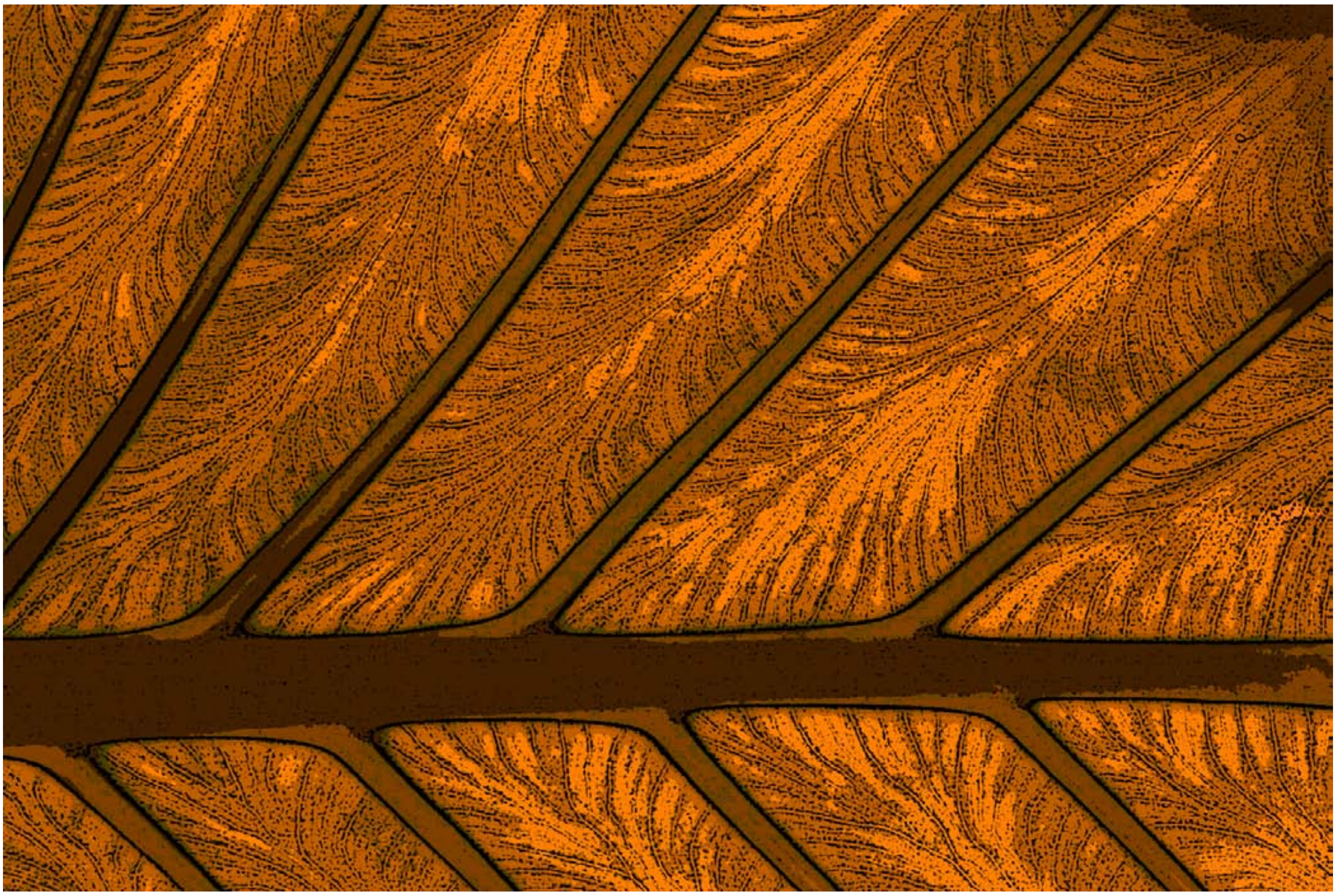
Upland Ecosystem Services: Final Report



The University of Nottingham

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CEM Centre for Environmental Management

Upland Ecosystem Services:

Co-ordination Contract

Report To

NATURAL ENGLAND

(Project Code PTY02/10/002.27)

Final Report

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Executive Summary

Background

This study follows on from earlier work commissioned by Natural England which has explored how conceptual maps can be built and used to understand ecosystem services in the Uplands of England. The need to build such maps is two-fold. First, to systematically document what is known about particular ecosystem services and hence identify any important knowledge gaps. Second, to find a way of using existing evidence more actively in the context of the visioning work for the Uplands, that is being led by Natural England. Conceptual maps that describe how different ecosystems services are generated can be a focus for discussions between stakeholders. By capturing the important structural characteristics of ecosystems and their likely responses to different drivers of change, these conceptual maps can be a tool for building scenarios. Potentially, they can also be a way of representing the marginal changes in service output that might be expected under different management or policy interventions.

The particular approach to building conceptual maps that was explored in this work was based on the construction of Bayesian Belief Networks. These networks have been widely used to support decision making in natural resource management. They allow systems to be represented as a set of key variables and the states that they can exhibit, and the ways these different elements influence each other, in terms of the strength and direction of the relationships between them.

The particular strength of Bayesian Networks is that they not only allow the structure of a system to be represented in a clear and understandable way, but also that they allow the uncertainties that arise in relation to predicting likely system responses to be communicated to users. A further strength is that they allow different kinds of evidence to be brought together and linked, so that empirical information, model output and expert judgement can be integrated and made accessible to people. In this way users who need to gain an overview of 'what is known' in relation to a particular ecosystem or issue can do so rapidly.

If robust strategies and visions for the future of England's Uplands are to be created, then Natural England and its partners need to be aware both of the extent of the current evidence base and the uncertainties that exist when applying it. They also need to be able to communicate that understanding to others in effective and efficient ways. Conceptual maps based on Bayesian Networks are one tool that can help ensure that this can be done.

Achievements of this study

Four ecosystem services were considered in the present study: carbon storage and sequestration, water quality regulation, flood mitigation and recreation. The work involved inviting experts to make a critical review of the structure of the networks built during the earlier phase of work for Natural England, and to examine the extent to which these networks could be refined. The study was necessary because, although the initial work had successfully demonstrated the value of the Bayesian Network Approach, the breadth of the earlier study and time constraints meant that the range of evidence considered was in some cases restricted. In particular, it had not been possible to fully expose the prototype networks to informed expert comment. The present study has therefore sought to test the outcomes of the earlier work and, on the basis of the outcomes, identify the ways conceptual mapping could be used in the future.

The expert review confirmed the findings of the earlier study, namely that evidence base supporting the development of such models was fragmented and variable in its depth and coverage. This is not to imply there is a flaw in current scientific approaches, but merely reflects the fact that the focus of the two studies is wide and involves making linkages across different knowledge domains. Inevitably more is known about some thematic areas than others. Of the four areas considered, the evidence supporting the model for carbon storage was the most complete. In terms of linking the models into some larger structure, the close relationship between the factors that influence water quality and quantity (and hence the service for flood regulation) means that these probably offers the best scope for integration. Recreation was the most problematic of the topics considered in terms of representing it as an ecosystem service and in understanding how the biophysical characteristics of the uplands influence the different kinds of activity.

The expert reviews also suggested that on the basis of the current evidence the overall structure of the prototype networks were a plausible representation of the services prioritised by Natural England. Some modifications were suggested and the structure of each was refined, but broadly given the types of perspective needed by Natural England, and there was support for the conceptual mapping undertaken in the earlier study. Specifically:

- In relation to carbon, the major changes to the network concerned the relative strengths of the relationships between the variables that influence peat formation and decomposition, and on the influence of different types of vegetation cover. The resulting revised model was fully implemented as a Bayesian Network, which was able to predict in general terms the marginal changes carbon offset value under different land management and climate regimes.
- In relation to water quantity and quantity (flood mitigation), the review made a number of suggestions about how the two networks could be linked to each other, and to that for carbon. All were influenced by a number of common land management interventions which meant that potentially an integrated network could be created. The main problem identified in taking this forward was that a better understanding of how location or geographical context influence interactions is not available, although this often changes the ways in which systems respond, and the level of service output achieved. This lack of information represented one of the major gaps in the present evidence base and prevented these networks from being fully implemented.
- Table 1 identifies the key drivers of change that were common to the networks developed in the study. The reviews confirmed the complexity of representing recreation in all its form as a single conceptual network, but there is clearly some basis for linking them. The experts emphasised, however, that there was a need to represent more explicitly in the network additional influences such as the level of knowledge people had about different places, their requirements in terms of services offered, as well as the factors that shape their appreciation of environmental quality. Although empirical evidence giving insights into these factors is available, it was not easily usable given the requirements of the Bayesian Network Approach. Nevertheless, on the basis of the expert review, some of the factors identified could be included in a recreational network that dealt with walking and cycling. Like the network for carbon, the model could be used to represent the relative strengths of the different types of influence on output variables such as participation rate and health benefits.

Table 1: Commonality of change drivers between networks

Driver	Carbon	Water quantity	Water quality	Recreation
Grazing pressure	**	**	**	?
Fire regime	**	**	**	?
Liming	*	?	?	
Drainage management	**	**	**	
Land use change	**	*	*	*
Vegetation cover	**	**	**	*
Water table	**	*	*	
Ground Water Temperature			*	
Gullying	**	**	**	
Base saturation			*	
pH			*	
Geology	*	*	*	
Diffuse pollution load	*		*	
Temperature	**	*	**	
Rainfall	**	**	**	
Summer drought	**	**	**	
Adequacy of public transport				*
Parking provision				*
Travel cost				*
Designation				?
Access conditions				**
Information				**

**= very important; *=important; ?=possibly important.

Using conceptual maps of ecosystem services

Although network approaches used by this study has been widely employed to build operational decision support systems, it is clear from the current study that it is probably premature to think of using them in this way for the ecosystem services considered here. Not only is further work needed to overcome gaps in the evidence base, but also a fully and better understanding of the organisation context in which they might be applied in Natural England is also necessary. Both these barriers would have to be overcome before a reliable decision support system for ecosystem services could be built.

However, while these networks maps cannot be used directly for decision support it is clear from the experience gained in this work that they do have a number of other important advantages and uses and that they could nevertheless be used to inform key aspects of current debates and shape decisions in a strategic way. Specifically, Bayesian Networks can be actively used:

- As a device for taking stock of what is known about individual services and of organising it in relation to particular user needs;
- As a communication tool that can facilitate discussion about how upland systems might react under different management, policy or environmental scenarios;
- As a way of investigating the weights different users assign to various scenario or management outcomes, and hence the changes in marginal value brought about by different components of the network; and,

- As heuristic device to rapidly prototype ideas and allow users and experts to connect up topics that are not currently well integrated.

As the second phase of work has demonstrated, Bayesian Networks are a good way of conveying ideas to others, of capturing and structuring their knowledge and representing it in forms that can easily be discussed and potentially used critically by others. In short such networks are valuable social learning devices.

There is currently much interest in embedding an Ecosystems Approach in decision making. If it is to be effective, decision makers need to think through cross-sectoral linkages and attempt to understand how interventions might change the values people attach to ecosystem services. ***Rather than using these networks to build operational decision support systems, our principle recommendation is that a more appropriate way forward would be to consider the network approach as a tool to help people represent complex problems, assess the likely consequences of decisions, and identify where judgements are based on empirical data or more uncertain sources***. With tools which allow ideas to be communicated and tested more effectively, adaptive ecosystem management is, we suggest, more likely to be achieved.

Acknowledgements

We would like to thank the various experts who provided critical input to this study (see appendices)

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Part 1 Upland Ecosystem Services

Introduction

There is growing interest amongst those concerned with the management of land and biodiversity in the links between ecosystem services and human well being. One of the key challenges is to better understand the ways ecological and social systems are interact, and how the various drivers of change may affect the benefits that these systems provide for people.

This study has explored the topic of ecosystem services through the lens of the English uplands. Not only do these areas contain many of the nation's most valued landscapes and natural habitats, it is also clear they also provide a number of other important resources. In addition to their recreation and heritage value, for example, they are important in terms of the carbon that is stored in their soils and vegetation, as source areas for clean water, and for the potential that they have in the production of renewable energy. Upland agricultural ecosystems are also important for food they produce.

Although the uplands are an important natural resource, the ecosystems they contain are also vulnerable. Changing economic and social circumstances, for example, may mean that that patterns of management and ownership that were once essential in sustaining their character may no longer be viable. The potential impact of climate change on these areas, and what kind of mitigation and management might be necessary to maintain the benefits they provide, also needs to be understood.

If we are to design appropriate management and policy responses to meet the challenges that the Uplands face, we need to understand how these 'socio-ecosystems' work, and what kinds of intervention or protection measures might be possible. This study has therefore looked critically at the evidence we have about ecosystems services in these areas. The aim has been to identify what is known about the key drivers of change in these areas, and how they might impact on the output of ecosystem services. The study has also explored the potential synergies or conflicts that may exist between management or policy strategies that might be considered to secure particular ecosystem services, when we consider the range of services that can be generated by the uplands as a whole. The uplands are 'multi-functional' systems, that is, they are capable of providing multiple-benefits to Society. If their long-term value is to be sustained, then integrated or holistic approaches to the design of future management and policy responses will be needed.

Background

The present study forms part of Natural England's *Upland Futures* Project, which is designed to develop a shared vision for these areas looking ahead to 2050. The goal is to develop an action plan for delivering that vision. As part of the first phase of the initiative a study was commissioned on ways in which ecosystem services might be mapped both conceptually and spatially (Haines-Young and Potschin, 2008). The idea of developing conceptual maps was to summarise what the evidence base currently tells about how upland ecosystem service function. In this way those working on these future visions can more easily understand the linkages and relationships that need to be considered. It was also thought that such conceptual maps might be useful in helping to map of ecosystem services spatially. An understanding of how ecosystem service output potentially varies from place to place is clearly fundamental, but such maps are often based on modelled relationships and so it is important to be clear about what kinds of assumption are being made in producing them.

The conceptual mapping study initially focused on five ecosystem services: carbon storage and sequestration, water quality regulation, flood mitigation, renewable energy and recreation. It used a particular technique for developing these conceptual maps, known as Bayesian Belief Networks (BBN), which have been used widely as a decision support tool for natural resource management. The BBN approach proved itself useful in working with stakeholders to represent how they saw the structure of the socio-ecological systems that generated particular ecosystem service. The networks were also useful in showing what kinds of evidence were available for the relationships between key elements of the system. A key feature of Bayesian Networks is that they can integrate different types of evidence. In the upland study, empirical data, conclusions derived from the peer reviewed literature and expert judgements were used to develop an picture of the processes underpinning the different services, what kinds of factor might impact upon them, and how certain we are that particular outcomes might arise given the overall state of the system.

The outcomes of the initial conceptual mapping study was sufficiently promising to justify a second phase of work designed to refine the networks further. This document reports on what has been achieved, in relation to four of them; time and resources did not allow the renewable energy theme to be examined. In this second stage of work, additional expert input was invited to make a critical review of the structure of the networks proposed in the first phase. Experts were also asked to comment on the extent to which the current evidence could be used to make the networks more robust decision support tools, and what gaps remain that might be addressed in future work.

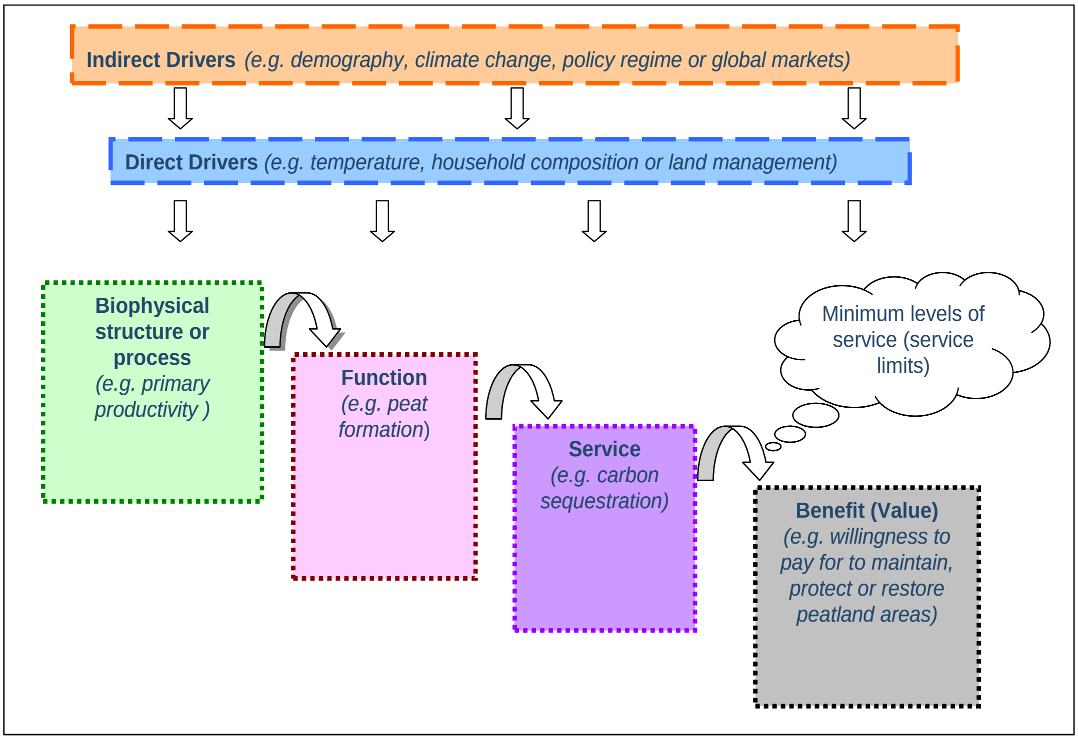

Figure 1: Ecosystem Service cascade (after Haines-Young and Potschin, 2008)

Framing ecosystem services

Figure 1 is the overarching framework within which conceptual maps developed in this, and the earlier study, were created. The figure expresses the fundamental proposition of the 'ecosystem services paradigm', namely that there is a causal link between underlying ecological structures and processes, and specific, measurable benefits that people can 'enjoy'. It is proposed that ecological structures and processes give rise to various functions or capacities in the system, which in turn may provide a service to society that has some benefit or value. The model also suggests how the view we take of the adequacy of service output might shape our responses to the pressures that impact on the overall system. The nature of this 'service cascade' is illustrated in Figure 1, by reference to carbon sequestration.

It was argued in the earlier study that any conceptual mapping exercise designed to show how particular services are generated in the uplands, ought at least to include reference to the four elements of the service cascade and the factors that might influence their state or behaviour. This approach is illustrated by reference to the simplified conceptual map developed for carbon sequestration shown in Figure 2.

