upland services

8.1 Introduction

There are in the literature a number of ecosystem service typologies. The aims that have prompted their development have been various. On the one hand they are used mainly to illustrate or highlight the range of benefits that ecosystems can provide (MA, 2005). On the other they have sought to provide an exhaustive and systematic characterisation of *all* ecosystem services and types (e.g. De Groot 1992; 2006; De Groot et al., 2002). In the brief for this study we were asked to consider whether a general service typology is needed for the uplands and how this might help future conceptual and spatial mapping. We were also asked to consider how the typology might relate to issues of habitat quality, conservation status and biodiversity characteristics of a site or area.

In this part of our report we argue that given the typologies available it is probably not in terms of refining their thematic detail that the main challenge for development is to be found. Rather it is in more precisely specifying what the different service elements actually involve, what processes underpin them and how they can be measured where the main contribution of future work might be made. The typology we present is intended as a schema that helps guide users in identifying what an ecosystem service is and how the mechanisms underpinning it might be identified.

8.2 Ecosystem, Environmental and Landscape Services

Our consultations with NE staff and other experts suggested that despite the wide spread use of the term ‘ecosystem services’ there were considerable differences in the ways people framed the notion of an ecosystem. At one extreme, some people simply regarded an ‘ecosystem’ as represented by the entirety of the biological and physical elements found in an area. As a result they made no distinction between abiotic resources such as wind and hydro power, and those that were more closely linked to biodiversity, such as the sequestration of carbon in peat. On the other hand some people argued that fundamentally ecosystem services are those benefits that nature provides that are dependent upon living organisms. This seems to be the position represented in, for example the Millennium Ecosystem Assessment (MA, 2005).

Clearly questions about what is and is not an ecosystem service are fundamental to the development of a service typology, since these decisions determine what kinds of benefit are included in any schema. Thus the problem is not simply an academic one.

The difficulty of drawing the definition of an ecosystem service so widely is that using this approach it is difficult to see what is not an ‘ecosystem service’. With these more inclusive definitions of ecosystem services, it would be difficult to argue, for example, that socio-economic systems should not also be included since they also involve the interaction of biotic and abiotic units. Is quarrying an ecosystem service?

The close coupling of ecological and socio-economic systems like we find in the uplands and cultural landscapes elsewhere makes it very difficult to construct service typologies. Many of the benefits we see arising from nature in the uplands depend on the conjunction of ecological and socio-economic processes, as the case of management of heather moors by burning reveals. Nevertheless, it is probably worthwhile to try to distinguish the benefits to well-being associated with these areas that are more closely dependent upon biodiversity from those that are not. We therefore propose that:

- The term ‘ecosystem services’ is used to refer to the benefits that people enjoy that are fundamentally or directly dependent on the operation of living systems;
- Whereas the label ‘environmental’ or ‘landscape’ service is used to describe those benefits that arise because of the more general abotic characteristics of an area, that give rise to such potentials as wind or hydro power.

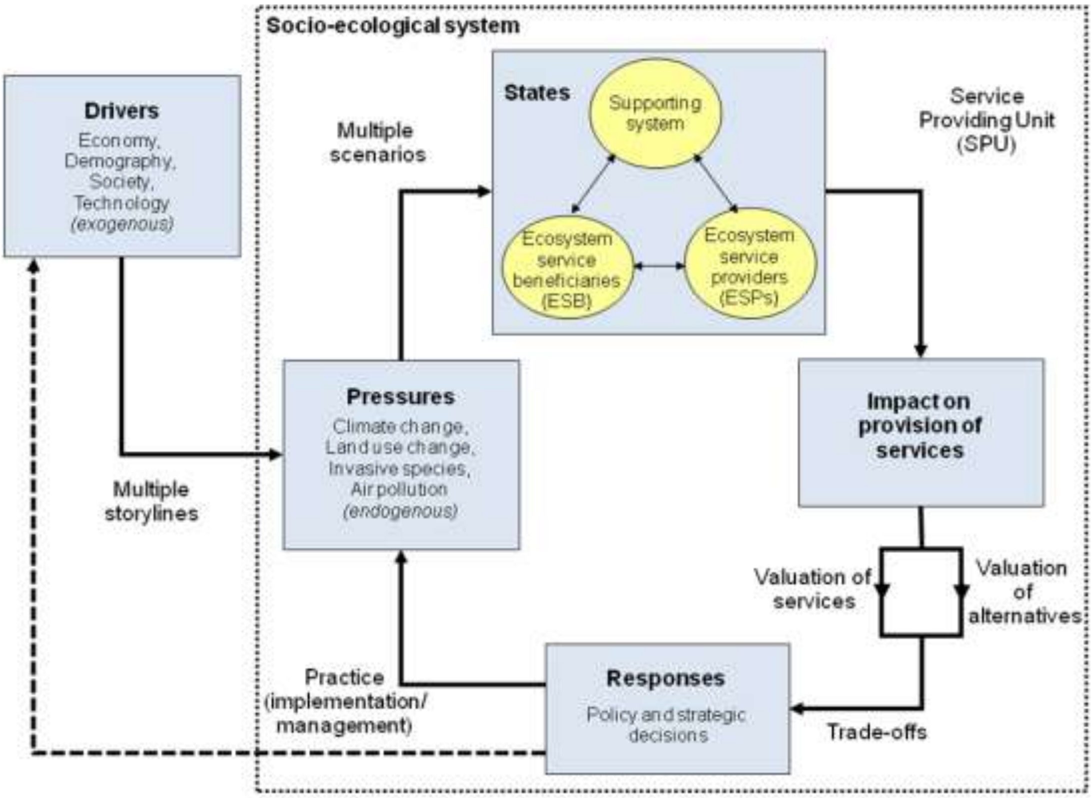
This is not to say that ecosystem and environmental or landscape services do not interact, but rather that probably different sorts of emphasis apply to these different areas of concern. Thus habitat structure may partially affect the potential of a site for wind power generation – but that potential would exist whether organisms were present at that site or not. The service provided by the ecological system is ‘air flow regulation’ not wind-power *per se*.