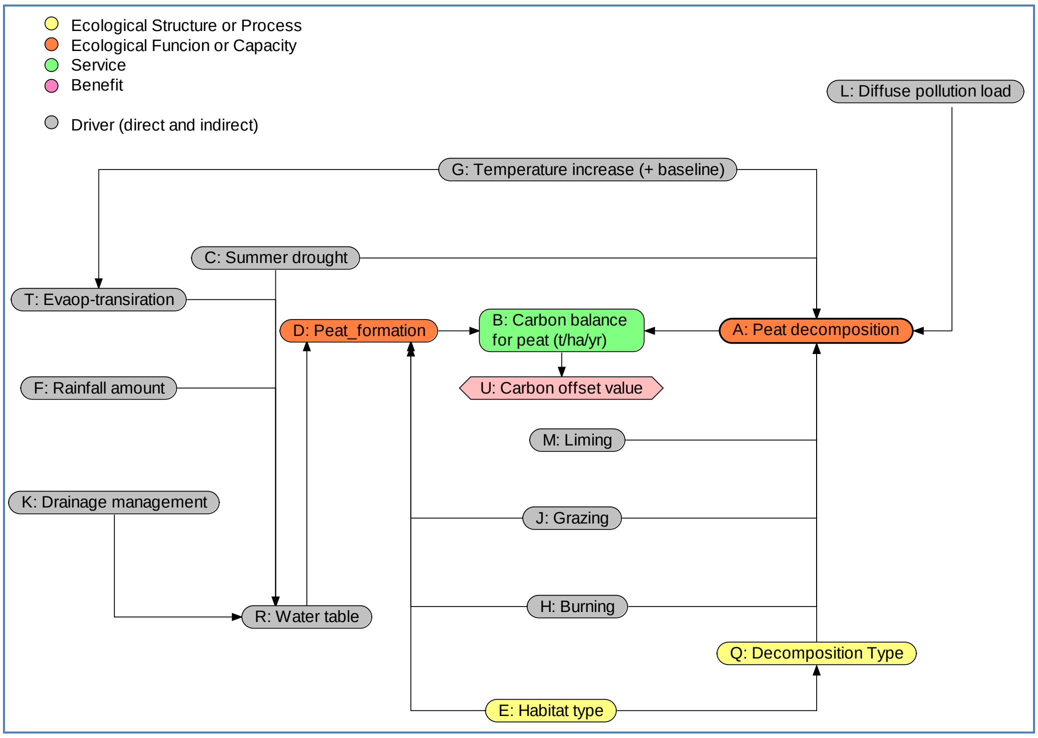

Figure 2: A network for showing the influences on carbon storage and sequestration in the uplands

In Figure 2 the underlying ecological structure is the presence of peat-forming habitats (heathland, mire, acid grassland); the key functions or capacities of the system that provide the basis of the carbon sequestration service are peat formation and peat decomposition. The balance between them determines whether carbon sequestration is positive, negative or stable, and the benefit that arises would be the corresponding carbon offset value. If there was net carbon uptake then the benefit would be equivalent to the carbon savings achieved; if negative then it is a disbenefit, and the cost is the carbon saving that would need to be achieve elsewhere. The performance of the whole system is influenced by the various direct and indirect drivers of change that include various climate parameters and land management interventions that an impact upon rates of peat formation or peat decomposition and erosion.

Figure 2 is a simplified conceptual map in that represents no more than an 'influence' diagram, describing the relationships between the variables that make up the system. The variables are shown as nodes in a network, and the relationships between them are shown by the arrows that give the direction of influence. The approach used in this study, involving the Bayesian Belief networks, merely refines and extends this idea. It attempts to express more precisely how these relationships work (e.g. are the relationships positive or negative) and how strong they might be. With the BBN approach this is done by describing each node in terms of the states it can exhibit, and the probability that it is in a particular state, given the other nodes that influence it.

In the sections that follow we describe how the belief networks for carbon, water quality regulation, flood mitigation, renewable energy and recreation were developed using the BBN framework, and what insights were gained in terms the key drivers of change and potential management interventions. The report concludes with an examination of the extent to which the separate networks might be linked so that the part of the multi-functional character of upland ecosystems might be described.

Part 2: Carbon Storage

Introduction

The carbon stored in many of ecosystems found in the uplands is an important asset for the UK in relation to climate regulation. It has been estimated, for example, that peatland ecosystems, most of which are associated with the uplands, represent the single largest carbon reserve in the UK[1]. Quite apart from the future carbon that they may sequester, the ability to of these systems to retain the carbon they already lock away is important, if the attempts made elsewhere in society to reduce carbon emissions is not be undermined through damage or loss to these systems. Evidence suggests that the ability of upland ecosystems to sequester and store carbon is highly sensitive to land management decisions as well as long term climate change (Holden et al. 2007; Orr et al. 2008). Thus any future strategy for the ecosystem services in the uplands would have to consider the factors influencing this important resource.

The network for carbon

The refined network for ecosystem service represented by carbon sequestration is shown in Figure 3. It is assumed that we are dealing with a system in which peat formation can potentially occur, or where peat has formed in the past, so that the level of service output is essentially determined by the balance between the rates of peat formation and decomposition. These are the key functions that give rise to the service. As Figure 3 suggests, these functions are influenced by a number of other factors including particular ecological structures (habitats) and processes (decomposition type) and various drivers of change, related to climate and land management practices.

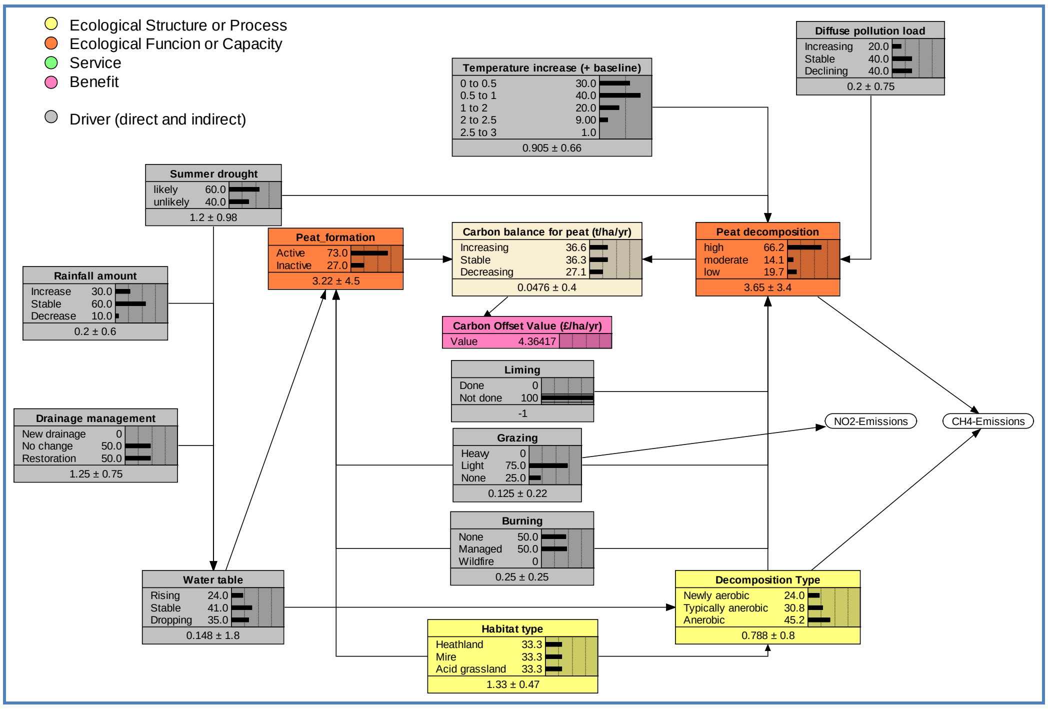

Figure 3: The refined network for carbon storage and sequestration shown as a BBN.

[1] Moors for the Future Research Note No 12

Figure 3 differs from the simple influence diagram described earlier in the way the nodes are represented. It uses one of the formats in which Bayesian networks are often presented. Thus the different states that each node can exhibit are listed, and the probability that the node is in a particular state is shown by means of a small bar chart. In the network the probabilities assigned to the states for each node are controlled by the other nodes that provide an input to it. The particular feature of the BBNs that make them useful is that once set up, we can explore the effects of changing the state of any particular node on the other elements of the system.

The expert review confirmed[2] many aspects of the network suggested in the initial study, but also suggested a number of important modifications based on the evidence available. Figure 3 is therefore an updated version of the initial carbon sequestration model.

On the basis of the review it was argued that peat decomposition is the key process which needs to be captured to understand how changes to upland ecosystems will impact on their ability to store and sequester carbon in the future. While an increase in temperature is arguably the most commonly emphasised aspect of climate change, current evidence suggests that its impact on decomposition is inconclusive and unresolved, while the impact of changes in soil water conditions are better understood. Thus it was suggested that the network should focus on better capturing this relationship, especially as the effects of changes in rainfall and summer drought can be mitigated or compounded by drainage management strategies. The network was also modified to describe better the relationships between grazing and burning management and peat decomposition and formation by using larger range of states to characterise the management factors.

The carbon balance as an ecosystem service

The central node in the network, which represents the ecosystem service, is the node for the carbon balance of the peat soils. The aim of the model is to determine the likelihood of this balance being positive, negative or stable. Evidence suggests that the overall carbon balance should lie somewhere within the range of a net increase of 0.21 t C ha^{-1} yr^{-1} (based on Clymo et al., 1998) for the most pristine, undamaged sites, where peat formation is active and decomposition is low, up to a loss of carbon in the range of 0.8-8.3 t C ha^{-1} yr^{-1} (Nykanen et al., 1995; Maljanen et al., 2001 & 2004; Lohila et al., 2004) for sites with high decomposition and no new peat formation, due to draining and disturbance.

On the basis of the expected range of values, the network has been designed to give an indication of the resulting benefit, expressed in terms of the social cost of carbon (SCC) emitted or taken up. The model uses the Defra (2007)[3] estimate for SCC of £25/tCO_2e, which has been converted into the equivalent figure for tCe.[4] All figures are expressed on a per hectare basis.

In using the model it should be noted that numerical values that it presents should not be taken as precise estimates because the BBN is not a fully calibrated deterministic model. Node states have been expressed in real units so that it is easier to assign relative weights of the factors that might influence them based on the evidence available. For any node it is the direction and magnitude of change that is of most interest, rather than its absolute value.

The network attempts to describe potential changes in the carbon balance for the three major moorland habitats (see Holden et al, 2007). These are:

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[2] See Appendix 1

[3] http://www.defra.gov.uk/environment/climatechange/research/carboncost/pdf/background.pdf

[4] the calculations in the network assume one ton of carbon is equivalent to 3.67 tons of CO_2

heathland, which is peat-forming but has a naturally fluctuating water table and corresponds to the NVC classes H9, H10 and H12-22;

mire, which is peat-forming, and generally inundated and corresponds to NVC classes M15 and M17-20; and

acid grassland, which is not peat-forming, has a naturally fluctuating water table and corresponds to NVC classes U4-6

In the way the model has been set up in Figure 3, all are assumed to be equally likely. However, in using the network in a relation to a specific case study area, the probability of each habitat type can therefore be set according to their spatial from a vegetation cover dataset. Alternatively, the states can be set to test the impacts of changes on a single habitat type.

Peat decomposition

It could be argued that the node for peat decomposition is probably the most important in the network. This is because it is potentially a much faster process than the formation of new peat and so likely to be the main driver of overall carbon balance. As the network is set up it is influenced by drivers related to climate, pollution input and land management and its impact on various physical parameters such as water table depth.

The assumption of a positive relationship between organic matter decomposition rates and **temperature** made in the network is backed up by a large body of evidence (see for example, Kirschbaum, 1995). There is less agreement about the exact nature of this relationship, and whether it is varies, for example, with temperature or organic matter quality (Kirschbaum, 2006), but it is possible that some of these problems are minimised by restricting the analysis to conditions found in the uplands of England. The general consensus is that for every 10C^o increase in temperature, CO_2 emissions roughly increase threefold (Blodau, 2002). Although there is evidence to suggest that the rate of increase may be faster at lower temperatures (Davidson & Janssens, 2006), this effect has been ignored at this stage because the model only attempts to trace the effects of future average temperature change under different climate change assumptions; thus a simple linear relationship may be sufficient.

An important change made in the revised model involves the relationship between **diffuse pollution** and decomposition. Evidence suggests that this relationship is positive rather than negative, as had previously been assumed. Both nitrogen and sulphur deposition tend to reduce decomposition and therefore lead to increased C accumulation in soils (Evans et al. 2005 & 2006a; Persson & Wiren, 1989; Sanger et al, 1994; Situala et al, 1995). In the case of sulphur deposition, for example, it appears that as upland ecosystems have recovered from the effects of acidification, levels of Dissolved Organic Carbon (DOC) in UK surface waters have risen by an average of 91 %. This suggests that past acidification was probably inhibiting carbon loss from catchments (Evans et al, 2006b).

However, linking the nitrogen and sulphur in a single node for diffuse pollution needs to be considered carefully, because it is apparent that they show quite different temporal trends which may have tended offset each other. While the deposition of reactive nitrogen compounds has increased markedly in recent years, now reaching levels of 40 kg N ha^{-1} year^{-1} over large areas of the UK (NEGTAP, 2001), acidic sulphur deposition has declined by about 60 % in the last two decades (Fowler at al., 2005). It was decided to retain a single node because it was thought that in the case of sulphur deposition, effects of reducing levels have now largely been seen and that the situation is probably stabilising. Moreover, since the relative weights for the impact of changes in nitrogen and sulphur deposition on decomposition rates are unknown it seemed appropriate to lump them together at this stage, and set up the node merely to describe the impact of change relative to the present situation. Further investigation is needed to determine these weightings and their influence relative to changes temperature;

at the moment it is assumed that the effect of changes in diffuse pollution is roughly equivalent to those of changing temperature.

One of the changes in the revised model is the new node for the ecosystem function described as **decomposition type**. This node is used to set the base decomposition rate as determined by the typical water table conditions (indicated by the habitat type node) and the current or future water table level. When the combinations of nodes feed into decomposition rates, it is assumed that 'newly aerobic' conditions should give the most carbon loss, and therefore the highest chance of high decomposition, followed by 'typically aerobic'. 'Anaerobic' decomposition is a much slower process, and so the probability of decomposition is set much lower.

Water table depth is an important control on peat decomposition because below the water table, conditions become anaerobic and decomposition rates are around 2.5 times lower than under aerobic conditions (Bridgham and Richardson, 1992; Moore and Dalva, 1997). Lower water tables have been shown to enhance CO_2 production in a number of studies, conducted both in the laboratory and the field (Kim and Verma, 1992; Moore and Dalva, 1993; Silvola et al, 1996; Alm et al, 1997; Carroll and Crill, 1997; Bellisario et al, 1998). In the current model it has been assumed that the effects of changes in water table on decomposition are greater than those of temperature or diffuse pollution. However, it should be noted that as with temperature, the relationship between decomposition rates and water table depth is not straight forward. A recent review by Laiho (2006) noted that increases in CO_2 emissions generally tail off when the water table drops below a certain depth (Silvola et al, 1996; Chimner and Cooper, 2003) and argued that deeper layers may lack easily oxidizable labile C (Chimner and Cooper, 2003; Hogg et al, 1992). For simplicity, these kinds of effect have not been incorporated in the network.

The model assumes that water table is influenced by rainfall amount, the incidence of summer drought and various land management interventions. The rainfall and summer drought nodes have been included to capture further the potential effects of changing climate; both measure change relative to the present. In the absence of empirical data linking rainfall amounts and drought frequency to water tables, no absolute values are attached the states for these nodes. Rather it is assumed that the increases in precipitation amount and drought frequency indicated in the UKCIP02 scenarios, and that these change the likelihood that average annual water tables levels are rising or falling.

The key land management interventions that are assumed to impact on peat decomposition are liming, grazing pressure and burning. As already noted in relation to diffuse pollution, increased soil acidity tends to inhibit the decomposition of peat and increase carbon accumulation. It follows therefore, that liming, which reduces soil acidity, is likely to increase carbon loss from upland soils, and indeed, experiments have shown that it can increase the concentrations of organic matter, DOC and DON in soil water (Andersson et al, 1994, 1999; Curtin and Smillie, 1983). As liming is currently underway in parts of the UK to mitigate historic acidification, adding a new liming node to the revised network allows the possible effect of this practice to be illustrated.

Pressure from grazing and burning both would tend to increase the rates of peat decomposition by the damage to the vegetation cover. Trampling by grazing animals can cause severe erosion and stimulate decomposition by acting like tillage to increase aeration, and grazing animals also input extra nutrients particularly N, which can also stimulate decomposition (Britton et al, 2005, Milne et al., 1998; Rudeforth et al., 1984). Evidence suggests that burning, whether managed or not, can increase rates of peat decomposition. As well as physically breaking down organic matter, burning also enhances mineralization after the fire due to increased microbial activity; microbial respiration has been reported to be three times higher following burning, in response to higher nutrient and substrate levels in remnant soils and enhanced soil temperature (Kim and Tanaka, 2003); and there is also some evidence that burning increases the pH of organic soils, which would also favour increased rates of decomposition (Allen, 1964; Stevenson et al, 1996). Wildfire is assumed to have the most sever effects, and so in the model this is set to exert a strong direct effect on decomposition rates. Managed burning also increases decomposition, but less so than wild fire, while the 'no burning' state has no effect on decomposition.

Peat Formation

The review of evidence suggests that most favourable conditions for peat formation should be mire habitats with a rising or stable water table, with light or no grazing and no burning, or a heathland habitat with a rising water table, and light grazing and no burning. The least chance of active peat formation should be assigned to acid grassland regardless of the state of the other input nodes, and heathlands with a dropping water table, heavy grazing and a high chance of wild fire. Other combinations of inputs are assumed to give a probability within these two extremes, with wild fire having the strongest negative effect, followed by heavy grazing.

In relation to peat formation, evidence suggests that in some cases light grazing and managed burns may have a small stimulating effect on peat formation. There is evidence, for example, that appropriate stocking levels and well managed grazing, can aid carbon storage in organic soils (Garnett et al, 2000). Moreover, while in the short term burning clearly destroys the vegetation that produces peat forming litter, over the longer term, it may aids the regeneration of this vegetation and helps to keep it at its most productive (Holden et al, 2007). Thus for both these land management activities, the network has been set up to produce a small positive effect peat formation for low grazing and for managed burns. However, as noted above, it is assumed that the detrimental effects of physical damage from heavy grazing and wildfire have a much greater impact on the carbon balance through their impact on decomposition rates.

As noted above, increasing water table levels are assumed to reduce rates of decomposition. In the network shown in Figure 3 it is also assumed that they would tend to increase rates of peat formation, largely by causing changes in vegetation type. However, as in the case of the other land management factors, the proportional influence on peat formation is likely to be much less than its effects on decomposition.

Developing the carbon network

The expert review was designed to examine a number of key issues. For example, in taking this work forward it is important to determine whether the right assumptions have been made about how the system works and whether the right terminology has been used. Clearly the review resulted in a number of modifications, but in general terms the approach suggested in the first phase of work was accepted as a reasonable basis.

In terms of the evidence that could be drawn upon to support the implementation of the network using the BBN approach, it was clear that although it was largely consistent, information was much better in some areas than others, and in particular it was difficult to translate insights into probabilities in a very systematic way. Instead, it was suggested that the assignment of probabilities should reflect present understandings of the relative weights of the different influences on the sequestration service. Thus in operationalising the new network (Figure 3) it has been assumed that sequestration is more sensitive to the factors affecting peat decomposition than peat formation.

Thus the most significant drivers are the biophysical factors that affect decomposition rates, such as vegetation type, temperature and soils water levels, and the land management interventions that can influence them such as drainage management, grazing and burning. While in the long term climate change may have significant impacts on sequestration, it is clear that these land management can have the large and significant impacts at in the short to medium term. Since the different land management factors could potentially work against each other, it is clear that coordinated intervention strategies are necessary.

Despite the changes made, there are some areas where further development of the network could be considered. The impact of land use change, for example, has not been included in the structure of the model. It has mainly been framed around peat-forming habitats. Clearly if land conversion occurred, say to intensive grassland, arable or forestry, then the carbon balance of peat-rich soils would change markedly. Conversion to intensive grassland and arable are both known to cause high rates of carbon loss. Affroestation is less straightforward because tree biomass has a high potential to sequester carbon. In terms of soil carbon storage, however, drainage and further drawdown of the water table by increased interception and transpiration, coupled with initial fertiliser applications, result in increased decomposition and carbon loss in response to afforestation.

The simplest way to include land use change in the existing model would be to extend the list of categories associated with the habitat type node (Figure 4); by switching to intensive grassland, for example, high rates of decomposition could be triggered. However, if this strategy is employed, it should be noted that the model would only describe responses on peat rich soils. In the case of forestry in upland areas with organo-mineral soils rather than deep peat, the effect of afforestation may be more neutral. Increased decomposition offset by increased carbon in the litter layer, but there is currently a lack of evidence to confirm this with any degree of confidence (see review by Reynolds, 2007). Thus a more complex network is probably needed that would take account of sequestration for all the major soil groups that occur in the uplands.

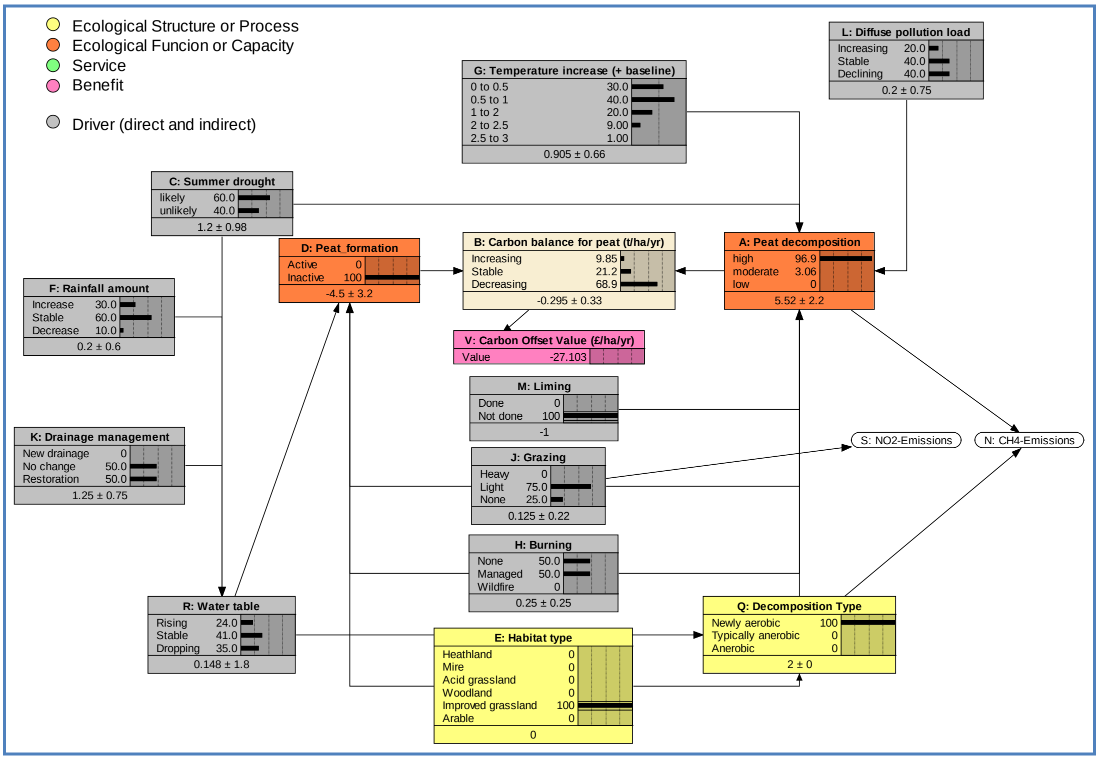

Figure 4: Modification to carbon sequestration network to accommodate the possibility of land use change on peat soils.

The network has been configured so that the habitat node (E) includes alternative cover types. When woodland, improved grassland or arable are selected. Peat formation is absent and decomposition processes dominate. High rates of carbon loss occur under newly aerobic conditions. All other conditions are the same as in Figure 3.

A second area where the model might be developed further is in relation to other green house gases, methane and nitrous oxide. Both have presently not been included because the expert review concluded that these were much less important issues in the uplands than in more intensively managed agricultural landscapes. Methane, it was suggested, is produced only under anaerobic conditions and oxidation processes quickly stop soils being net emitters of CH_4 once the water table drops below the surface (Christensen et al, 2000). Similarly, in relation to nitrous oxide, while it is known that both aerobic and anaerobic processes can contribute to the emission of N_2O from soils, the highest emissions are generally recorded in soils of high water content or immediately following heavy rainfall (Smith et al, 1998). However, emissions are also dependent on levels of N in the soil, which in the uplands tend to be low, unless grazing pressure is high.

Part 3: Water quality

Introduction

Upland catchments are an important resource in relation to the supply of water, both in terms of its quantity and quality. Although the two aspects of supply are closely linked it was decided to focus primarily at the regulation of quality as an ecosystem service. This was because it was thought that quality was probably more sensitive to management interventions than water quantity, and that would be valuable to look at these drivers in relation to those influencing other ecosystem services provided by the uplands, such as carbon sequestration. Any future strategy for the uplands would have to consider the factors influencing this important resource and how they interact with other ecosystem services associated with these areas.

The network for water quality

The development of an operation Bayesian Network for water quality in the uplands was constrained by the fact that the first phase of work only mapped the system in broad conceptual terms. Thus the main purpose of the review stage was to suggest how these initial ideas could be refined and made more specific.

The expert review (Appendix 2) suggested that any conceptual mapping of water quality might usefully distinguish three components of quality, namely dissolved organic carbon and suspended sediment and water colour. While the first two are partially independent of each other, the third, water colour, is thought largely to be governed by a combination of them. Although these components are interlinked, for clarity it is helpful to discuss them separately.

Dissolved Organic Carbon (DOC)

There are a number of potential environmental impacts arising from an increase in dissolved organic carbon. At local scales they include effects on water transparency, acidity and metal toxicity, while more broadly there may be implications for drinking water quality, the possible destabilisation of terrestrial carbon stores leading to increased contributions to more reactive riverine, marine and atmospheric carbon pools (Holden et al. 2007).

A number of potential indirect drivers of DOC levels have been identified. These include changes in rainfall, temperature, ground water levels and antecedent moisture conditions, seasonality, soil organic carbon content, soil microbial activity, soil oxidation levels, soil erosion and climate change impacts. These in turn influence the more direct drives such as ground water temperature, soil temperature, hill slope runoff, stream flow discharge and also DOC release potential and other DOC 'flushing' mechanisms.

In fact the issue of what drives DIOC levels has been the subject of much recent scientific interest, given the 91% increase in DOC observed since 1988 in the lakes and streams covered by the UK Acid Waters Monitoring Network (AWMN) (Evans et al., 2006). Similar increases have been detected in surface waters across much of Europe and North America. Monteith et al. (2007) have examined the hypotheses that have been advanced to explain such trends, and concluded that DOC concentrations are returning toward pre-industrial levels as a result of a gradual decline in the sulphate content of atmospheric deposition.

The proposition that acid deposition to upland ecosystems has been partially buffered by changes in organic acidity, and that the rise in and that the rise in DOC is related to the recovery from acidification, is one of the assumptions made in constructing the carbon sequestration model described earlier, and for consistence it should be carried over into the development of the network for water quality. Nevertheless, given that this factor can only be influenced by actions at the macro level, it seems wise to examine how they might be modified by more local interventions.

There are clearly other mechanisms that contribute to the generation of DOC. For example, the burning of the moorlands (both controlled and accidental) is seen as a driver for DOC generation in certain situations, but the mechanisms involved and the role they play in the catchment scale character of water quality has yet to be resolved. In terms of a hierarchy of importance, burning may be less influential on water quality if other factors, such as water level management were effectively applied. The expert review (Appendix B) suggests that any causal link between upland burning practices and events, and the generation of DOC is potentially complex. There may be a number of intervening factors which are reflected in the current BBN model of the soil, hydrometric, geomorphic and climatic factors and the associated processes at work within the system. Thus a complete cessation of upland burning would reduce the potential rate of peat degradation, and possible localised oxidation, but any worthwhile changes in water quality would only be derived if the physical benefits of non-burning practices were supported by more influential factors such water level management and vegetation recovery.

Other local factors suggested by the review potentially affecting DOC output include soil temperature and soil water levels, and their influence on soil microbial activity. It was argued that the substantial body of primary data available through the United Utilities Sustainable Catchment Management Programme (SCaMP), demonstrates a clear, if time lagged relationship between the level of the water table within the peat mass, the temperature of the water within it and the generation of DOC (colour) *in situ* at the catchment scale. Water table and vegetation management are perhaps key interventions that might be made. Grip blocking and vegetation restoration would tend to lower the mean peat water temperature, and its variability, leading to reduced overall potential for the generation of DOC.

The mechanism linking grip blocking DOC output is however, complex. The expert review suggests that the SCaMP project shows that total organic carbon discharge in catchments where grips have been blocked has declined. However, different interpretations of the effect are possible. It may, for example, be related to a fall in the total amount of runoff from the catchment rather than the total quantity of DOC being generated. The SCaMP data suggests that the early hydrological response to grip blocking appears to be a lowering in the scale of the hydrograph, possibly as the water level in the peat mass rebounds to a pre-gripping situation. In time, the hydrograph may regain its previous level as the catchment runoff response reflects a more consistently saturated peat. However, as the water tables in the peat remain stable, and peat water temperatures are retained at a lower more consistent level, the generation of colour will be suppressed. So as the catchment re-wets and the discharge re-establishes a more ’natural’ equilibrium, total organic carbon leaving the catchment via the stream system will decline. The expert review suggested that it should be noted that such mechanisms may be substantially altered under the influence of climate change. The predictability of the effects of water level management on water quality is possibly less certain in the long-term.

On the basis of the review of evidence, a conceptual map for dissolved organic carbon was suggested (Figure 5). The complex nature of the system underlying this service is apparent, with biotic functions (soil microbial activity, oxidation and soil DOC release potential) embedded in a much wider set of abotic mechanisms. As the system stands, however, the role of land management interventions is not clear, although this might be brought out by developing a better understanding of the factors linking to the soil restoration and soil moisture levels. These issues are, perhaps, best considered after the networks for the second component of water quality (suspended sediment) is considered so that a more integrated perspective is developed.

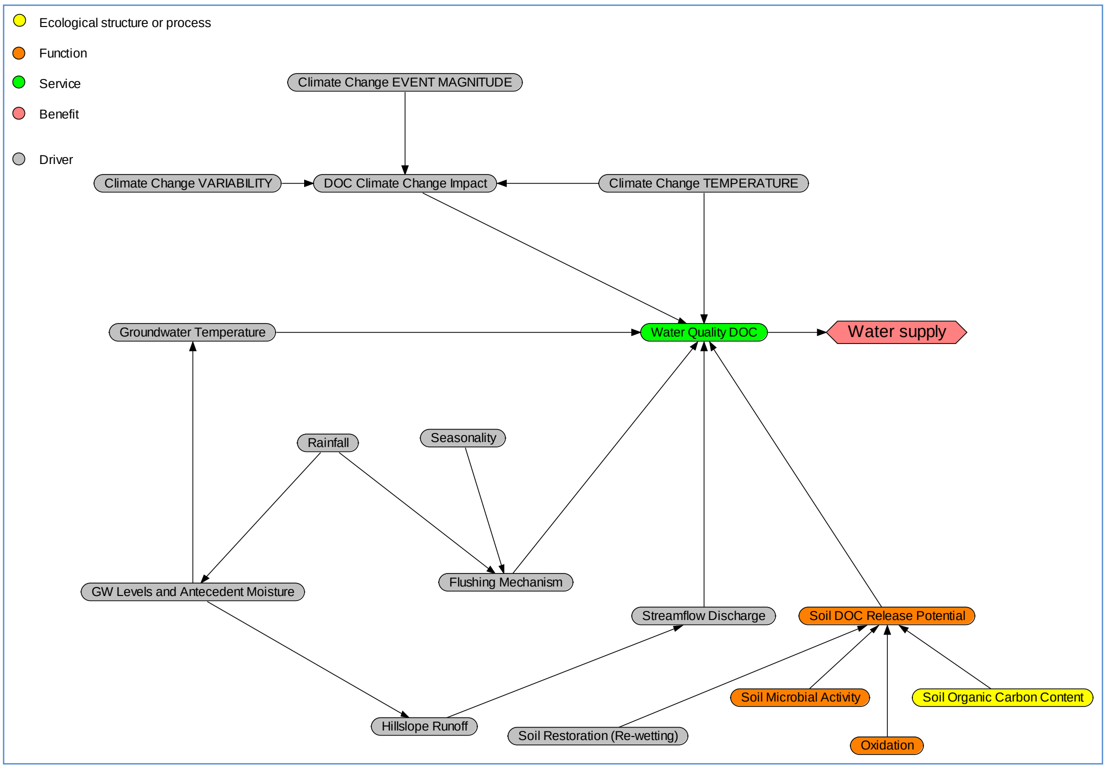

Figure 5: Water quality subsystem for dissolved organic carbon

Suspended Sediment

As with DOC, there are a number of potential environmental impacts arising from an increase in the level of suspended sediment arising from catchments, including the transport of nutrients and contaminants, such as phosphorus (P), pesticides, PCBs, heavy metals and pathogens. Sediment deposition may also impact on lakes and reservoirs. Van der Post et al. (1997) reported, for example, that the accelerated rates of sedimentation in Blelham Tarn, English Lake District could largely attributed to increased sheep stocking density within which the lake catchment in the late 1980s. Thus the ability of upland catchments to retain suspended sediment is a potentially important ecosystem service.

The expert review suggested that the DOC and suspended sediment were affected by many of the broad drivers, including rainfall, seasonality, ground water and antecedent moisture levels, soil erosion and direct hill slope surface runoff, and climate change impacts (especially in terms of the changing magnitude and frequency of events). Vegetation cover, type and density were also highlighted as significant influences, along with soil restoration measures through land management activities.

The influence of vegetation type, density and cover were considered to be critical components of any conceptual map that seeks to capture the water quality issue. Retaining a vegetation cover that avoids soil erosion processes from becoming dominant is an obvious factor in retaining and enhancing the value of this ecosystem service. The expert review argued that work at a number of sites including SCaMP and National Trust properties in the Southern Pennines has clearly demonstrated that sediment loads rapidly decline when bare peat restoration is adopted on a significant scale. However, while restoring and retaining adequate vegetation cover on the uplands is a critical factor in water quality management it was suggested that its success is dependent on both socio-economic drivers as it will on the physical processes within the system itself. Maintenance of an appropriate vegetation cover on the uplands to provide water quality benefits will only occur if the activity is economically viable for more than just the value of the water quality component alone.

It was suggested that large scale afforestation within the uplands may well provide significant water quality benefits but the funding streams to sustain this approach need to be long-term and of a sufficient scale to generate a cultural change in the way the uplands are currently managed. However, historic data suggests that the impacts on sediment loads are critically dependent upon the way that afforestation is done. Holden et al. (2004) report that sedimentation rates may increase as a result of activities to prepare ground for planting, only to reduce once the forest canopy closes.

The expert review noted that that there are some synergies between interventions that might limit the output of suspended sediment and DOC. Large scale generation of suspended sediments through habitat management, for example, may also limit the means by which DOC and nutrients, enter the hydrological system, but the effects may not be synchronous. Although re-vegetating bare peat will reduce the source of suspended sediments, however, the generation of DOC may continue because of the large quantities of organic materials already within the catchment stream system. Moreover, while re-vegetation may well reduce suspended sediments loads within the catchment unless other variables are managed, such as sustaining peat water table levels, the generation of DOC may continue for a considerable time.

The conceptual model for suspended sediment suggested by review is shown in Figure 6. As can be seen by comparison with the network shown in Figure 5 there are a number of common nodes that may effectively be used to link them, although this has not been done at this stage, in order to reduce the complexity of the diagrams. There is for example a common structure to the model for the climate change impacts, and antecedent moisture conditions influences both of the suggested networks. As with the model for DOC, however, land management interventions are not explicitly included, except in terms of the rather general elements relating to 'soil restoration' and vegetation. It was argued that although land management influences such as burning and grazing intensity are important contributory mechanisms affecting both components of water quality variables, they could not easily be included in the suggested model structure due to the uncertainties associated with each of them.

Developing the water quality network

The expert review made a number of modifications to the network suggested in the first phase of work, although the broad structure and terminology of the original study was largely confirmed. However, the justification for the proposed mode remains largely based on 'expert judgement' rather than empirical data or the peer reviewed literature. Thus it is difficult to assess the adequacy of the evidence base at this stage or any potential conflicts.

On the basis of the outcomes of the expert review it was suggested, however, that it is probably premature to link the networks for DOC and sediment into a single Bayesian Networks, because evidence supporting any judgements about the relative weights of links is lacking. The review recommended that if this work was taken forward then integration should, however, be attempted. It was suggested that one of the advantages of a linked model would be that some of the inherent conflicts between quality, water quantity and flood services could them be highlighted. It is believed, for example, that by re-wetting the uplands and establishing more woodland, scrub and sustainable dwarf shrub heath, significant benefits would accrue to water quality at a cost to water quantity. This potential trade-off between the ecosystem services framed around the idea of water quality and water quantity needs further investigation.