The recommendation that the term ecosystem service is restricted to those benefits that are fundamentally or immediately dependent upon living organisms would ensure that NE usage of the term is consistent with on-going scientific debates that may ultimately inform further work in this area. For example, the distinction between ecosystem-based services involving living systems and land-based systems is one made in a range of recent work funded by the EU which aims to develop tools for sustainability impact assessment (Perez-Soba et al., 2008). More significantly, it is consistent with evolving theoretical and analytical debates surrounding the concept of a Service Providing Unit (SPU) (Figure 8.1).

The concept was first introduced by Luck et al. (2003), who argued that instead of defining a population or organisms along geographic, demographic or genetic lines, it could also be specified in terms of the service or benefit it generates at a particular scale. For example, an SPU might comprise all those organisms contributing to the wildlife interest of a site or region, or all those organisms or habitats that have a role in water purification in a catchment. Given that it is part of NE remit to conserve biodiversity, the ability to define precisely those ecological units that are essential to the generation of some benefit to society will help ensure that the most robust case can be made for their wise management.

The implication of this argument for the way we frame the conceptual maps presented here is that for those in which living organisms play a key role (e.g. Carbon) the model

Figure 8.1: A framework for linking direct and indirect drivers, pressures and responses in a coupled socio-ecological system for assessment of the effects of environmental change drivers on ecosystem services (after: Rubicode, 2008).



Key: ESB = Ecosystem Service Beneficiary; ESP = Ecosystem Service Provider; ESA = Ecosystem Service Antagoniser' SPU = Service Providing Unit.

represents a first approximation of a Service Providing Unit. In those other systems, such as hydro- and wind-power, living systems have a more secondary or intermediate role in their generation.

8.3 Ecosystem Service Cascades

In the introduction to this Report we agued that services are best thought of in terms of a 'cascade', starting with some specified ecological structure or process that is translated into some final benefit through some intermediate set of steps. It is within this framework that we have sought to develop the concept maps, in that for them to properly represent a service they should seek to identify the key supporting elements on which the integrity of the output depends. Thus while the general BBN nomenclature (see Figure 2.3) of 'controlling', 'intermediate' and 'output nodes' is useful, in the context of a network that models an ecosystem service as an SPU, there should always be some differentiation between 'structures and processes', 'functions or capacities', 'services' and the 'values or benefits' people assign to them. Figure 8.2 illustrates the suggested typology as it applies to our initial, simplified carbon budget model for peat.

The concept of a 'service cascade' and the way it helps to structure conceptual maps for ecosystem services has a number of important features:

- It helps distinguish clearly between 'intermediate' and 'final' ecosystem products, and thus may assist those concerned with the valuation of services to avoid the problem of 'double counting';
- It allows the relative contribution of the intermediate elements to be identified and assessed in term of their overall importance to the final output;
- It encourages the creation of nested and linked structures in networks so that 'cross sectoral' and multifunctional issues can potentially be identified.

It is also important to note that the idea of a cascade also allows the ecosystem service sub-models to be seen as part of a larger picture, and the relative contribution they make to some overall service derived at the wider landscape scale. The approach suggested is illustrated in Figure 8.3, using the example from renewable energy presented earlier.

Figure 8.2: Suggested typology for a BBN which seeks to identify an ecosystem service as an SPU.