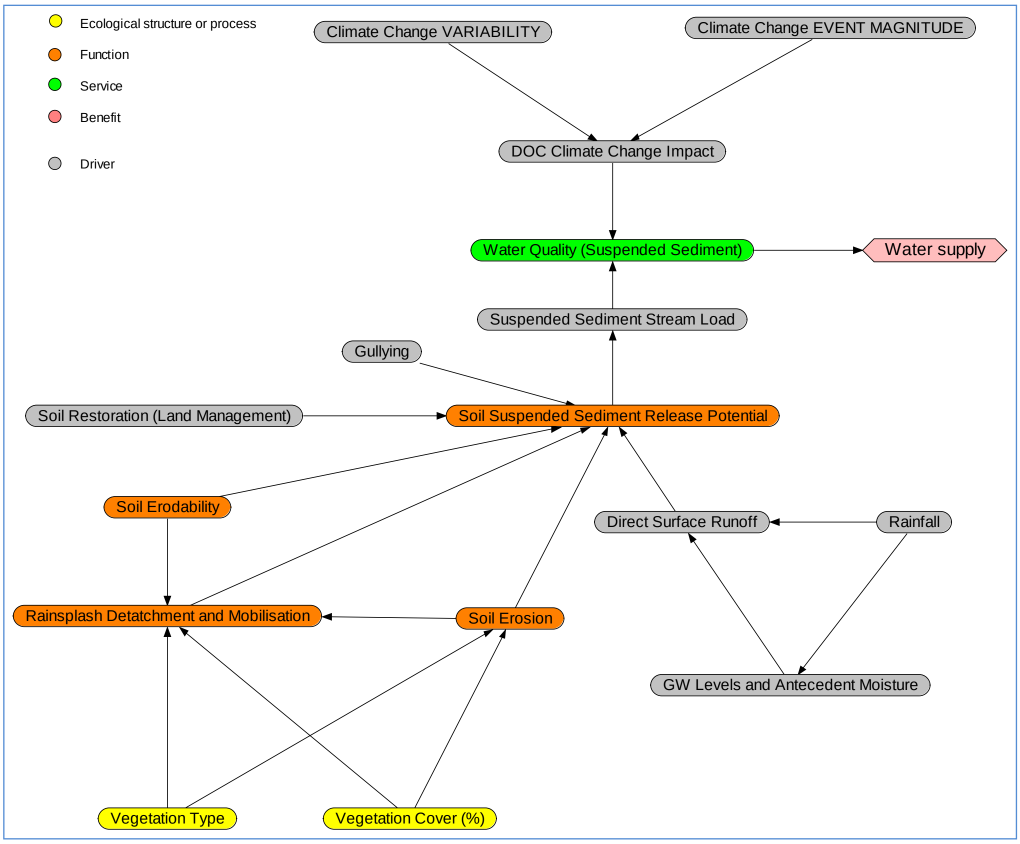

Figure 6: Conceptual model for suspended sediment

It is a particularly important issue to consider the issue of water quantity further, because it appears that by re-establishing hydrological equilibrium in the uplands the result may be a water resource that is more manageable and predictable. There is also evidence to suggest land management in the uplands can result in river hydrographs that contribute to relieving pressure on flood management lower in the catchment system. It is also apparent that there are many potential links to the network for carbon sequestration outlined earlier, particularly in relation to the influence of water table management and the various climate parameters. Following our review of the final network for flood mitigation, we will make recommendations on how this linkage might be made.

Part 4: Flood Mitigation

Introduction

The impact of land use management on flooding is the subject of recent research as part of the Making Space for Water (MSfW) strategy on flood and coastal erosion risk management in England. A number of land-use projects HA6 (catchment scale) and HA7 (farm or local scale) are investigating the role that rural land use and land management can play in reducing flood risk. Many of their findings provide insight into possible changes that could be made to the upland environment to improve the provision of flood mitigation as an ecosystem service. The project outputs, combined with those of Defra FD2114 project to Review of the impacts of rural land management on flood generation (2004), provide an assessment of the most recent evidence and scientific thinking in support of the link between land use and flood mitigation. The Defra project was most recently updated by Atkins to guide the direction of future HA6 and HA7 and funding in this area (Environment Agency, 2007).

The network for flood mitigation

As with the network for water quality, the development of an operational Bayesian Network for flood mitigation in the uplands was constrained by the fact that the first phase of work only mapped the system in broad conceptual terms. Thus the main purpose of the review stage was to suggest how these initial ideas could be refined and made more specific.

The expert review (Appendix 3) sought to summarise the relationship between land use and management types (or in some cases practices) within the uplands and flood mitigation. This included an analysis of how flood mitigation is achieved, namely through a reduction in flood generation or propagation downstream. The review considered both current evidence for the mechanisms underpinning flood mitigation and the benefits which particular measures might have for other ecosystem services. A number of modifications and additions were suggested.

The new network (Figure 7) proposed by the review was simplified by focusing mainly on food control; the model developed in the first phase attempted to consider both water quantity and quality. However, a single water quality node was kept within the new structure to emphasise how links between the two topic areas could be made, because many of the processes and relationships influencing flood mitigation also have a particular impact upon diffuse water pollution.

The key elements were divided into two groups depending on the strength of their relationship to flood mitigation. The assumption underlying the proposed structure was that it describes mechanisms operating primarily at the catchment scale. It was noted that the strength and pattern of relationships would change with scale and location. Taking the uplands as a whole, it was suggested that the most important nodes in the model would relate to where it was being applied; these locational characteristics were not included in the new proposed structure.

The most important influence in the revised mode was considered to be vegetation cover. It was argued that a much more comprehensive list of types was needed than those proposed in the original structure, and should include: arable, woodland, heathland, hedgerows, upland fens and swamp, rivers, blanket bog, wet woodland, as well as bare ground.

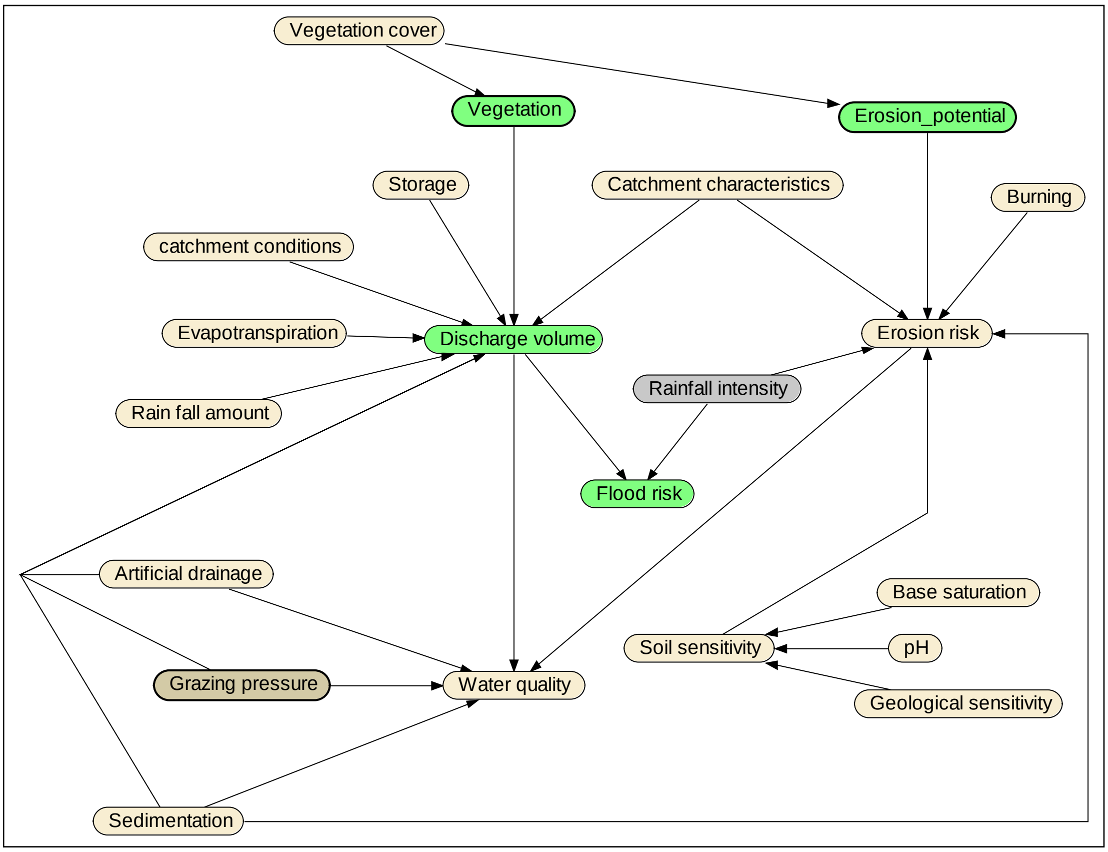

Figure 7: Network for flood mitigation

Tree cover can provide a buffering function for water courses, by attenuation overland flow they may limiting flood generation and reducing the propagation of flood flows downstream (Defra, 2008). However, it is also apparent that the siting of woodland is critical. Floodplain woodland must, for example, be strategically situated to achieve flood mitigation, as the resultant increased floodplain roughness may cause flood depths to increase upstream of the site. The risk of floating debris moving downstream being trapped in woodlands and causing blockages that locally exacerbate flood risk is also a potential issue. There is also evidence that permanent pasture may reduce the risk of flood propagation through its increased water storage capacity compared to other land uses, such as arable. However, it would appear that quite large-scale changes in grassland land use are required to produce a relatively small reduction or delay in downstream flood peaks.

The management of drainage on farmed land is also an important factor. Additional water storage on farms has been shown to dramatically reduce flows, and bunded areas reduce flows entering watercourses can be effective in flood mitigation locally. More generally it is known that changes in land use from arable to grassland along rivers, and set-aside at field margins and headlands, contour ploughing, under-sowing, leaving uncultivated areas, and reduced grazing pressure, can reduce flood risk.

Particular land management practices are also likely to affect the capacity of vegetation to mitigate flood risk. The management of moorland drainage and grip blocking as part of efforts to restore areas of eroded and exposed peat are likely to improve infiltration of surface run-off, especially in extreme rainfall events, and therefore help reduce flood generation. However, the expert review noted that it is uncertain whether long-term changes in peat hydrology resulting from past drainage can be reversed. Current evidence suggests that the impact in any catchment varies according to peat type, climate, catchment characteristics and the behaviour of the peat water table. Therefore it is important to understand the characteristics of the peatland system before restoration in order to suggest what the implications might be for flood mitigation; unfortunately currently research into this issue is limited.

As noted in the discussion for carbon sequestration and water quality, burning practices in the uplands can influence their hydrological characteristics, by changing vegetation. Uncontrolled or badly managed fires are likely to have a negative impact on the provision of flood mitigation. However, there is limited evidence to suggests that in areas where burning is well managed there is any positive effect on their flood mitigation characteristics.

In the revised model shown in Figure 7 other modifications include: a node for evapo-transpiration, which may limit discharge volume at certain times of the year; water storage, a node that covers physical structures and vegetation; and, nodes for catchment conditions and catchment characteristics. Both are aggregates of a number of factors which would have to be separated out in any operation al model. Catchment conditions would capture the influence of such factors as soil moisture levels and recent meteorological characteristics. Catchment characteristics describe the influences of catchment size, underlying geology and lithology, topography, soil type, drainage network characteristics, and extent of built-up areas (including hard-standing, roads, etc.).

Developing the flood mitigation network

The expert review suggested that in developing the network there was a real difficulty in conceptualising this ecosystem service both in terms scale (local or catchment scale) and in ways that would enable the insights to be transferred from one area to another. The revised network was focused at the local or catchment scale; there is at present no real mechanism for potentially modifying its 'outputs' according to specific types of local conditions.

As in the case of the initial network for water quality, the broad structure of the initial model was confirmed by the expert review, although significant changes were suggested. Unfortunately the time available did not allow the current evidence-base to be used to suggest probabilities or weights between the various factors. Nevertheless it was confirmed that vegetation cover and structure was a key factor in understanding the flood mitigation service that the uplands potentially provide, and so many of the management interventions identified as significant (grazing, burning, water table management) were the same as those highlighted in the reviews of the other services. In the short term it is likely that these interventions would be highly significant in controlling the capacity of systems to mitigate flooding, although the model does not yet offer any real understanding of the circumstances in which they would be most effective. Since there is considerable spatial variation in the capacity of upland ecosystems to mitigate flooding, it is clear that any future model would have to include some mechanism to permit 'parameterisation', to capture the specific characteristics of the area being considered.

It should also be noted that the influence of climate change on future dynamics is also omitted from the model. The expert review noted that climate change is likely to be the most important future driver influencing the provision of flood mitigation as an ecosystem service, through the increased frequency and magnitude of flood events. The implications of future climate change are likely to be complex and highly uncertain (Defra, 2005). Although the resultant changes to flood risk will vary from catchment to catchment, and within catchments, the upland environment is likely to be more seriously affected by some elements of future climate change than other environments. For example, hotter drier summers are likely to cause more peat soils to dry out and more wild fires to occur on the moors; whilst wetter winters may mean increased soil erosion and downstream flooding.

Climate change may in itself precipitate changes to land use and management, especially agriculture (Defra, 2005a). Any associated changes to the type of crops grown, stocking densities and farming practices could have impacts on soil structure, vegetation cover, infiltration and interception rates. A change in land management could also help mitigate the causes and impacts of climate change in the uplands. For example, management to preserve peatland habitat has the potential to provide mitigation for the effects of climate change through carbon sequestration.

Part 5 Recreation

Introduction

The Uplands of England are an important recreational resource and the first phase of this study attempted to examine the topic from the perspective of an 'ecosystem service'. Cultural services, which include recreation, are one of the major categories highlighted by the Millennium Ecosystem Assessment. Thus it was useful to consider the extent to which it could be modelled using the Bayesian Network approach alongside the other topics that were more explicitly related to biophysical processes.

The initial study concluded that of all the service themes considered recreation was the one that was the most difficult to represent as an ecosystem service. Countryside recreation was found to be wide ranging in character and whatever role 'ecosystems' play played in it, they were only part of a much broader set of process which included socio-economic and behavioural factors as well as the biophysical characteristics of particular places. In short, while recreation or aspects of it could potentially be modelled, it was not clear the representation of it as an 'ecosystem service' brought much insight. Most of the factors that appeared to strongly influence measures such as 'participation rate' or 'quality of the recreational experience' appeared to be strongly related to socio-economic drivers, and biophysical influences, although important, were mostly a given. Terrain and its scenic quality are more or less fixed and vegetation cover changes only slowly.

The independent expert reviewers (Appendix 4) were asked to consider these issues critically, and to suggest what the factors were the most important to take account of in any modelling exercise.

Measuring recreation and the factors that influencing it

The expert reviewers agreed with the suggestion made in the initial study that there are few measurable outputs relating to recreation, and that participation rates and health benefits are the most important and most useful measures. These were used as the principle measures of service output in the Bayesian Model proposed from in the earlier round of work. However, the reviewers did not feel that overall the model represented their understanding of upland recreation.

It was suggested that the model should be divided into 4 sections relating to participation, transport, disturbance and biodiversity. On the basis of the evidence available it was argued that it was only for participation could any real progress currently be made.

In the context of the biophysical factors such as climate, geology, vegetation and biodiversity interest, the review argued that there is little information about how these affect or are affected by recreation. While tranquil and wild areas are known to attract people, it is suggested that there is little evidence that that can be used to predict what people consider 'attractive' countryside to be or what people's preference are. Indeed, different people or groups may have quite different responses to different aspects of the countryside, and what might attract some could deter others. Similarly, it was suggested there appears to be little evidence to support the idea that recreation leads to disturbance in the countryside or that this is a factor in shaping peoples use.

In order to highlight the factors that influence participation, the expert review drew in the information recently collected for Natural England as part of the of National Trails[5] study. This included market research from 2008[6] that gave a picture of the opinions of a representative sample of the English adults, in relation to recreational need, motivations, barriers and triggers for behaviour change. Although the survey mainly dealt with recreational walking, it was suggested by the reviewers that many of the key findings are applicable to a wider range of recreational activities, and were relevant to issues in the uplands.

The National Trails data could be interpreted to suggest that participation was influenced by four groups of factors (Figure 8): information, environmental product, services and quality management. The percentage figures shown in Figure 8 indicate the relative importance of each factor according to this surveyed, although it should be noted that since the categories are not mutually exclusive, respondents could identify several as important, and so the proportions do not sum to 100%. Where no figures are given, these factors were not included in the survey but were included to link the schema with nodes given in the original model.

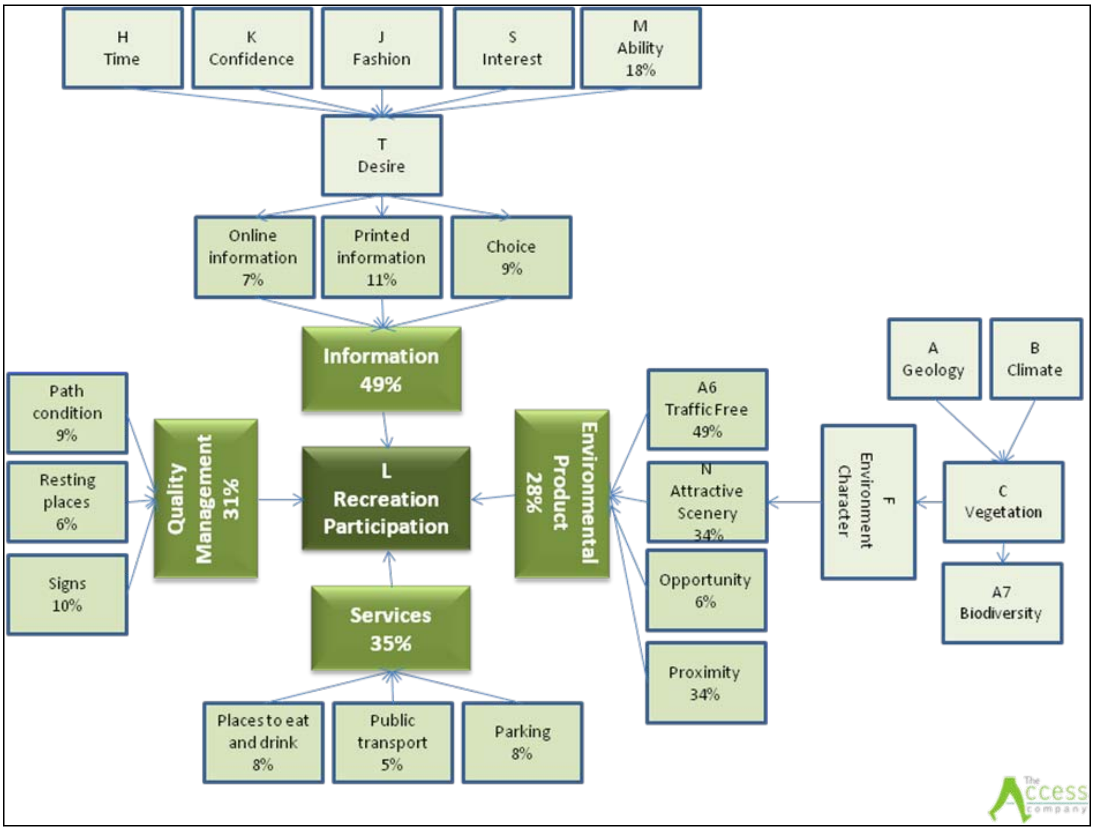

Figure 8: Recreation Participation Model (note, letters refer to nodes shown in the network developed in the initial study, namely Figure 4.1)

The data suggested that having the right information at the right time and in the right place is the most key factor to recreation participation; 49% of the people surveyed cited this factor as significant. The services on offer were next in terms influence. About 35% of people surveyed were found to need supporting services and facilities to be available before deciding to visit an area. Of the different types of services of people wanted places to eat and drink (8%), a place to park (8%), and connections to public transport (5%).

[5] Full findings and report yet to be published – contact Peter Ashcroft, Natural England
[6] Internal NE report - The Market for Strategic Recreational Routes TNS UK Ltd, August 2008

The quality of the management of the countryside is important to 31% of people. About 10% of people want to know that there are signs, 9% good paths and 6% rest areas.

The 'environmental product' was found to be the least important factor, with only 28% of people citing this as an important influence over their participation in recreation. Of those citing this as important, 49% of people were looking for traffic free recreation experiences, 34% in attractive landscapes and for 34% of people the fact that these experiences are within 30 minutes of home is important.

The expert review concluded that since the only evidence available was for participation the any model is necessarily partial. On the basis of the findings available it was suggested that any recreation model of the type attempted in the earlier study would have to more fully take account of the complexity of different people demanding different recreational experiences from different environments. It was felt that the interrelationships between these issues were only just beginning to be explored and that further market research is probably needed in relation to the uplands. Although the quality, tranquillity and general attractiveness of the landscape is likely to influence participation rates, it was suggested that it was difficult to predict where these paces are, and that further work to identify them would be essential.

Developing the recreation network

Although the findings of the expert review were generally pessimistic in terms of developing the initial Bayesian models further, it is possible to modify the structure to some extent in order to take account of the comments. It proved easier to work with the sub-model proposed in the earlier study than the larger, more general one, because the nodes were more tightly specified. The nature of the statistical information available from the National Trails survey meant that they could not be easily translated into the probabilistic tables needed to implement a network, but it was felt that the suggestions about the relative strengths of the major types of influence can be represented in an approximate way.

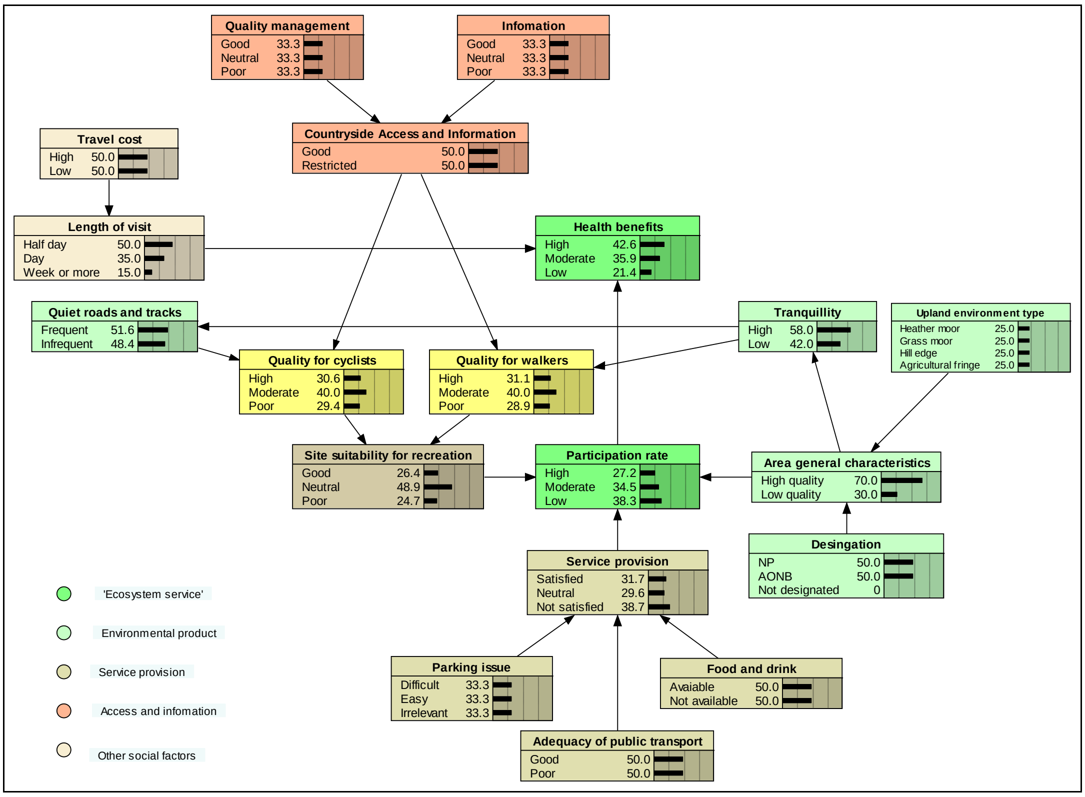

Figure 9: Modified network for recreation

Figure 9 is the resulting adaptation of the recreational sub-model presented in the earlier study. In order to retain some suggestion that there are different types of recreational use, the focus on walkers and cyclists has been retained to show how different types of use can be included in any future model. It was also considered important to retain the nodes for health benefits, even though empirical data were lacking. As before health benefits are assumed to be directly proportional to participation rate and length of visit, and represent the aggregate benefits for the population as a whole. The latter is represented as an 'external social factor', and more research is clearly needed to determine what kinds of influence might shape decisions about the duration of stay. At this preliminary stage we have assumed that travel costs might be one such factor, and that high costs would tend to favour longer visits.

It should also be noted, that while the concept of overall quality of the environment for different types of recreation was not included in the discussion from the expert reviewers, it was useful to retain these nodes for modelling purposes, so that the various types of influence could be aggregated and their influence on participation rate simplified.

On the basis of the comments of the expert reviewers, the major changes made to the original network are as follows:

- The elements described in relation to 'service provision' by the expert review have been added to the lower part of the diagram. The network has been set up so that they directly influence participation rate.
- The nodes in the original network diagram that represented landscape characteristics and tranquillity were considered to be broadly equivalent to the 'environmental product' category suggested in the expert review and so have been grouped together and made to link directly into participation as before.
- A new node 'access and information' has been introduced to replace the old 'countryside access node'. This aggregates the effect of the two categories suggested in the expert review, 'quality management' and 'information', which are set up as its two parent nodes. They were treated in this way to simplify the way in which they may differentially influence the quality of the environment for walking and cycling.

The nodes shown in Figure 9 have been set up on the basis of trial and error, so that participation rate is most strongly influenced by the node for 'site suitability for recreation'. This is assumed to sum the suitably for walkers and cyclists, which in turn is strongly influenced by the 'quality of access' and the 'level of information' about the site prior to visit; for the 'quality of access node', 'information' has a stronger influence than the 'quality management' node. In the network the next most influential factor is service provision, followed by the group representing 'environmental product'.

Figure 10 illustrates the impact of switching the node 'countryside access' to its most favourable states. The back-chaining effect on the nodes for 'quality management' and 'information' shows that of the two, the latter has the strongest influence on this node. With 'countryside access' set to 'good' the model shows that in comparison to the configuration shown in Figure 9, participation rate and health benefit outputs are higher compared to situations where the probability of good 'countryside access' is lower.

Although the revised network can be used to represent the marginal effects of the principle influences on participation rate that were highlighted by the expert review, the model shown in Figure 10 remains a highly simplified representation of recreation in the uplands. Land management, and biophysical structures and processes are only represented in the most general way, and it is difficult to see how, at this stage, the network could connect up with issues highlighted in the other topic areas considered in this study. Moreover, while the relative strengths of the factors known to influence participation rate have been included, it is clear that further work is required to really establish the nature of the links to health, and the more place specific factors that might begin to differentiate one locality in the uplands from another in relation to different types of recreation.

Overall it is hard not to draw the conclusion that to progress models of this kind we need to look at recreation more as a social process than an ecosystem service –the countryside just happens to be the arena in which it occurs.

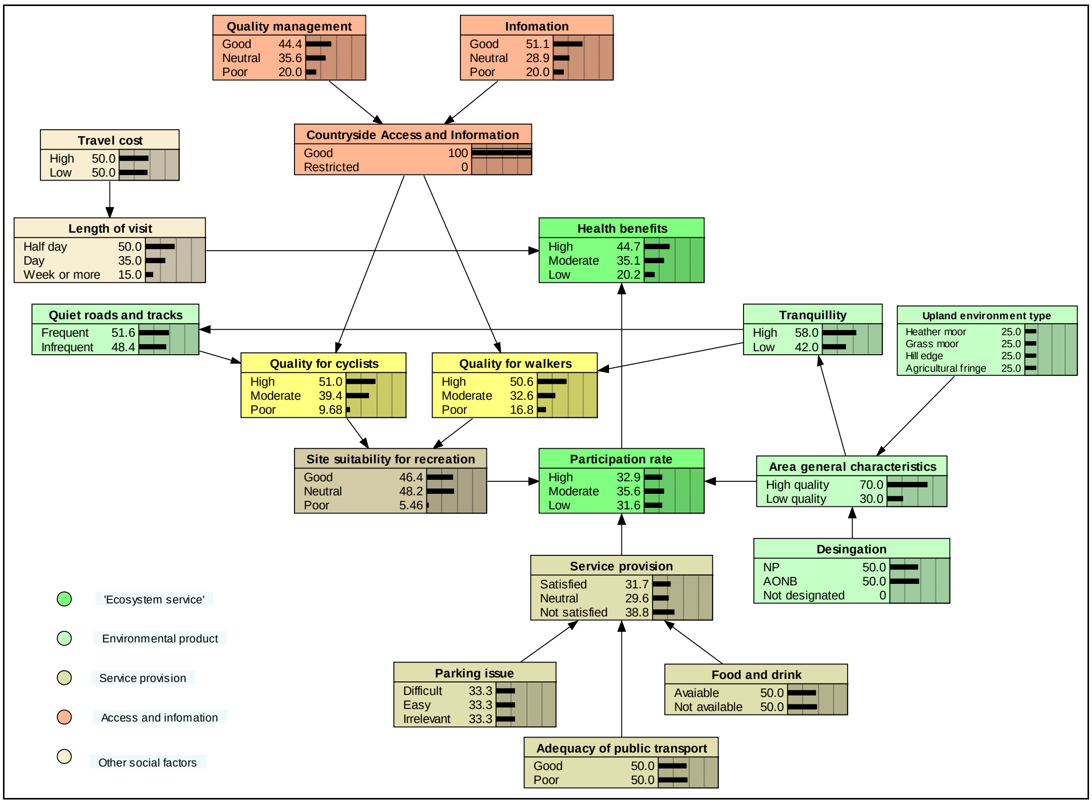

Figure 10: Recreational network set up to illustrate the impact of high levels of access and information, good service provision and high quality environment on participation rate and health benefits.

Part 6: Conceptual Models for Ecosystem Services

Taking stock

This Report documents and reflects upon the comments made by invited experts on four models of ecosystem services that are important in the uplands: carbon storage, water quality, flood protection and recreation. The experts were asked to examine the extent to which current evidence could be used to make the models more robust decision support tools, and identify what gaps remain need to be addressed in future work. In this final section we draw out some of the key conclusions and consider what directions future work might take.

The important conclusions that emerge are as follows:

- That broadly, the right kinds of assumption were made in the development of the networks proposed by the initial study, and which kinds of land management interventions were being considered. The terminology used in the earlier study was also broadly acceptable, although some modifications, particular to the recreation model were proposed.
- The expert reviews also confirmed the findings of the earlier study, namely that evidence base supporting the development of such models was fragmented and variable in its depth and coverage.
- Of the four areas considered, the reviews suggested that the evidence supporting the model for carbon storage was perhaps the most complete, although even here, important gaps remain. For example:
    - The refined carbon model is rather narrow, only dealing with peat rich soils. If such a model is to be useful then future work should aim to develop a more general model of soils in the uplands, and particularly the impacts of specific types of land cover change upon them.
    - The model does not address the impact of land management activities what aim to promote carbon storage on other green house gases, which may involve some trade-offs in relation to the benefits achieved.
- In terms of linking the models into some larger structure, the close relationship between the factors that influence water quality and quantity (and hence the service for flood regulation) means that these probably offers the best scope for integration. Given the influence of dissolved organic carbon arising from upland soils, the link to the carbon storage model is also promising. However, before such work can be undertaken, it was clear from the reviews that decisions about the spatial scale at which the model has to operate need to be made. Specifically:
    - Is the model intended to capture processes at the catchment scale? If so, then the model would need to include a wider set of biophysical factors that could be used to capture the characteristics of particular catchments for which decisions need to be made or management options explored. Unfortunately, a ‘ready-made’ catchment typology is lacking, and so before such an integrated network is considered further work is needed to develop a framework that could be used to make the model place-specific.

- Since many of the wider environmental and socio-economic influences do not operate at the catchment scale, there may be some merit in continuing to develop the more general models suggested in study, but including nodes that broadly capture the types of locality that might be particular sensitive to such changes. Although empirical information about such sensitivities is lacking – it may be easier to capture from expert knowledge than to devise a catchment typology from scratch.

- Despite such difficulties about the spatial scales at which the water and carbon models might be framed, it was clear from the reviews that in terms of beginning to identify some of the synergies and conflicts between different land management strategies, these three topic areas were a good place to start:
    - Vegetation cover and structure emerged as a key factor in understanding the carbon storage, water quality and flood mitigation in the uplands;
    - Many of the most significant management interventions identified (grazing, burning, water table management) were common to each topic area; and,
    - Since the effects of these interventions may act differentially on the three services the effects of trade-offs can begin to be explored. For example, a linked model could highlight some of the potential conflicts between water quality, water quantity and flood regulation. The reviewers suggested that re-wetting the uplands and establishing more woodland, scrub and sustainable dwarf shrub heath, could secure benefits for water quality at the expense of water quantity.

- Finally, recreation remained problematic in terms of representing it as an ecosystem service, or at least in relation to understanding how the biophysical characteristics of the uplands influence the different kinds of recreational use. The outcomes of the expert review point to a need for further 'market based research' to understand recreational processes more generally, and the factors that motivate people. However, from the perspective of better understanding the topic as an ecosystem service it would probably be most useful to target this research quite narrowly. Specifically:
    - The market based research should not seek to understand the recreational process in totality, but attempt to explore how the marginal values that people attach to particular places (or types of place or landscape) change under different biophysical conditions. Thus the research could, in relation to the different types of recreational activity, examine the marginal impact of biophysical changes in, say, tranquillity, vegetation cover or level of development (e.g. wind farms) on participation rate. Thus the question posed would be 'Would you be more or less likely to visit this area if….'
    - If these biophysical changes could be linked to specific land management practices, policies or scenarios, then the outcome of the research could potentially be linked to the kinds of integrated model proposed for water quantity, quality and carbon. Thus the model of 'recreation as an ecosystem service' should mainly the marginal contribution that the biophysical characteristics of the uplands play in a much broader set of social processes.

Overall, although the reviews did not identify any significant conflicts in what the evidence base was telling us about these four topic areas that need to be resolved through future work, the translation of these understandings into the probabilities needed to fully implement the networks remained a challenge.

Next Steps

On the basis of the work carried out in the initial study, it was suggested that Natural England should consider developing the conceptual mapping approach based on Bayesian Networks as a way of grounding their understanding of ecosystem services on the range of evidence currently available. It was also suggested that it could provide a useful framework in which different scenarios for the uplands can be explored. The results of this study broadly confirm this earlier recommendation, but it is now possible to be more precise about what directions this kind of work might take.

Although conceptual networks of the kind presented here can and have been used for operational decision support, it is clear on the basis of the expert reviews that we are a long way from providing such tools for the services considered here. There are considerable gaps in the evidence base and uncertainties about how such systems might be used, and both these barriers have to be overcome before a reliable decision support system can be built. However, this does not mean that conceptual networks of the kind described here have no value. Their immediate contribution, in fact, lies in other areas.

First, it is clear both from this study and the earlier one, that the act of conceptual mapping is a good way of taking stock of what is known and of organising it in relation to particular user needs. The merits of the BBN approach over simple influence diagrams, is that either on the basis of empirical data where it exists, or expert judgement where it does not, the direction and strengths of the different linkages can be represented. Moreover, by helping people to conceptualise and represent the world that they are thinking about, the model can be used to identify the sorts of evidence that needs to be collected in the future. In the context of the present study, this has been illustrated by what is in all other respects, the least tractable system considered – namely recreation. It may currently be over-ambitions to build a fully operational, place-specific recreational model using the Bayesian Approach, but the attempt to construct one has been useful in terms of looking at what recreation actually means as an 'ecosystem service', and how one might characterise it as such.

Second, it is also clear from this and the earlier studies, that the conceptual maps are useful communication tools, and could well be a way of facilitating discussion about how systems might react under different management, policy or environmental scenarios. Given that this work has been undertaken as part of a longer term *Upland Futures* exercise, one recommendation could be that approach developed could be used as an enabling device in a set of participative, scenario building exercises. By representing the scenarios as different combinations of states across a BBN, supposed effects could easily be demonstrated to different sorts of stakeholders, and their views captures as to the likelihood or acceptability of such outcomes.

Thirdly, when we think about how these networks might be used in relation to the growing body of work concerned with the valuation of ecosystem services, it seem clear that they are potentially useful devices to help represent the way different factors change the marginal value of service outputs. This has been illustrated in the current study in carbon network, where a utility function was constructed to represent the change in carbon offset value per ha that resulted from the changing balance between peat formation and decomposition. The same approach could be applied in relation to the other networks, and potentially made even more sophisticated by separating out the different components of Total Economic Value. These networks could also be used to help construct 'choice experiments' from values might be deduced by asking users to assign proportional weights to particular outcome states represented by a particular target node.

Finally, and this leads on directly from the three observations made above, conceptual maps of the kind considered here are useful heuristic devices. While they may be speculative in character, the conceptual maps can rapidly prototype ideas by allowing users and experts to connect up topics that are not currently well integrated. There is currently much interest in embedding the Ecosystems Approach in decision making at all levels (Defra, 2007). For such an approach to be effective, decision makers not only need to think through the cross sectoral linkages but also attempt to understand how interventions might change the marginal values people attach to ecosystem services. Rather than using these networks to build operational decision support systems, perhaps a more appropriate vision might be to consider how they can be used as a tool box to help people represent complex problems, assess the likely consequences of decisions, and identify where judgements are based on empirical data rather than on expert opinion.

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Appendices

Appendix 1: Original Paper on Carbon Sequestration

Upland Ecosystem Service Report on Carbon Storage and Sequestration

by

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Summary

This report builds on the Bayesian Belief Network (BBN) described in Haines-Young et al. (2008), reviewing the existing nodes and the relationships between them, suggesting how they may be improved and refined, and documenting the relevant evidence from scientific literature. The main suggestion to come out of this work is that the peat decomposition node should be altered to better capture the crucial role of soil water conditions in determining the rate of decomposition. To achieve this, it is recommended that the peat mass node be changed to reflect habitat type, which together with an altered water table node, will feed into a new node to reflect whether decomposition is aerobic or anaerobic and whether this is typical of the system or represents perturbation. This new node will then set a kind of default rate of decomposition, which the other factors can act on in the existing node A. Possible values for the overall carbon balance are given for a range of systems, from the pristine to the heavily disturbed, which will assist in the final parameterisation of the network. Other suggestions include more minor alterations of the way some variables influence their child nodes, for example reversing the current relationship between decomposition and diffuse pollution load, and adding extra states to the management nodes of grazing and burning to increase the options for future management strategy testing. Finally, other issues such as non-carbon GHG emissions and land use change are discussed, and recommendations are made as to whether they should be included and if so, how.

Reviewing and refining the service network

The following sections consider each node of the BBN in turn and discuss how they are related the nodes which feed into them and the evidence base to support this relationship, or in the case of parent nodes, how they are determined. Suggestions are then made for how each node may be improved to better reflect the available data.

Node A: Peat decomposition

This is the sole node representing loss of carbon from storage and since this is potentially a much faster process than the formation of new peat, it is arguably the main driver of overall carbon balance and therefore the single most important node in the network. As the network currently stands, decomposition is a function of temperature, summer drought, water table, diffuse pollution load, grazing, burning, and peat mass, and is calculated on the basis of weighted scores, with temperature and burning potentially having the greatest impact.