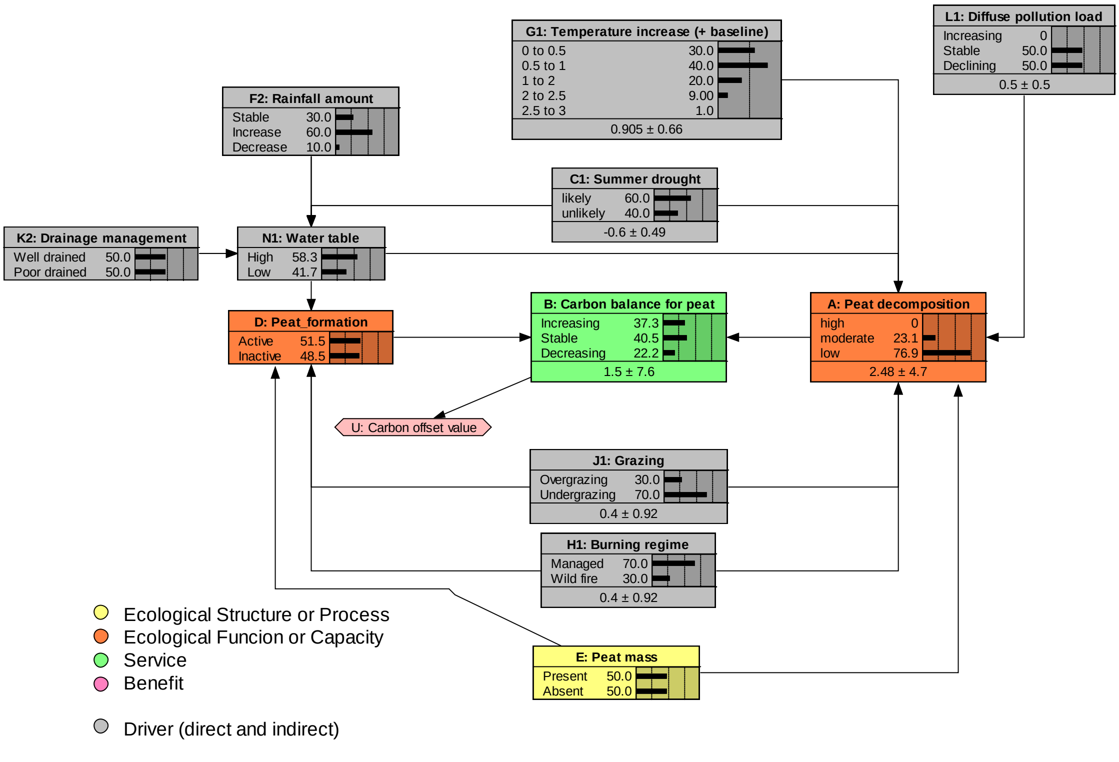
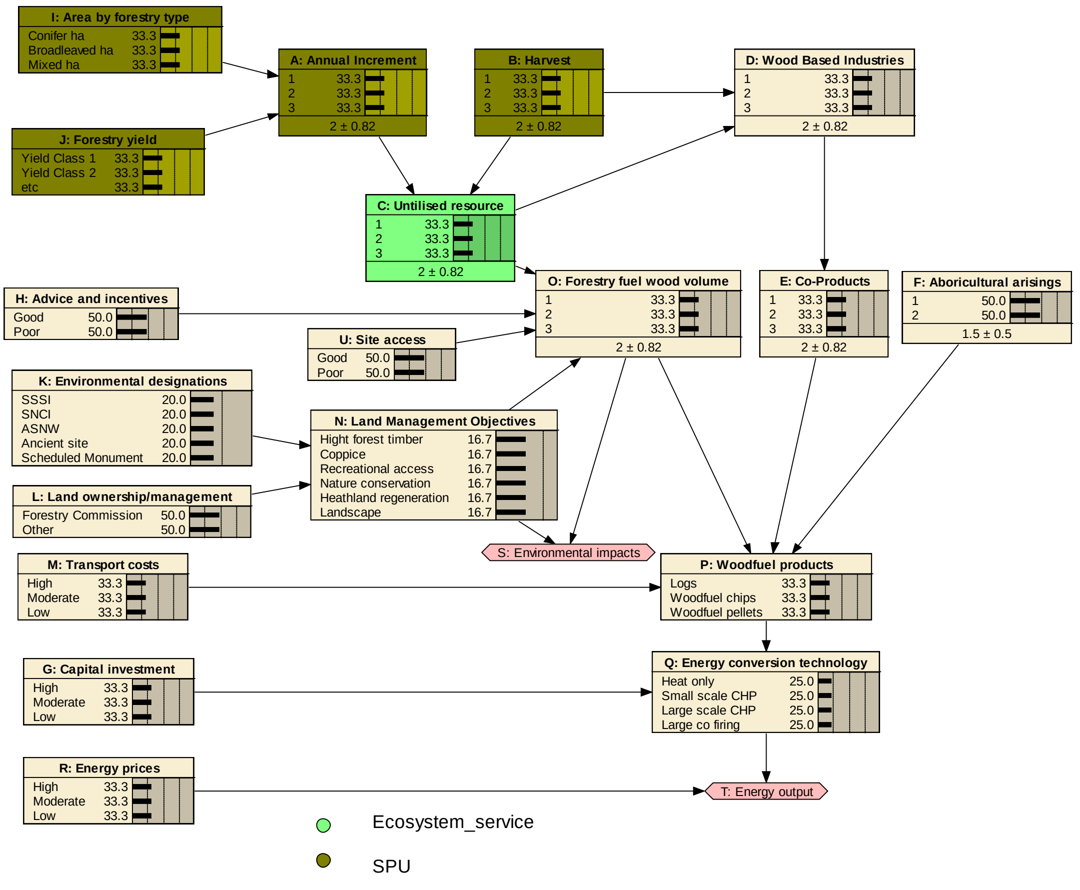


Figure 8.3: Nesting of an ecosystem service within a wider landscape or environmental service that includes broader socio-economic factors.