Temperature

The assumption of a positive relationship between organic matter decomposition rates and temperature made in the network is backed up by a large body of evidence (see for example, Kirschbaum, 1995). However, there is rather less agreement about the exact nature of this relationship, and whether it is varies, for example with temperature or organic matter quality; a good summary of the areas of contention is provided by Kirschbaum (2006). By focussing only on the response of English upland soils to increases in their native temperature, this project avoids many of the problems inherent in trying to model the general response across all conditions. However, the linear relationship currently indicated is not ideal, as the activity of bacteria, which make up a significant portion of the decomposer community, is known to respond to temperature in an exponential fashion.There is a general consensus on a Q_{10} value of 3 for peat soils in boreal and temperate regions, i.e. for every 10 ^{o}C increase in temperature, CO_2 emissions increase threefold (Blodau, 2002), however the relationship is actually an Arrhenius one, where an increase in temperature has more impact at a lower temperature (see Davidson & Janssens, 2006) This type of relationship could therefore be used to modify decomposition rate from a default value, set by existing conditions (see below for further details about a new decomposition type node to describe this).

Water table

Water table depth is an important control on peat decomposition because below the water table, conditions become anaerobic and, in short-term laboratory incubations of peat soils, decomposition rates have been reported to be around 2.5 times lower than under aerobic conditions (Bridgham and Richardson, 1992; Moore and Dalva, 1997). Lower water tables have been shown to enhance CO_2 production in a number of studies, conducted both in the laboratory and the field (Kim and Verma, 1992; Moore and Dalva, 1993; Silvola et al, 1996; Alm et al, 1997; Carroll and Crill, 1997; Bellisario et al, 1998). It is particularly significant on a seasonal basis (Bubier et al, 1998), making it an important driver for this type of simplified modelling tool. Currently, the network is set up such that a low water table actually reduces decomposition so this needs to be changed. Also, water table should probably be weighed to have a greater impact than the equivalent of a 1 ^{o}C increase in temperature.

However, as with temperature, the relationship between decomposition rates and water table depth is not straight forward. A recent review by Laiho (2006) noted that increases in CO_2 emissions generally tail off when the water table drops below a certain depth (Silvola et al, 1996; Chimner and Cooper, 2003) and argued that deeper layers may lack easily oxidizable labile C (Chimner and Cooper, 2003; Hogg et al, 1992). Peatlands where the water table is generally 20 cm or more below the surface over the summer will already have been exposed to aerobic decomposition for extended periods, leaving only more resistant OM (Bridgham and Richardson, 1992) and therefore further drawdown, or unseasonal dry periods, may not lead to increased C turnover. In contrast, peatlands such as wet fens which are generally continuously inundated, may exhibit strong responses to a drop in water table as there may be a large pool of labile C which has not been decomposed due to the waterlogged, anaerobic conditions. This indicates that the impact of water table depth may be dependent on the baseline or typical conditions of the system. Possible changes to the network to include a node for habitat type which reflects water conditions, and to make the water table node a measure of deviation from these conditions, are discussed below (and see nodes E and N).

Summer drought

Currently, summer drought being unlikely has no impact on decomposition rates while being likely causes an equivalent increase in decomposition to a 1 ^{o}C increase in temperature. As discussed above, the impact of particularly dry seasons on decomposition rates may well be dependent on the previous or typical conditions of the system. Therefore, if the network is altered to make the water table node reflect a change from typical conditions, it may be preferable to have summer drought act on that node and not have a separate individual impact on decomposition.

Pollution

In the existing BBN, increasing pollution is shown to increase decomposition. However, this trend is not supported by evidence which indicates that both nitrogen and sulphur deposition reduce decomposition and lead to increased C accumulation in soils. Evans et al (2006a) report that field manipulations of heathland sites show increasing nitrogen inputs result in increased C accumulation, and increased soil acidity, which can be caused by acid deposition, has been shown to reduce CO_2 emissions from soils (Persson & Wiren, 1989; Sanger et al, 1994; Situala et al, 1995). Also, the decrease in acid sulphur deposition in the UK in past two decades has been linked to increases in DOC levels in UK surface waters, which can be seen as an indicator of increased C loss from soils (Evans et al, 2005). Therefore, this relationship needs to be reversed in the network.

Grazing

In the current network, the system is deemed to be either undergrazed, which reduces decomposition, or overgrazed, which increases the rate of decomposition (again by the equivalent of a 1 ^{o}C increase in temperature). This ignores the possibility of appropriate stocking levels and well managed grazing, which has been shown to possibly aid carbon storage in organic soils; studies of the Moorhouse NNR in the Pennines have indicated that grazed plots tend to accumulate carbon slightly faster than ungrazed areas and certainly light grazing did not cause any reduction in C accumulation in comparison with no grazing (Garnett et al, 2000). It also probably underestimates the impact of overgrazing, as while it is difficult to measure the impact of grazing on CO_2 emissions in the field (because it is measured using chambers which easily damaged if grazing animals are not excluded from the site, and is usually measured as NEE which includes plant and rhizosphere exchange from respiration and photosynthesis as well as soil respiration from decomposition processes (see for example, Nieveen et al, 2005)), information is available on the impacts of heavy grazing on soil carbon storage. Trampling by grazing animals can cause severe erosion and stimulate decomposition by acting like tillage to increase aeration, and grazing animals also input extra nutrients particularly N, which can also stimulate decomposition. In an upland area of North Wales, which has seen an increase in grazing density from around 1.2 sheep ha^{-1} in the 1950s to an average of around 5-6 sheep ha^{-1}, ranker and peaty podzol soils in degraded areas contain significantly less carbon, a mean of 5 % C in comparison with 24-27 % C in intact heathland ecosystems at the same site (Britton et al, 2005), and this effect is typical of sustained heavy grazing pressure (Milne et al, 1998; Rudeforth et al, 1984).

Therefore, the possible states of the node could be changed to no, light or heavy grazing, with both no and light grazing having no impact on decomposition rates (and acting on peat formation rates instead, see below) and heavy grazing causing a significant increase in decomposition rates.

Burning

In the network as it stands, managed burning is seen as a positive thing for C storage while wild fire is modelled as causing a significant increase in peat decomposition. In reality, evidence suggests that even managed burning is detrimental to soil carbon storage; organic matter accumulation at the Moorhouse NNR in the Pennines has been reported to be lower for plots which have been burnt every 10 years than for those which have not been burnt since 1954 (Adamson, 2003; Garnett et al, 2000). As well as physically breaking down organic matter, burning also enhances mineralization after the fire due to increased microbial activity; microbial respiration has been reported to be three times higher following burning, in response to higher nutrient and substrate levels in remnant soils and enhanced soil temperature (Kim and Tanaka, 2003); and there is also some evidence that burning increases the pH of organic soils, which would also favour increased rates of decomposition (Allen, 1964; Stevenson et al, 1996). Wild fire is undoubtedly more damaging, as it is likely to lead to more removal of vegetation and therefore increased C losses through erosion. A study of post-fire erosion of podzols and peaty gleys in the North Yorkshire Moors concluded that vegetation cover was the main determinant of erosion rates, and reported that severe burning, which exposed the peaty or mineral subsoils, caused up to 10 times higher erosion rates than burning which left heather remains covering the ground surface (Imeson, 1971). Therefore, wild fire should continue to exert a strong positive effect on decomposition rates and managed burning should be changed to also increase decomposition, but less so than wild fire, and a new no burning option should be introduced, which has no effect on decomposition. This is discussed further below, in the 'node H: burning' section.

Peat mass

Currently, a small peat mass reduces decomposition so this node can be seen as a surrogate measure for the spatial extent of peat, to limit decomposition losses where not much peat is present. However, this is a somewhat artificial relationship, as discussed further below, and therefore it is proposed to replace this node with a habitat type node (described further below) which reflects the presence of existing peat stocks without alluding to factors such as depth and volume of peat which are not taken into consideration.

As it stands, the impact of each input node can be seen as being weighted in comparison with the effect of temperature, since this is the only input based on real values rather than assigned scores. These weightings do not capture the true key drivers of the system, particularly for water conditions, and do not take into account the fact that the impact of several factors may well be based on how much they cause deviation from the typical state of the system. Therefore, the network may be improved by introducing a new node to reflect whether decomposition is mostly aerobic or anaerobic and whether this is typical of the system (with the new habitat type node, and a modified water table node as the inputs) and then have the other factors act on this. This should get around the fact that by the nature of BBNs, it is not possible to have the state of one node act on the child node in different ways depending on the state of other parent nodes i.e. a drop in water table cannot increase decomposition more for a naturally inundated habitat than for one where the water table frequently drops in summer anyway. This new node is described in the 'Proposed new network structure' section below and should be made the main determinant of the probabilities of high, moderate or low decomposition. Setting actual values for decomposition rates is difficult because field measurements are generally of net carbon loss, and laboratory measurements from soil cores are highly variable due to differences in methodology. Therefore, it may be better to concentrate on parameterising the network to give a sensible range of overall carbon balance values (see node B below), rather than getting this individual node to reflect real decomposition rates, especially as peat formation is not a variable rate within the network.

Node B: Carbon balance for peat

This is the output node of the system which determines the level of the ecosystem service, and is based on assigned probabilities depending on the state of the two input nodes, i.e., whether peat decomposition is high moderate or low, and whether peat formation is active or inactive.

Peat formation

Without actively forming peat, anything above a low rate of decomposition is likely to result in the net loss of carbon from the system and this is reflected in the probability table, where the inactive state of this node reduces the likelihood of an increasing carbon balance to 10 %, and active peat formation makes a decreasing carbon balance less likely than a stable or increasing one.

Peat decomposition

The higher the rate of decomposition, the higher the chance of a decreasing carbon balance so the probability table needs to be adjusted slightly, because currently a moderate rate of decomposition with active peat formation is giving a 20 % chance of decreasing carbon balance while a high rate is only giving a 10 % chance.

This node can be given a value in terms of net carbon loss or gain. The overall carbon balance should lie somewhere within the range of a net increase of 0.21 t C ha^{-1} yr^{-1} (based on Clymo et al, 1998) for the most pristine, undamaged sites, where peat formation is active and decomposition is low, up to a loss of carbon in the range of 0.8-8.3 t C ha^{-1} yr^{-1} (Nykanen et al, 1995; Maljanen et al, 2001 & 2004; Lohila et al, 2004) for sites with high decomposition and no new peat formation, due to draining and disturbance.

Node C: Summer drought

This is a parent input node where the likelihood of summer drought is set either to test scenarios or based on climate data. As the network stands, it is independent of changes in temperature and drainage management, which may not be ideal. However, the node only feeds into the water table and peat decomposition nodes, and both of these are also affected by temperature and drainage (via its effect on water table in the case of decomposition) so while the drainage node cannot directly offset drought, it can offset its effects.

As discussed below in the rainfall node (F), the likelihood of summer drought should reflect the likelihood of decreased summer rainfall to make up for the lack of seasonality in that node, as drier, hotter summers are likely to have the greatest impact on carbon balance in terms of climate change. The UKCIP02 data sets contain projected monthly precipitation changes and can therefore be used to indicate decreases in summer rainfall.

Node D: Peat formation

This node is based on assigned probabilities according to the states of four input variables; water table, grazing, burning and peat mass, and the result merely determines whether formation is active or inactive and gives no indication of the rate of accumulation.

Peat mass

This input node has the strongest impact on the state of the peat formation node, as a small peat mass automatically gives a 90 % chance of peat formation being inactive regardless of the state of the other input nodes. In reality, if conditions are suitable, whether the existing peat layer is deep or shallow does not have any bearing on whether new peat will be formed above it and therefore this node can be see as either a surrogate measure of the spatial extent of peat or of whether the habitat is suitable for peat formation or not, and maybe better described in this way, as discussed below. Habitat type would then be the main determinant of whether peat formation is active or not, with peat forming habitats being assumed to have a very high chance of active peat formation unless negatively impacted by the other input nodes, and non-peat forming, acidic grassland having a very low percentage.

Water table

This input has the second strongest effect as a low water table makes the maximum chance of active peat formation only 30 %. As already discussed, it is proposed to change this node to reflect changes in water table depth and have the new habitat type node (which would replace peat mass as node E) reflect the typical water conditions. In this case, a dropping water table would reduce the chance of active peat formation, while a rising water table would increase it, and a stable water table would give a different chance depending on whether the habitat was naturally water logged all year round or not.

Grazing

Undergrazing generally increases the probability of active peat formation in the network, which is supported by the evidence discussed above in node A, that light grazing can aid carbon accumulation. The state should be renamed light grazing however, as undergrazing suggests detrimental effects on heathland vegetation whereas well managed grazing with the right stocking density can help to control shrub development without damaging soils (Grant et al, 1982; Garnett et al, 2000). Overgrazing, which could be renamed as heavy grazing, reduces the probability of active peat formation slightly, which fits with the fact that it reduces vegetation. If a no grazing option is introduced, this could also reduce peat formation via the development of more shrubby vegetation which is not peat forming, although this would be a long term effect, so should not have as much impact as heavy grazing. Also, evidence suggests that for blanket bogs, the removal of grazing does not lead to heather degeneration (Adamson & Kahl, 2003) so this effect should be dependent on habitat type.

Burning

As the network stands, wild fire decreases the probability of active peat formation in comparison with managed burning, which fits with the fact that it is much more likely to completely destroy the vegetation and upper organic layers, leaving patches of bare earth, which are then subject to erosion (Imeson, 1971) and will not form new peat until the vegetation recovers. As discussed above in reference to peat decomposition, the option of no burning should be added, and this would then give a default no effect on peat formation. The net effect of managed burning has been shown to be slightly negative effect on C accumulation (Adamson, 2003; Garnett et al, 2000), but this has already been accounted for by its effect on peat decomposition (see node A above) so it is hard to establish its impact on peat formation alone. In the short term, burning destroys the vegetation that produces peat forming litter, but over the longer term, it aids the regeneration of this vegetation and helps to keep it at its most productive (Holden et al, 2007), so on balance it could be considered to slightly increase the probability of active peat formation, although care should be taken to ensure that this is not sufficient to outweigh its impact on peat decomposition when overall carbon balance is calculated.

Ideally, peat formation would be converted to a variable rate to improve the carbon balance calculation, however, this is a complex process and actually tends to be quite constant over the longer term (Belyea & Clymo, 2001), so keeping the states as active and inactive and just changing the input nodes may be the course of action best supported by the available data. This means that the probability of active peat formation under difference circumstances cannot easily be set using field data and expert opinion must be relied upon to a certain extent. The most favourable conditions for peat formation should be a mire habitat with a rising or stable water table, with light or no grazing and no burning, or a heathland habitat with a rising water table, light grazing and no burning. The least chance of active peat formation should be assigned to acid grassland regardless of the state of the other input nodes, and heathlands with a dropping water table, heavy grazing and a high chance of wild fire. Other combinations of inputs should give a probability within these two extremes, with wild fire having the strongest negative effect, followed by heavy grazing.

Node E: Peat Mass

This is a parent node which can be seen as a surrogate measure for the spatial extent of peat within the area being considered or as an indication of whether the habitat is a potentially peat forming type. Peat mass is therefore a misleading name, as it suggests more complex relationships concerned with depth, volume and quality, which are too complex to capture in such a simplified model. Therefore, this node could be replaced with a habitat type node, with the probabilities set to reflect to spatial extent of each habitat type within English uplands, or in the area under consideration. Habitat state could be divided into peat forming or non-peat forming, therefore keeping the node essentially the same but with a more logical name, or could include the standard water conditions of the system i.e., splitting peat forming habitats up into drier heathland habitats or water logged bog or fen habitats. This would give a default state for the water table depth allowing the water table node to become a change in water table node, and feed into the proposed new node for decomposition type as discussed in node A above.

Node F: Rainfall amount

This is a parent node where the probability of stable, increasing or decreasing rainfall can be set according to climate change predictions or to test scenarios of climate change. The UKCIP02 data sets (available from www.ukcip.org.uk) include projected total precipitation (mm per month) for future climate change scenarios for the 2020s, 2050s and 2080s at both the 50 km and 5 km resolutions.

Currently, there is no seasonality reflected in this node although this problem may be mostly offset by the presence of a separate summer drought node. Changes in summer rainfall may be more important in terms of impact on peat decomposition than changes in winter rainfall, because decomposition rates are so low in winter anyway due to low temperatures.

Node G: Temperature increase (+ baseline)

As for rainfall above, this node can either reflect the probability of a certain increase in temperature or can be used to test the impact of climate change scenarios. The UKCIP02 data sets include daily mean temperatures for future climate change scenarios for the 2020s, 2050s and 2080s at both the 50 km and 5 km resolutions, and for a future monthly time series from 2011-2100.

Aside from the impact on peat decomposition indicated in the existing network, an increase in temperature could have more wide ranging effects. An increase plant growth in response to higher temperatures could increase peat formation due to higher inputs of litter, and evapo-transpiration could be increased, especially if wind also increases and rainfall decreases, which would draw down the water table and therefore impact on both peat formation and decomposition. Since these different effects would work in opposition to each other, it is difficult to understand what the overall impact of an increase in temperature will be over the longer term, particularly give the controversy over its effect on decomposition rates, as mentioned in node A above. Given that it is not possible to directly mitigate against this change, it is arguably preferable to focus on changes which are better understood and can be mitigated by management changes. Also, soil warming experiments suggest that initial increases in CO_2 release from soils under elevated temperatures are due to rapid mineralization of the labile carbon pool and therefore over the longer term, these increases may tail-off as the pool is depleted leaving more recalcitrant organic matter (Rustad & Fernandez, 1998a,b).

Node H: Burning

Burning is a parent node which currently has two states, managed or wild fire, allowing the probability of each to be set according to typical conditions of the system/area in question or to test a scenario or management strategy. Therefore, a third state, no burning, should be added to better reflect the possible management strategies available, as evidence indicates that any burning can be detrimental to carbon storage or accumulation (see discussion in node A above) and it has been suggested that burning should be phased out, particularly for areas of blanket bog (Holden et al, 2007). The probability of wildfire occurring should be set using a combination of historical data[7] and expert opinion, taking into account that the risk will be increased by increasing temperatures, decreasing rainfall and increasing summer drought and will be lower for wet mire habitats than drier heaths and grassland. Once this is done, the remaining probability of either no or managed burning can be set either to test a management scenario, or to reflect the spatial extent of each within the area under consideration.