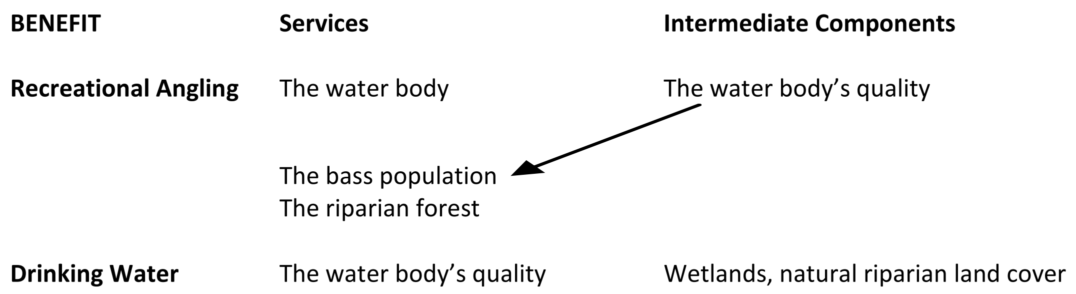


8.4 Service Themes

One of the most significant difficulties of developing any service typology is that most of them are developed from a ‘supply-side’ perspective, outlining what ecosystems can potentially provide, rather than considering the issue from a ‘demand’ side perspective and approaching identification of services from the understanding of what people want or need. In fact without some service beneficiary an ecosystem service, by definition, does not exist, only the *potential* to provide one. Moreover, the nature of the beneficiary largely determines what it is that is to be regarded as the final ‘product’ – the thing that is ultimately finally valued. The so-called ‘problem of the contingent nature of ecosystem services’ is illustrated in Figure 8.4, which shows how water quality is both a service when it is used for supply, and an intermediate product, when we consider its role in, say recreational angling.

In order to deal with this problem, we have suggested elsewhere that it is possibly best to treat typologies such as those of the Millennium Ecosystem Assessment more as identifying themes that need to be unpacked, rather than a comprehensive list of services that need to be assessed or considered in any particular situation. This seems to imply that the kind of framework in which such typologies should be presented is a hierarchical way, to reflect the nested and overlapping nature of services, with successive levels in the cascade being used to identify exactly where outputs are linked to particular beneficiary groups or underpinned by specific processes.

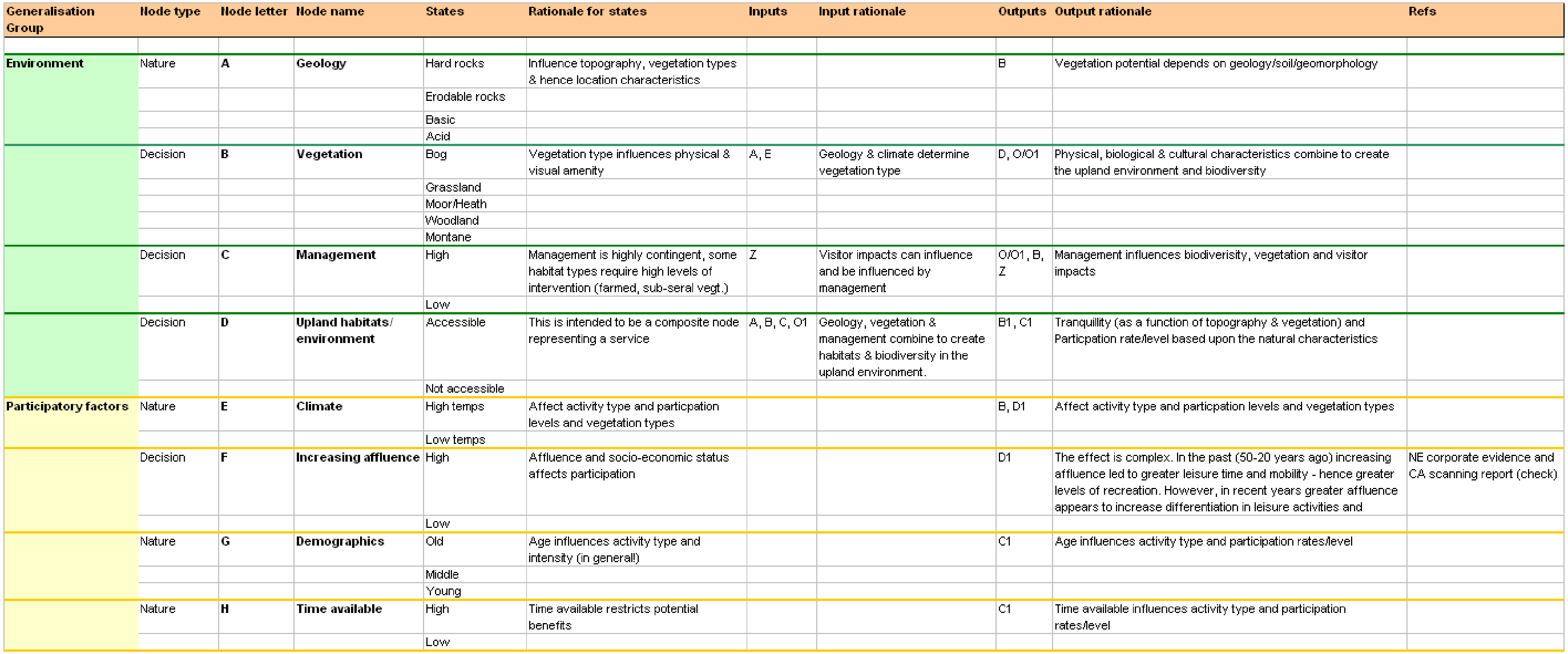
Figure 8.4: The identification of benefits, service and functions in the context of recreational angling and the provision of drinking water (after Banzhaf and Boyd, 2005, and Haines-Young & Potschin, 2008).



BENEFIT	**Services**	**Intermediate Components**
Recreational Angling	The water body	The water body’s quality
	The bass population The riparian forest	
Drinking Water	The water body’s quality	Wetlands, natural riparian land cover

The discipline of developing ecosystem models such as BBN has, in fact, allowed us to begin to develop just such a typological structure, and we have used this in documenting the node structure of the networks and how they are related to each other (Table 8.1). **Further work is required to generalise this schema and show how the specific ecosystem service elements can be distinguished from the wider landscape or environmental service components.** Further work is also required to link this approach to current frameworks that seek to describe the range of services that are associated with particular areas, such as the uplands.

Table 8.1: Illustration of service typology used to document conceptual maps (example is an extract from the documentation for the recreation map, see Figure 4.1)



Generalisation Group	Node type	Node letter	Node name	States	Rationale for states	Inputs	Input rationale	Outputs	Output rationale	Refs
Environment	Nature	**A**	**Geology**	Hard rocks	Influence topography, vegetation types & hence location characteristics			B	Vegetation potential depends on geology/soil/geomorphology	
				Erodable rocks						
				Basic						
				Acid						
	Decision	**B**	**Vegetation**	Bog	Vegetation type influences physical & visual amenity	A, E	Geology & climate determine vegetation type	D, O/O1	Physical, biological & cultural characteristics combine to create the upland environment and biodiversity	
				Grassland						
				Moor/Heath						
				Woodland						
				Montane						
	Decision	**C**	**Management**	High	Management is highly contingent, some habitat types require high levels of intervention (farmed, sub-seral vegt.)	Z	Visitor impacts can influence and be influenced by management	O/O1, B, Z	Management influences biodiverisity, vegetation and visitor impacts	
				Low						
	Decision	**D**	**Upland habitats/ environment**	Accessible	This is intended to be a composite node representing a service	A, B, C, O1	Geology, vegetation & management combine to create habitats & biodiversity in the upland environment.	B1, C1	Tranquillity (as a function of topography & vegetation) and Particpation rate/level based upon the natural characteristics	
				Not accessible						
Participatory factors	Nature	**E**	**Climate**	High temps	Affect activity type and particpation levels and vegetation types			B, D1	Affect activity type and particpation levels and vegetation types	
				Low temps						
	Decision	**F**	**Increasing affluence**	High	Affluence and socio-economic status affects participation			D1	The effect is complex. In the past (50-20 years ago) increasing affluence led to greater leisure time and mobility - hence greater levels of recreation. However, in recent years greater affluence appears to increase differentiation in leisure activities and	NE corporate evidence and CA scanning report (check)
				Low						
	Nature	**G**	**Demographics**	Old	Age influences activity type and intensity (in general!)			C1	Age influences activity type and participation rates/level	
				Middle						
				Young						
	Nature	**H**	**Time available**	High	Time available restricts potential benefits			C1	Time available influences activity type and participation rates/level	
				Low						

8.5 Review

The short time available for this project did not allow us to refine a comprehensive typology for upland services - in the sense of listing all that might potentially be generated. Nevertheless the experience of this work suggests a logical structure for such a typology, and shows how it is based upon the kinds of conceptual models that are now being discussed in the wider scientific literature. The network typology discussed here shows how problems of nesting ecosystem services in wider landscape or environmental systems can be approached and how final products and the problem of 'double counting' can be handled. **Further work is now required to develop a framework in which this better understanding of network structure is embedded in the more general typologies that aim to give an overview of what services might be present in any given situation.**

Key issues from Part 8 are as follows:

- Clarity on what is and what is not an ecosystem service is fundamental to the development of a service typology and the identification of benefits.
- The concept of Service Providing Units (SPU) provides an additional approach to defining services along functional lines that can transcend geographical or population focussed approaches.
- Using SPUs to define ecological units essential to the generation of societal benefits could help build robust cases for management.
- The concept of a 'service cascade' and the way it helps to structure conceptual maps for ecosystem services has proved useful in distinguishing between 'intermediate' and 'final' ecosystem products. This distinction is particularly important when moving to valuation exercises as it can help avoid the problem of 'double counting'.
- Service cascades also encourage the creation of nested and linked structures in networks so that 'cross-sectoral' and multifunctional issues can potentially be identified. They also allow ecosystem service sub-models to be seen as part of a larger picture and include contributions made at a wider landscape-scale.
- The identification and description of services is complicated by their contingent nature. For example water quality can be considered as both a service when it is used for supply, and an intermediate product in supporting angling or canoeing.
- To address the contingent nature of these issues we suggest that typologies such as those of the Millennium Ecosystem Assessment are treated more as identifying themes that need to be unpacked, rather than a comprehensive list of services that need to be assessed or considered in any particular situation. This can then contribute to a hierarchical framework that reflects the nested and overlapping nature of services, with successive levels in the service cascade being used to identify exactly where outputs are linked to beneficiary groups.
- Further work is required to generalise this schema and show how the specific ecosystem service elements can be distinguished from the wider landscape or environmental service components and also to link this approach to current

frameworks that seek to describe the range of services that are associated with the uplands.

Part 9: Reviewing the evidence base

9.1 Introduction

The wide-ranging nature of the ecosystem services approach requires the consideration of many inter-related factors across a number of different disciplines and drawing upon a diverse knowledge base. Looking forward, a potentially large range of data will be required to calibrate the network models and to support the mapping of services. Careful integration and attention to the scales at which networks and maps are developed and delivered will help to streamline this approach, but despite this the information requirements will be substantial.

In this section we provide a brief review of the potential information requirements and data sources that might support future work.

9.2 Data resources

In Part 7 we considered some of the common elements that should be considered and further developed to support the mapping process. This is an important pre-requisite for building an evidence base as the value and usefulness of data is always contingent upon the application. Thus, a common spatial scale – or a common scale for integration and interoperability, cross-cutting issues, policy relevance and the relative importance of biophysical characteristics must all be taken into account.