Node J: Grazing

Like burning, the grazing node is a parent node designed to reflect current and/or future management strategies. The current states are under or over-grazed, which fails to capture no grazing as a separate effect and suggests that an appropriate level of grazing is not possible. As discussed in node A above, evidence suggests that light grazing can benefit carbon accumulation, while still giving benefits in terms of vegetation management (Garnett et al, 2000). Therefore, the states should be changed to no, light and heavy grazing. The line between light and heavy grazing is in practice, not the easiest to draw. In principle, heavy grazing would be characterized by significant trampling damage, erosion and damage to vegetation, including significant changes in species composition. This would require a site survey however, so in practice, it needs to be defined by stocking density and livestock type. For English uplands, sheep are the most commonly used grazing animals and while in general, most heather will grow at densities below 2 sheep ha^{-1}, blanket bogs in the northern Pennines have been shown to suffer erosion over densities as low as 0.55 sheep ha^{-1} (Hawes & Hobbs, 1979), and modelling studies have recommended a density of between 0.48 and 0.98 ewes ha^{-1} for the Northern Isles of Scotland (Simpson et al, 1998). This illustrates that it is not possible to set a universal recommended stocking density for UK moorland, as different areas can support different numbers depending on vegetation community structure and also depending on the season, and whether shepherding is used to help reduce local concentrations of animals. Adding in the possibility of different types of livestock further complicates the situation. Cattle, being by their very nature much heavier animals, cause more trampling damage and also deposit more nutrients which can affect vegetation and soil emissions, but they can be useful as they are less selective grazers than sheep, and more traditional breeds also tend to be smaller and better suited to moorland conditions (see Shaw et al, 1996 for an extensive review

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[7] The European Environment Agency has a map of the change in fire risk from 1956-2006: http://dataservice.eea.europa.eu/atlas/viewdata/viewpub.asp?id=3781

of the dietary preferences and reported effects of different grazing animals). Therefore, while the probability of no grazing can be set according to spatial extent, the probability of light and heavy grazing may require the addition of expert opinion if stocking densities are not clearly in one category or the other; for example if an area under consideration has a stocking density of 1 sheep ha^{-1}, the probabilities of light and heavy grazing could be set to 50/50, or maybe 25/75 if it was an area of blanket bog.

Node K: Drainage management

This parent node has two states, poorly drained and well drained, which are set by inputting the probability of each, currently assumed to be 50/50 although this can be changed to test management scenarios. If the network is to be changed so that the impacts of water conditions become dependent on the natural or typical conditions of the system as determined by a new habitat type input node, this node would need to be changed too as habitat type and drainage conditions (which is what the node currently shows, despite being described as a management node) are not independent of each other; habitat type will reflect long standing drainage conditions, either semi-natural or managed. If the function of this node is to allow the impact of future changes in drainage management to be tested, then the states should be changed to no change, new drainage and restoration (i.e. blocking old drains). This discussed further in the water table node described below. Restoration or drain blocking should be included as option because, as well as the benefits associated with a higher water table in terms of reduced decomposition, drains contribute to the formation of drainage pipes, an effect which increases over time and causes particulate carbon loss from drained peat slopes to increase exponentially (Holden, 2006).

Node L: Diffuse pollution load

This parent node reflects the trend in the deposition of atmospheric pollutants, most notably sulphur and nitrogen compounds. Acid deposition, which peaked in the early 1980s, has had major impacts on the environment, particularly in upland areas where ecosystems are made particularly vulnerable by the prevalence of peaty and already acidic soils. Important moorland species such as sphagnum mosses and lichen have been strongly adversely affected, and the resulting acidification of soils and surface water has had wide-ranging impacts (see Holden et al, 2007 for a summary). In the past 20 years however, acidic sulphur deposition has declined by 60 % (Fowler at al, 2005) and as ecosystems recover from the effects of acidification, DOC levels in UK surface waters have risen by an average of 91 %, indicating that past acidification was inhibiting carbon loss from catchments (Evans et al, 2006b). This would seem to suggest that the state of this node is most likely to be declining or stable in the future, however, in contrast to the decline in industrial and vehicular related sulphur deposition, the deposition of reactive nitrogen compounds has increased markedly, reaching levels of 40 kg N ha^{-1} $year^{-1}$ over large areas of the UK (NEGTAP, 2001). As discussed in node A above, this type of atmospheric pollution has also been shown to increase carbon accumulation in heathland ecosystems (Evans et al, 2006a).

Therefore, while any available data on atmospheric deposition levels (the European Environment Agency has a data set of modelled nitrogen and sulphur deposition, and also a map of projected future N deposition) can be taken into account in determining the probability of each state of this node under current conditions, a degree of expert opinion is also required, to weight the increase in N deposition more highly then the competing trend of a decline in S deposition, because the effects of this have largely already been seen and are now probably stabilising. Alternatively, probabilities can be set to test the impact of future scenarios.

Node N: Water table

In the current network, water table is based on assigned probabilities according to the state of the three input nodes, rainfall, drainage management and summer drought.

Rainfall

This input node has the strongest effect as stable or increasing rainfall gives a 50-80 % chance of a high water table, depending on the other two input nodes, whereas decreasing rainfall reduces this to a 20-35 % chance.

Drainage management

When rainfall is stable, drainage has a clear effect, changing the probability of a high water table from 50 to 70 % but its effect is currently underestimated and inconsistent where rainfall is changing. If this node is changed to reflect changes in drainage management as suggested above, new drainage or restoration should be by far the strongest determinants of water table changes.

Summer drought

This node currently has no effect on water table when rainfall amount is stable. This is misleading because summer rain could be lower while still maintaining the same level of annual rain if winter rain is increasing, and therefore these probabilities need to be changed.

As discussed in node A above, the effect of water table on peat decomposition may be better captured by altering this node to reflect a change from the typical conditions of the system. Therefore, it is proposed to change the current peat mass node to one reflecting habitat type, including typical water conditions, and have this set a default water table depth and then the rainfall, drainage management (also changed to better reflect changes in management rather than default drainage conditions since these will be major factors in habitat type), and summer drought nodes can determine the probability of a change in water conditions to feed into the decomposition node. As water table depths are dependent on a wide range of variables in the field, expert opinion must be used to determine the node probabilities depending on the state of the inputs. Any change in drainage management should have by far the strongest effect with, for example, new drainage giving something in the region of an 80 % chance of a dropping water table and restoration a similarly high chance of a rising one, and summer drought could be the second strongest determinant, as water table depth in summer will have a bigger influence of decomposition rates when they are not inhibited by low winter temperatures.

Other issues

Liming

As already discussed in relation to diffuse pollution load, increased soil acidity tends to inhibit the decomposition of peat and increase carbon accumulation. It follows therefore, that liming, which reduces soil acidity, is likely to increase carbon loss from upland soils, and indeed, experiments have shown that it can increase the concentrations of organic matter, DOC and DON in soil water (Andersson et al, 1994, 1999; Curtin and Smillie, 1983). As liming is currently underway in parts of the UK to mitigate historic acidification, adding a liming node would allow the BBN to illustrate the possible impact of this.

Non-carbon GHG

Methane

Methane is produced only under anaerobic conditions and oxidation processes quickly stop soils being net emitters of CH_4 once the water table drops below the surface (Christensen et al, 2000). Across northern European wetlands, CH_4 emissions contribute only 1-4.7 % of total carbon loss from soil respiration (Christensen et al, 1996) and the highest emitters of CH_4 are more nutrient-rich fenland habitats, particularly those with a high level of sedge cover (Bellisario et al, 1999) as their stems transport the gas to the surface, reducing the chances of it being oxidized before reaching the atmosphere (Lloyd et al, 1998). In practice, this means that CH_4 emission is not a significant component of the carbon balance of most upland soils in the UK and adding it to the BBN is probably unnecessary, particularly as the actual carbon lost in this form is accounted for within the overall carbon balance values, which are not just based on CO_2 exchange

Nitrogen

Both aerobic and anaerobic processes contribute to the emission of N_2O from soils, although the highest emissions are generally recorded in response to high soil water content or immediately following heavy rainfall (Smith et al, 1998). Emissions are dependent on levels of N in the soil though, so a node could be introduced to reflect an increase in N_2O emissions response to heavy grazing (and associated N deposition by livestock) and increasing N deposition. In reality though, fertilised agricultural soils have a much greater contribution to UK N_2O emissions than semi-natural areas (see for example, Sozanska et al, 2001), and therefore, as with CH_4, its inclusion in the BBN is not really necessary.

Wind

As discussed in the temperature node (G) above, an increase in wind would contribute to an increase in evapo-transpiration, which could in turn contribute to water table drawdown. In practice this is a complex relationship, with evapo-transpiration being determined by a combination of climate factors (wind speed, temperature, humidity and radiation) and vegetation cover, including a consideration of whether this vegetation is suffering from water or environmental stresses. Although this climate data is available from the UKCIP02 sets, the fact that heathland features a variety of quite different vegetation types, means this type of relationship is probably beyond the capabilities of such a simplified model, even before the complex relationship between evapo-transpiration and water table level is considered.

Land use change

Currently, the most common agricultural uses of moorlands are for rough grazing and grouse rearing, and a change to more intensive agriculture would cause a dramatic shift in the overall carbon balance.

Conversion to intensive grassland, involving drainage, ploughing and reseeding with productive grass species, and moderate to high levels of fertiliser application, would cause the fast loss of stored carbon (Byrne et al, 2004). For example, conversion of a peat bog to pasture for dairy farming reduced carbon storage by an average of 3.7 t ha^{-1} yr^{-1} over 40 years (Schipper and McLeod, 2002), and for boreal organic soils used for grassland in Finland, annual net carbon losses of 750 g CO_2-C m^{-2} yr^{-1}, and 3.3-4.6 t CO_2-C ha^{-1} yr^{-1} have been reported (Maljanen et al, 2001; Maljanen, 2003). Based on flux measurements from European sites, average CO_2 emissions from grassland on nutrient-poor, ombrotrophic bog soils are estimated to be 1.5-3.5 t C ha^{-1} yr^{-1}, and 0.82-6.58 t C ha^{-1} yr^{-1} for more nutrient-rich, minerotrophic fen soils (Byrne et al, 2004).

Conversion to arable land use is the worst case scenario for peat soils, with the combined effects of drainage, tillage and fertiliser input causing very fast loss of stored carbon (Byrne et al, 2004). Carbon losses of 400-830 g CO_2-C m^{-2} yr^{-1} have been reported for boreal organic soils used to grow barley in Finland (Maljanen, 2003). These losses are also exaggerated by the presence of bare soil between crops, which may emit more CO_2 than under crops, for example up to 11 t ha^{-1} yr^{-1} for Finnish organic agricultural soils (Maljanen, 2003). Flux measurements from sites across Europe indicate that an average of 4400 CO_2-C kg ha^{-1} yr^{-1} is emitted from nutrient-poor bog soils converted to arable usage, while nutrient-rich fen soils lose an average of 1.09-10.6 t C ha^{-1} yr^{-1} (Byrne et al, 2004).

Conversion to forestry is a less straight forward issue, not least because tree biomass has such a high potential to sequester carbon. In terms of soil carbon storage however, drainage and further drawdown of the water table by increased interception and transpiration, coupled with initial fertiliser applications, result in increased decomposition and carbon loss in response to afforestation. For peat soils, measurements of net ecosystem exchange indicate that this loss of soil carbon may outweigh carbon sequestration by biomass, making the systems small net sources of carbon (Hargreaves et al, 2003). For upland areas with organo-mineral soils rather than deep peat, the effects may be more neutral, with increased decomposition offset by increased carbon in the litter layer, but there is currently a lack of evidence to confirm this with any degree of confidence (see review by Reynolds, 2007).

Proposed new network structure

The basic structure of the revised BBN is illustrated below, with the possible position of the other considerations from above shown in grey and two firm new nodes:

Habitat type (node E)

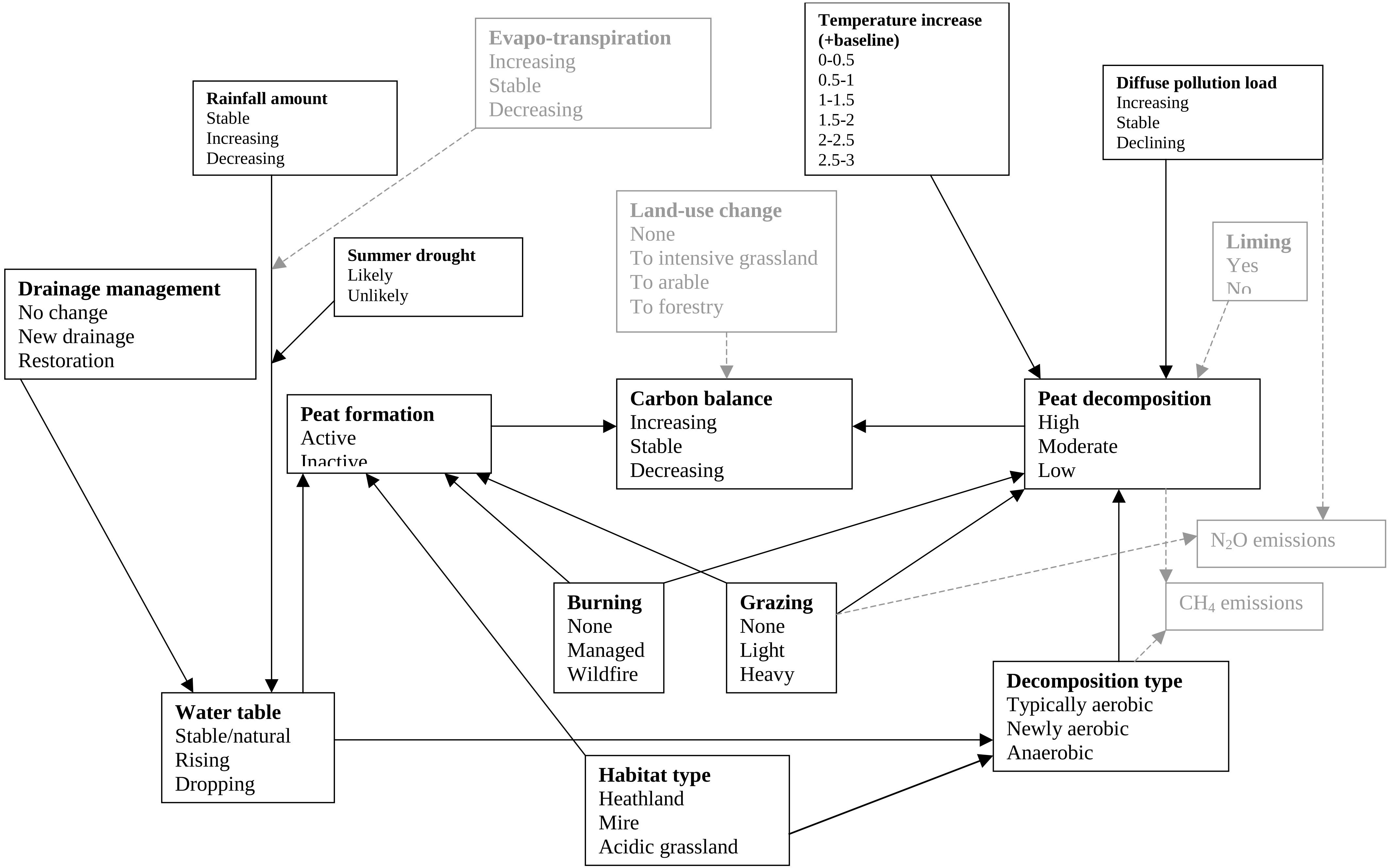
The purpose of this node is to replace peat mass and also indicate typical water table conditions. The three possible states are heathland, which is peat-forming but has a naturally fluctuating water table and corresponds to the NVC classes H9, H10 and H12-22, mire, which is peat-forming, generally inundated and corresponds to NVC classes M15 and M17-20, and acid grassland, which is not peat-forming, has a naturally fluctuating water table and corresponds to NVC classes U4-6 (see Holden et al, 2007). The probability of each habitat type can therefore be set according to the spatial extent of each within the area under consideration, from a vegetation cover dataset, or set to test the impacts of changes on a single habitat type.

Decomposition type (node P)

This node should set the base decomposition rate as determined by the typical water table conditions (indicated by the habitat type node) and the current or future water table level. To reflect the relationship between decomposition and water table discussed in node A above, the probability table should be set up as follows; if the habitat is a mire, decomposition should be mostly anaerobic if the water table is stable or rising, and a mixture of anaerobic and newly aerobic if the water table is dropping. For heaths and acid grasslands, decomposition should be a mixture of anaerobic, typically aerobic, and newly aerobic, with the probability of being anaerobic reduced by a dropping water table and increased by a rising one, and the probability of newly aerobic very low but increased by a dropping water table. The exact probabilities need to be set using expert opinion in the absence of any data about the proportion of the soil profile which is below the water table. When feeding into node A, 'newly aerobic' should give the most carbon loss, and therefore the highest chance of high decomposition, followed by 'typically aerobic', with 'anaerobic' decomposition being a much slower process, with a high probability of decomposition being low.

Conclusions

This work indicates that peat decomposition is the key process which needs to be captured to understand how changes to heathland ecosystems will impact on their ability to store and sequester carbon in the future. While an increase in temperature is arguably the most commonly emphasised aspect of climate change, evidence of its impact on decomposition is inconclusive and often in disagreement, while the impact of changes in soil water conditions are better understood. Therefore, it is suggested that the BBN should focus on better capturing this relationship, especially as the effects of changes in rainfall and summer drought can be mitigated or compounded by drainage management strategies. Also in need of strengthening are the relationships between grazing and burning management and peat decomposition and formation, the impacts of which have been underestimated in the existing BBN.


Evapo-transpiration
Increasing
Stable
Decreasing
Temperature increase (+baseline)
0-0.5
0.5-1
1-1.5
1.5-2
2-2.5
2.5-3
Rainfall amount
Stable
Increasing
Decreasing
Diffuse pollution load
Increasing
Stable
Declining
Land-use change
None
To intensive grassland
To arable
To forestry
Liming
Yes
No
Summer drought
Likely
Unlikely
Drainage management
No change
New drainage
Restoration
Peat formation
Active
Inactive
Carbon balance
Increasing
Stable
Decreasing
Peat decomposition
High
Moderate
Low
N2O emissions
CH4 emissions
Burning
None
Managed
Wildfire
Grazing
None
Light
Heavy
Decomposition type
Typically aerobic
Newly aerobic
Anaerobic
Water table
Stable/natural
Rising
Dropping
Habitat type
Heathland
Mire
Acidic grassland

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Appendix 2: Original Paper on Water Quality

Received by Project Coordinator: 24.11.2009– here given without graphs

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NATURAL ENGLAND

Upland ecosystem services

refining the evidence base and service networks' for water quality

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This project has been undertaken in accordance with PAA policies and procedures on quality assurance.

Signed:__________________________________

C O N T E N T S

1. INTRODUCTION

Project Objectives

1.1 Penny Anderson Associates Ltd (PAA) was commissioned by Natural England in October 2008 to undertake a review and validation of the Bayesian Belief Network (BBN) model for water quality, as presented in the Natural England research report, Upland Ecosystem Services: Phase I Report (June 2008).

1.2 In the Upland Ecosystem Services: Phase I Report, for each of the five ecosystem services (carbon storage & sequestration; water quality; flood mitigation; recreation, and potential for renewable energy) a preliminary review of the evidence for these services was captured in a series of Bayesian Belief Networks (BBNs) to show the relationships between, and drivers of, the factors combining to deliver these services in the uplands. These networks are 'interactive' to some degree in that different factors (e.g. land management or climate variables) can be altered, alone or in combination, to show the possible impact on service output.

1.3 This report was very much a scoping study and so the purpose of this study was to develop and refine these networks, in order to ensure that the work has taken account of (and documented) the available evidence, and developed their precision to the best possible extent.

1.4 In respect to water quality in uplands, the Phase I Report presented only a very basic BBN model for water quality and flood provisioning, and so an additional, first key task identified by PAA was to develop a fully-specified conceptual model for uplands water quality, and from this, try to develop an equivalent, fully-specified BBN model for water quality, focussing in on the two key variables of dissolved organic content (DOC) and suspended sediment loading in watercourses.