Data should be assessed according to common criteria but with respect to the intended use:

i. Thematic relevance – the appropriateness of the variables measured to the intended use;
ii. Temporal relevance – do the data relate to an appropriate timescale;
iii. Spatial relevance – are the data related to the intended geographical area;
iv. Resolution/precision – is there sufficient spatial/non-spatial resolution?
v. Accuracy – do the reported data give a true measure of reality within acceptable tolerances? It should be noted that accuracy is inherently multi-dimensional: it refers not only to simple accuracy of quantification, but also the reliability of feature identification, logical consistency, spatial consistency (e.g. topology) and repeatability. It also has to be assessed in terms of classifications and generalisations employed within the dataset.

Because most data are created for different specific purposes they do not always fit the specific requirements of a different application. This is highlighted, for example, in the case of carbon where data and models are primarily focused on assessing flux but provide less information on carbon stocks and do not differentiate different vegetation or habitat types beyond broad land cover classes.

Even at the conceptual stage, the Bayesian Network examples can be complicated and include areas where knowledge is limited or uncertainty exists. Therefore the next step – of attempting to operationalise and map the networks is not necessarily straightforward. However, this is another area where the BN approach can provide value as it enables scenarios to be investigated even if all process cannot be measured or fully understood. When seeking to map the networks we need to extend this approach to mapping those nodes of the network that are either most useful or more susceptible to investigation. This is likely to vary according to each network. The recreation network provides a good example; there are a number of complex interacting factors that influence the type of recreation activity participated in (including affluence, demographics, fashion/technology etc). It would be very difficult to measure and map these supply-side factors. However, we do know that they contribute to participation levels and that these are directly related to the benefit the 'system' provides. It is easier, and closer to the system output, to measure participation rates – i.e. the number of people participating in recreational activities. However, data may not exist to support mapping on a national basis, and current levels of use may not either meet demand or be utilised anywhere near their carrying capacity. We know that patterns of use are very unevenly distributed, and from a management viewpoint it is often desirable to spread and zone visitor pressures and impacts. Therefore, the 'supply side' of the network should also be considered.

Natural England have developed a range of data and gained access to others to support their work. We have limited our review to the potential use of NE data, because other studies have looked at information availability more generally (see Osborne et al. , 2006; ADAS, 2008).

Taking the data inventory provided by Natural England, we considered the relevance of the available data to mapping carbon, recreation, water and energy related services. The data sets that were considered of potential relevance are listed in Appendix 1 of this document together with a set of comments on possible use. As this was a short feasibility study this exercise was only able to consider the data sets from the available metadata, it was not possible to access the actual data and conduct a more detailed assessment.

Natural England has access to a large range of data and many data sets will be useful for future mapping of ecosystem services – whether directly or indirectly. Taking the list in Appendix 1 as a starting point it's possible to develop some mapping scenarios that could be considered in the next steps for service mapping, these are shown in Tables 9.1 to 9.4.

Table 9.1: Recreation: Possible mapping scenarios drawing upon Natural England's data holdings.

Rationale
Build a 'cost landscape' surface based upon accessible land within the uplands plus footpath presence/density. This should be a cost surface representing ability to access areas within the uplands. Accessibility is largely limited by physical access and this is represented by a. accessible land and b. footpath density and c. access points. Tranquillity mapping could be used to help explore quality dimensions of the resource. If suitable stakeholder motivation data are available, quality components could be developed further looking at features of interest. The 'supply side' surface could be compared with known visiting patterns where data are available to calibrate the model. The 'difference' may provide areas that are either a) not used because they are not accessible in reality or are seen as unattractive, and/or b) possible targets for management intervention.

Mask	Base data	Quality elements	Calibrate
Uplands LFA (Severely disadvantaged land)	CROW Access land Common Land FC woodland, WGS WT woodland NT land CS + other scheme access land PRoW National Trails Regional Trails (To derive attractiveness of site – run Huff analysis & calibrate with visitor data?)	Tranquillity Scoring system based on added points for: Semi-natural habitats, Ancient Woodland Presence/density of water features (lakes, rivers) IFT Woodland Type Important bird areas (RSPB) National Parks AONBs Slope Terrain MAPS1/Land-Form PROFILE DTM	Quantitative visitor data where available

Demand/Profiling

Rationale
Taking the most comprehensive visitor data available for different target areas (e.g. National Parks) explore the spatial characteristics of visitors to find primarily distance travelled and location of residence, the latter can be used to explore socio-economic profiles (see below).

Mask	Base data	Quality elements	Calibrate
Target - Uplands LFA (Severely disadvantaged land) Origins – England/International	Visitor survey data – origins of visitors, derive locations and distances travelled for modelling.	Profile by socio-economic group (ACORN)	

Demand/Profiling

Rationale
If visited locations can be classified by attractiveness their visit catchments could be mapped and profiled.

Mask	Base data	Quality elements	Calibrate
England	Acorn classification of residential neighbourhoods Population Density 2001		Visitor survey data

Table. 9.2: Carbon - Possible mapping scenarios drawing upon Natural England's data holdings.

Rationale
Carbon storage could be mapped by classifying then mapping soil and vegetation types. Trends could be considered by assessing average temperatures and rainfall, and site condition (i.e. peat forming or over grazing/eroding) and as a negative factor over grazing. Water quality (sediment loads) could be used to identify units (catchments) undergoing erosion.

Mask	Base data	Quality elements	Calibrate
Uplands LFA	Land-Form PROFILE® Contours & Digital Terrain Model Land Cover Map (LCM 2000) National Soils Map (NATMAP) - 1:250 000 Interpreted Forestry Type (National Inventory of Woodland and Trees with IFT) Accumulated Temperature (ATO) Average Annual Rainfall (AAR) Ancient Woodland Inventory BAP Priority Blanket bog v1.3 Other BAP habitats SSSI Condition Assessment (Site Units) (England) TerrainMAPS1	Overgrazing Investigations (HLCA) (trends ?) Woodland Grant Scheme SSSI Condition Assessment (Site Units) (England)	HLS Targeting - High Risk Soil Erosion Areas

Table 9.3: Water - Possible mapping scenarios drawing upon Natural England's data holdings.

Rationale

Mask	**Base data**	**Quality elements**	**Calibrate**
Uplands LFA (Severely disadvantaged land)	Terrain MAPS1/Land-Form PROFILE DTM River Centre Line Network Hydrological Digital Terrain Model - Cumulative Catchment ARea (CCAR) Hydrological Digital Terrain Model - Inflow Pattern Hydrological Digital Terrain Model - Outflow Pattern Hydrological Digital Terrain Model - Surface Type Land Cover Map (LCM 2000) - vegetation types influence interception, storage and flow rates. Catchment Boundaries HLS Targeting - High Risk Soil Erosion Areas Interpreted Forestry Type (National Inventory of Woodland and Trees with IFT) SSSI Condition Assessment (Site Units) (England) Average Annual Rainfall (AAR)	Water quality/risk assessments	

Table 9.4: **Energy - Possible mapping scenarios drawing upon Natural England's data holdings**

Energy – small-scale hydro-electric

Rationale			
Develop site and area opportunities map for small-scale and micro hydro generation potential. Using published parameters build a spatial model identifying areas with suitable water volumes, hydraulic heads and proximity to dwellings/infrastructure.			
Mask	**Base data**	**Quality elements**	**Calibrate**
Uplands LFA (Severely disadvantaged land)	Terrain MAPS1/Land-Form PROFILE DTM River Centre Line Network Hydrological Digital Terrain Model - Cumulative Catchment ARea (CCAR) Hydrological Digital Terrain Model - Inflow Pattern Hydrological Digital Terrain Model - Outflow Pattern Hydrological Digital Terrain Model - Surface Type Land Cover Map (LCM 2000) - vegetation types influence interception, storage and flow rates. Catchment Boundaries Average Annual Rainfall (AAR) Flow volume data and models.	MasterMap + Rural settlement morphology to identify proximity to dwellings/infrastructure.	Flow volume data and models

Energy – small-scale biogas

Rationale			
Biogas generation is largely determined by the availability and proximity of suitable waste outputs from plant material high in nitrogen and animal waste. An opportunity map could be developed mapping the potential availability of input materials to identify 'hotspots'. A waste products 'surface' could be developed using the quantities of productive grassland and stocking levels.			
Mask	**Base data**	**Quality elements**	**Calibrate**
Uplands LFA – (Severely disadvantaged land)	Defra agricultural survey (stocking levels and area of productive grassland). Land cover map – improved/semi-improved grassland parcels	Nitrate Sensitive Areas	More detailed investigations – if available

Although these ‘recipes’ provide the basis for further work on mapping, there are still a number of gaps in the evidence base. There are also still uncertainties in a number of parameters required to conduct mapping exercises.

The issue of scale remains to be resolved. Different spatial scales appear to apply to different scenarios. Taking recreation as an example, the service supply is located within the accessible parts of the uplands but the users/benefits are enjoyed on a much wider geographical basis. Whilst modelling carbon storage/flux on a grid square basis may be suitable, this scale may not discriminate important variables for assessment of recreational demand or woodfuel supply. The issue of appropriate scale must therefore be resolved in looking at both service provision and service outputs. Because provision and outputs are not necessarily spatially co-incident it is also important to develop concepts and methods to show benefit flows between locations.

There are gaps in the available evidence base, these can broadly be grouped into those relating to knowledge development (i.e. of processes or behaviours) and those that are information based (where we know how things work but need more quantitative data). Ideally maps may be based upon directly measured data that relate closely to nodes in the conceptual networks. This isn’t always possible and it may be necessary to use proxies or indicators to express different elements.

It is also clear that the perfect should not be the enemy of the good. A number of complex and inter-related issues need to be resolved to map all services and seek both a rationale and a framework to integrate them. The evidence base also requires further development. However, it is also both possible and important to map certain aspects of the services. The spatial expression of different factors is useful in developing models and maps and in testing and calibrating them – maps are immensely useful communication tools in this respect. Maps can be used in independent testing, working with stakeholders and providing revised input for models. Some services are less tangible and require further parameters for modelling and maps can help with this – they can also be used to examine changes in different places and the implications of these for the system and different locations.

9.3 Review

The key messages from Part 9 are:

- A large quantity of data are available that are of direct and indirect use for mapping ecosystem services.
- Despite the large quantity of data there are still evidence gaps – either related to process or to spatial data to quantify particular characteristics or to map resources or features.
- Mapping elements of an operationalised Bayesian Network allows the opportunity for node generalisation and some integration spatially and conceptually. This isn’t just the mapping of nodes, the wider spatial framework is also important.
- Further thought is required on ‘where’, ‘when’ and ‘what to map’. This should include consideration of where in the evidence/impacts chain effort should concentrate and whether to look backwards or forwards in developing evidence.

Spatial frameworks must retain the flexibility to cover different scales and geographies.

- Spatial maps should not simply be seen as an output of the network mapping or modelling processes but an integral component of the overall exercise; they provide a means of displaying results and a way of gathering user input for modelling exercises.

Part 10: Conclusions and Recommendations

In this study we have sought to explore the use of Bayesian Belief Networks (BBN) as a framework in which conceptual maps for ecosystem services can be developed. The concepts have been tested by attempting to apply them to a range of important services associated with the uplands. The conclusions that we draw from this work, and the recommendations we make based on them are as follows:

10.1 Conceptual mapping and network typologies

BBN are a useful tool for both describing the mechanisms that underpin ecosystem service generation and investigating how services may operate in reality.

These networks have the advantage that they can also easily be made 'active' thus allowing users to explore the consequences of different assumptions, or changes in controlling factors, upon the service of interest.

As a result the networks provide a framework in which different scenarios can be constructed, described and potentially explored.

We have shown how a network typology can be developed alongside the BBN approach that allows knowledge about ecosystem services to be structured and described in a systematic and robust way.

The structure of BBNs allows different types of evidence to be combined in a flexible way, and prototype models rapidly developed and refined.

However, it is clear that for the BBN approach to be used most effectively it has to be undertaken in an iterative way, with phases of design and calibration interspersed with phases of testing and feedback from stakeholders and experts. The time available for this project meant that this kind of participative process was constrained and as a result the final conceptual maps are, as yet, only initial drafts.

<u>Recommendation 1:</u> On the basis of the experience of this project we suggest that NE consider developing the BBN approach further as a way of grounding their understanding of ecosystem services more firmly in the current evidence base, and that it could provide a useful framework in which different scenarios for the uplands can be explored.

***<u>Recommendation 2:</u>* That future work on creating upland visions could usefully be informed by the development of a service typology specifically for these areas, but that to be most useful it should take account of (a) the distinctions between services that have a stronger and weaker link to biodiversity and ecosystem processes; (b) that a richer terminology is considered that distinguishes ecosystem services from those associated with the physical and social structure of the wider cultural landscape, which are best described as 'environmental', 'land' or 'landscape' services.**

10.2 Service Case Studies

In terms of the specific services considered in this study and the evidence gaps that are apparent:

For **Carbon** there is sufficient empirical data to build an operational net that is capable of indicating directional changes in overall carbon budgets resulting from land use change and a range of different land use management that is relevant to the uplands.

***<u>Recommendation 3:</u>* We recommend that NE investigate the potential for using the national soil carbon databases that have been developed, and new land cover mapping information from Countryside Survey to create a more refined set of data for the uplands, so that the modelling approach suggested here can be moved to a higher level of thematic resolution in terms of the land uses and soils types included.**

For **Recreation** it is apparent that the topic is a very broad and poorly defined one and that more specific 'sub-models' that pick out the specific mechanisms that support particular types of activity be explored, e.g. walking, cycling, bird-watching. However, the topic area is a particularly interesting one in terms of the challenges it offers for connecting up the supply side and demand side characteristics of services.

***<u>Recommendation 4:</u>* We recommend that NE investigate the possibility of developing some specific recreation-based models for areas such as the Peak District where good data on visitor numbers, use and origin are available. Such work could serve as a demonstrator for what might be achieved in other places.**

For **Renewable Energy** there is a good prospect that operational networks can be developed for woodfuel, biogas, hydro and wind power, but that these are best done in the context of national studies.

***<u>Recommendation 5:</u>* We recommend that NE investigate the possibility of developing some broad, national scale models for renewable energy which can be used to identify the specific contributions that upland environments may have for these energy sources.**

For **Water Provisioning and Flood Regulation** there is a complex relationship between the physical and climatic factors that control water provisioning and flood regulation and ecological processes. Thus it is difficult to identify specific ecosystem services in relation to this theme, although the marginal effects of changes in ecosystem structure and function on these hydrological outputs can potentially be assessed.

<u>Recommendation 6:</u> We recommend that the role of ecosystems is explored as part of future work on risk assessments being made in the context of implementation of the Water Framework Directive, and that the focus should be on the marginal benefits that changes in ecological processes have on the key hydrological outputs at the catchment scale.

<u>Recommendation 7:</u> Our overall recommendation for taking modelling work forward is that it would benefit greatly from the development of a general framework for the key biophysical and socio-economic drivers to underpin the specific service models. The general framework could also develop a common set of spatial units that could be used to model service outputs and construct service geographies.

10.3 Spatial Mapping

There are a number of opportunities for mapping services and their underpinning processes spatially, and our work has identified a number of benefits of using such maps alongside the conceptual mapping exercise. These include the fact that the maps give spatial expression to model outputs and so make them both more testable and better understood. The maps can also be used as input to identify the sensitivity of particular places to changes in key drivers.

<u>Recommendation 8:</u> We recommend that future mapping work be undertaken in association with conceptual mapping. This will ensure that service geographies have a robust evidence base – because mapping service output is inherently a modelling exercise, and it is essential that the key assumptions are made explicit so that uncertainties associated with service assessment can be communicated.

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