1.5 Predictive models were not required, rather a tool that helps us to consider different variables at the same time, and the implications of changing these. On completion of these contracts there is a need to have a good understanding (based on all best available evidence) of how upland land management impacts (both positively and negatively) on the provision of different services, and whether and how other drivers (like climate change) are making things better or worse.

Detailed requirement – tasks and outputs

1.6 Specifically, the tender brief stated the following requirements, as listed in the tender Annex A:

Refine the service networks. We would like you to review the current network(s) relating to the service you are a specialist in, and refine them (altering the nodes and probabilities where necessary), until you are happy that they portray to the best of our current understanding how the different environmental systems work, illustrating only the key components, processes, relationships, interactions, drivers, and impacts of the system relating to each service.

We are particularly interested in answering the following questions:

Are the right assumptions made about how the system works, including the impact of land management, i.e. should particular nodes and links be added or removed?

Is the terminology correct, consistent, and not misleading or biased?

Is the evidence that is referenced sufficient to support. The conclusions made (about relationships between nodes etc), and if not, which main additional published and other sources are available? (See also item 2 below.)

Are there conflicts in what the evidence is telling us that need to be considered?

Are the probabilities identified in each of the nodes correct or, when based upon expert judgement, plausible? Can these be further refined?

What additional evidence on trends in service provision and the drivers of it (some of which is identified in the chapters of the existing report) is there?

Document the evidence about the nature and strength of the different relationships between the nodes and the probabilities within the nodes. An assessment of the confidence in the evidence for each relationship should be made, including an indication of the transferability of evidence obtained in a particular spatial location to other parts of the English uplands.

Draw out key conclusions. Using the networks interactively, explore the impacts of changing different variables (alone and in combination), to identify:

the most influential drivers of the system;

the changes that would result in the biggest environmental impacts (positive and negative); and

Comment on how the different drivers work in parallel.

Specific Issues for the Investigation Relating to Water Quality

1.7 Also included in the tender specification were several specific issues relating to water quality. These were stated as follows:

- The water provisioning and flood regulation networks in Chapter 6 of the Phase I scoping report should be separated out into two separate networks covering 'water quality' and 'flood mitigation'. The terminology therefore needs to be consistent throughout. Here, as agreed with the project officer, only water quality issues are addressed;
- Rainfall amount and intensity – is seasonality of rainfall also important?
- Vegetation cover - this does need to be consistent throughout and needs to include bare ground and improved ground, bracken? The condition of the vegetation needs to be covered as well although this could partly be covered by e.g. node;
- Grazing pressure – needs to be consistent with fig 3.2 (use terms under and over grazing) or vice versa. I assume a value of 100% for low grazing would be no grazing? The assessment of wild herbivores may also need to be made;
- Other factors, including:
    - burning can have a huge impact on surface run-off and colouration and requires a node similar to carbon;

- the presence of heather dominance on peat can increase the frequency of soil piping an important factor in water movements;

- different types of animal create different problems e.g. cattle and cryptosporidium and sheep dip both of which can which can affect water provisioning;

- presence of reservoirs and hydro may have some impact;

- As the text admits (see below) the conceptual model currently doesn't include catchment "roughness" as a factor influencing flood conveyance. This is probably an important omission;

- the flood conveyance role of infrastructure and development: roads, farmyard hard-standings, etc. should be added into the network;

- Spatial variation. All catchments have different flood generation and conveyance signatures due to the wide variation in precipitation, topography, size, land use and management, etc. This inter, and intra-catchment variability has been a key difficulty in developing agreement around generic land management change solutions;

- Measures in the uplands to benefit flood risk management would tend to work with natural processes to increase the storage/infiltration and slow the conveyance of flood waters. Generally, this would involve habitat/landscape restoration so as to restore the natural drainage/hydrological functioning of the catchment; and

- Transforming the simple qualitative model into a generic quantitative model would be very difficult. The data on the effects of specific factors at a catchment scale remains patchy and the number of variables makes predictive modelling difficult.

2. A Conceptual Model for Upland Water Quality

2.1 An initial review of the work undertaken with respect to water provisioning and flood regulation (Part 6 of the Phase 1 Report) indicated a lack of detail in the scope and level of investigation undertaken for this part of the work, a point acknowledged in the report (refer to section 6.1). This was reflected in the simplified and generic BBN model presented for water provisioning and flood mitigation, as illustrated in Figure 6.3 of the Phase 1 Report.

2.2 As a result of this, and on request from the project officer, Penny Anderson Associates Ltd were asked to undertake an initial phase of work, where a detailed conceptual model for upland water quality was developed and proposed (see Figures 1a to 1g). This conceptual model would then be used as a basis from which the specific, detailed BBN models would be developed.

2.3 After the initial phase of work to develop the conceptual model, the following work tasks were attempted:

- to develop representative Bayesian Belief Network models for the two key water quality variables of dissolved organic carbon and suspended sediment load;
- a review and description of the work, including expert guidance as to which factors and variables are of primary importance and which are of lesser direct importance to water quality;

2.4 The first phase of work involved an ideas and consultation session where in-house, expert opinion was used to develop a conceptual model for upland water quality. The model was graphically set out using the Microsoft PowerPoint tool, with each factor and variable under consideration represented as a box, with the causal relationships and interactions between these variables represented as arrows. This scheme was deliberately designed and laid out to look similar to the BBN model schema for ease of interpretation.

2.5 Once the structure and integrity of the conceptual model had been reviewed and finalised, a copy was sent out to all members of the project team for review and comment, before being used as the basis from which the BBN models for water quality were developed.

3. Development of BBN Models

3.1 The Phase I Report presents a detailed introduction to BBN modelling. Some of this is included here for general relevance and background.

3.2 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 can balance the desirability of an outcome 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.

3.3 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.

3.4 BBN models broadly consist of the following different kinds of features:

Parent nodes (only have outputs to other nodes)

Intermediate nodes (inputs and outputs)

Child nodes (only have inputs)

Causal or "belief" relationships between nodes, represented by arrows in the BBN network schema.

3.5 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, the relationships between nodes are shown by arrows. 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.

3.6 BBNs are viewed as a potentially useful tool for integrating knowledge about the biophysical, economic, social and policy drivers of change. In addition, they provide a potential mechanism for integrating quantitative and qualitative information, including informed expert judgement. In the longer term the networks can be replaced by quantitative models. BBNs have the potential, in due course, to guide specific local actions. However, in the short term it is envisaged that the models will be used to allow us to understand more explicitly which are the main drivers of the systems, so that policy options can be explored, particularly with regard to land-use. It is also hoped that the outputs from the work can be used to explore the value of networks, and more general network thinking, as tools for communication with policy makers, opinion formers and potentially wider audiences.

3.7 Once operational, BBN models can also be used to 'backcast' the effects of particular changes or scenarios. By setting a particular outcome to 100% i.e. a certain state, the model re-computes and self-adjusts, with all other probabilities adjusted accordingly.

3.8 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. 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.

3.9 Cain (2001) [8]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. Cain (2001) argues that 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.

3.10 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.

3.11 In this instance, a conceptual model for water quality was worked out by hand in this way, and then translated into two separate BBN network models, both with overlapping (i.e. complimentary) components and sub-systems.

3.12 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, and public policy. The practice of systems analysis, in its many forms, rests heavily upon 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, which to varying degrees for individual services requires a system boundary which encompasses ecological, social and economic components.

3.13 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.

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[8] Cain, J (2001) Planning improvements in natural resources management: Guidelines for using Bayesian networks to support the planning and management of development programmes in the water sector and beyond. CEH Wallingford.

3.1 The BBN Models

Model Outputs

3.1.1 Figures 1.a to 1g illustrate the range of variables which can be classified as water quality 'outputs'. In this study the major model outputs considered are dissolved organic carbon, and suspended sediment. Through these two outputs, the third output of water colour can be included, since water colour from the uplands is entirely governed by DOC and suspended sediment concentration levels. In the BBN model schema, these two outputs are represented by child nodes (refer to Figures 2a and 3a).

Major Model Drivers – Dissolved Organic Carbon

3.1.2 Based on our extensive experience of upland water quality studies, the following are seen as the major model drivers (parent BBN nodes) of water quality, and are therefore included in the BBN model schema:

- Rainfall
- Temperature
- Soil groundwater levels / antecedent moisture levels
- Seasonality
- Soil organic carbon content
- Soil microbial activity
- Soil oxidation levels
- Soil erosion
- Soil restoration (re-wetting)
- Climate change impacts: direction, magnitude and variability

3.1.3 These in turn influence the following intermediate model drivers (BBN nodes), which directly control water quality (DOC):

- Groundwater temperature
- Soil temperature
- Hillslope runoff
- Streamflow discharge
- DOC 'flushing' mechanism
- Soil DOC release potential

Major Model Drivers – Suspended Sediments

3.1.4 Again, based on our extensive experience of upland water quality studies, the following are seen as the major model drivers (parent BBN nodes) of suspended sediment loading in upland watercourses, and are therefore included in the BBN model schema:

- Rainfall.
- Event magnitude (rainfall type, intensity, duration etc.)
- Soil groundwater levels / antecedent moisture levels.
- Seasonality.
- Vegetation cover.
- Vegetation type (density, structure).
- Soil erodibility.
- Soil erosion.
- Gullying.
- Soil restoration (land management).
- Climate change impacts: event magnitude and variability.

3.1.5 These in turn influence the following intermediate model drivers (BBN nodes), which directly control the suspended sediment component of water quality:

- Soil suspended sediment release potential
- Rainsplash detachment and entrainment mechanism
- Direct surface hillslope runoff
- Suspended sediment stream load

3.1.6 The BBN model for DOC is presented in two separate network diagrams due to the licensing restrictions of the freeware version of the Netica software. Figure 2a illustrates the main BBN model for the DOC component of water quality; whilst Figure 2b illustrates the soil DOC release potential component of the model, which feeds directly into the main BBN (Figure 2a).

3.1.7 Similarly, the BBN model for suspended sediment is presented in two separate BBN network diagrams, with a main model (Figure 3a) and a soil sub-component model (Figure 3b).

3.1.8 The functionality of each model is discussed in more detail in Section 4.

3.2 Factors excluded from the BBN model

3.2.1 Several key influencing factors have been deliberately omitted from both the BBN models. These include:

- Current and historical levels of atmospheric pollution
- Current and historical levels of land management
- Effects of controlled and accidental moorland burning
- Livestock levels and grazing intensity

3.2.2 Although these are important contributory mechanisms in the modelling of either or both key water quality variables, it was considered that, in light of the inherent uncertainties associated with these components and the complexity of their incorporation into the BBN model, they would not be included at this time. This is discussed further in section 4

4. Discussion

4.1 Meeting the project definition for water quality had to be constrained by the fact that only a very limited BBN model for water quality had been previously produced, and that the production of a preliminary BBN for key aspects of water quality became a primary project task in order to support the development of upland ecosystem services concepts. In view of this, and the limited time and budget available, all evidence and probabilities for the water quality BBNs have had to be based on expert opinion (Type 4) only. With sufficient resources these 'work in progress' models could be refined using Type 2 and/or Type 3 information.

4.2 In addition, the development of the water quality BBNs has had to be restricted due to the node-limited, evaluation copy of the Netica software. In response to this, the two BBN models had to be split into networks that contained fewer than 15 nodes. Again, this could be resolved if further resources for this theme were available.

4.3 In approaching a review of the ecosystem services that our uplands provide for water quality, some form of hierarchy of relative importance of the influencing factors had to be made. This would not only reduce the complexity of the BBN but also increase its usefulness to the policy and decision making process. For example, although there is a significant body of evidence showing that atmospheric deposition, related to past industrial activities, can have profound implications on the peat soil processes that contribute to the scale of DOC generation and discharge, this factor is excluded from the preliminary BBN because it does not provide a mechanism that can be easily managed to influence a water quality ecosystem service. It is appreciated that past events may have left a legacy which is now influencing an upland ecosystem service but direct management of that factor would be complex, if at all possible, without triggering other, yet unknown, environmental responses.

4.4 There are other mechanisms that contribute to the generation of DOC, which, whilst they may have a growing body of supporting evidence, the scale of impact and the relative contribution the factor makes is yet to be fully understood. For example, the burning of the moorlands (both controlled and accidental) is seen as a driver for DOC generation in certain situations but the mechanisms involved and the role they play in the catchment scale character of water quality has yet to be resolved. In terms of a hierarchy of importance, burning may be less influential on water quality if other factors, such as water level management were effectively applied. Any causal link between upland burning practices and events, and the generation of DOC has a number of intervening factors which are reflected in the current BBN model of the soil, hydrometric, geomorphic and climatic factors and the associated processes at work within the system. A complete cessation of upland burning would reduce the potential rate of peat degradation, and possible localised oxidation, but any worthwhile changes in water quality would only be derived if the physical benefits of non-burning practices were supported by more influential factors such water level management and vegetation recovery.

4.5 Whilst it is appreciated that, for example, soil microbiological activity (whether influenced by past industrial activity or other environmental controls) is a component in the process of DOC release, other factors, such soil water temperature and soil water table level, are driving influences on water quality that can be managed to affect positive change in the ecosystem service. Our expert opinion, together with substantial primary data available through the United Utilities Sustainable Catchment Management Programme (SCaMP), demonstrates a clear, if time lagged relationship between the level of the water table within the peat mass, the temperature of the water within the peat mass and the generation of DOC (colour) *in situ* and at the catchment scale. Given the evidence base of a causal link between these factors, it should be possible to promote landscape scale management changes that sustain higher water table levels within the peat mass. To do so, by what ever means (grip blocking, vegetation restoration etc), would lower the mean peat water temperature, and its variability, leading to reduced overall potential for the generation of DOC. The evidence from SCaMP at least, would imply that retaining a higher water table in upland peat soils is the key component in improving and managing this aspect of water quality.

4.6 Other SCaMP generated data supports the notion that the overall discharge of DOC (colour) from sub-catchments may be related indirectly to the maintenance of higher water table levels in the peat (through extensive grip blocking). SCaMP data have shown that total organic carbon discharge from a particular sub-catchment has declined after substantial areas of the catchment had the grips blocked. However, this phenomenon may, at this stage, be related to a fall in the total amount of runoff from the catchment rather than the total quantity of DOC being generated. The early hydrological response to grip blocking on the study catchment appears to be a lowering in the scale of the hydrograph, possibly as the water level in the peat mass rebounds to a pre-gripping situation. In time, the hydrograph may regain its previous level as the catchment runoff response reflects a more consistently saturated peat. However, as the water tables in the peat remain stable, and peat water temperatures are retained at a lower more consistent level, the generation of colour will be suppressed. So as the catchment re-wets and the discharge re-establishes a more ’natural’ equilibrium, total organic carbon leaving the catchment via the stream system will decline. However, such mechanisms may be substantially altered under the influence of climate change, making the predictability of the effects of water level management on water quality less certain in the long-term.

4.7 With regard to suspended sediment loads, a similar process of establishing a hierarchy of importance and influence has been established for the BBN. Vegetation type and vegetation cover are the critical components of the BBN for this water quality issue. Retaining a vegetation cover that avoids soil erosion processes from becoming dominant is an obvious factor in retaining and enhancing the value of this ecosystem service. Work at a number of sites including SCaMP and National Trust properties in the Southern Pennines has clearly demonstrated that sediment loads rapidly decline when bare peat restoration is adopted on a significant scale. Restoring and retaining adequate vegetation cover on the uplands is a critical factor in water quality management but its success will be dependant as much on socio-economic drivers as it will on the physical processes within the system itself. Maintenance of an appropriate vegetation cover on the uplands to provide water quality benefits will only occur if the activity is economically viable for more than just the value of the water quality component alone. Large scale afforestation within the uplands may well provide significant water quality benefits but the funding streams to sustain this approach need to be long-term and of a sufficient scale to generate a cultural change in the way the uplands are currently managed.

4.8 Prevention of the large scale generation of suspended sediments through habitat management, limits the means by which other water quality variable, such as DOC and nutrients, enter the system. Although re-vegetating bare peat will reduce the source of suspended sediments, the generation of DOC may continue because of the large quantities of organic materials already within the catchment stream system. In addition, re-vegetation may well reduce suspended sediments loads within the catchment but unless other variables are managed, such as sustaining peat water table levels the generation of DOC may continue for a considerable time.

4.9 Climate change, its direction, magnitude and variability are key factors in the capacity of the uplands to provide positive ecosystem services for both DOC and suspended sediments. Predicting the response of upland ecosystems to the variations in climate change scenarios is presently poorly developed. However, if the stresses driven by climate change can be identified earlier enough it should be possible to affect land management changes to retain an optimal, positive water quality ecosystem service from the uplands

5. Recommendations and Further Work

5.1 The production of a water quality upland ecosystem service concept model which has then been used to generate descriptive BBNs, represents significant progress for this area of work. However, the programme would benefit from investing more resources towards adding continuous or quantifiable numerical scales to the network nodes of the BBNs and fully specifying the conditional probability tables for the key intermediate nodes within the models and giving more accurate specifications to the conditional probabilities described within the two draft BBN models.

5.2 By providing draft BBNs for water quality we have selected variables which in our expert opinion lie at the heart the particular ecosystem service provision. This significant step should now be backed up by undertaking a full review of scientific literature and current expert opinion in order to derive Type 2, and Type 3 information for the BBN models. Numerous literature reviews have already been undertaken by various institutions and agencies but these need now to be filtered in order to derive support to the BBN concept.

5.3 It is also essential that the links and interdependencies, especially between water quality, flood risk management and carbon balance, are fully defined and accounted for in the BBN process. However, it is our opinion that such extensive, inter-related BBNs could become unwieldy, over complex and inaccessible to policy makers and practitioners.

5.4 Integration of the BBNs could, however, be effectively achieved by selecting and following themes of combined ecosystem services. For example, water quality, water quantity and flood services are regarded by some experts as having inherent conflicts of need and outcome. It is believed that by re-wetting the uplands and establishing more woodland, scrub and sustainable dwarf shrub heath, significant benefits would accrue to water quality at a cost to water resources. This needs to be investigated further because there is also a case that by re-establishing hydrological equilibrium in our uplands would generate a water resource that is more manageable and predictable. Again, improvements in water quality driven by water level management schemes in the uplands is showing that river hydrographs are being affected in such a way that they would contribute to relieving pressure on flood management lower in the catchment system. Such theme or question based BBNs may provide useful tools to those engaged in strategic policy making for our uplands, and should in our opinion be developed as an off-shoot of this project.

Appendix 3 Paper on Flood Mitigation

Received by project coordinator: 14.11.2009

Upland Ecosystem Services:
Refining the evidence base and service 'networks'

Flood Regulation

Report to Natural England

14 November 2008

ATKINS

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Executive Summary

The concept of ecosystem services has been developed to aid our understanding of the human use and management of natural resources.

Upland areas of England contain many plant and animal communities that are only found in these areas and are nationally and internationally important for biodiversity, as well as being of significant landscape, archaeological, recreational, heritage, and natural resource value. They can also play a key role in climate change mitigation and adaptation, and the provision of a number of ecosystem services, the subject of this report.

One ecosystem service provided by the ecology and environmental management of the uplands is flood mitigation. Typically, this is achieved through the detention and storage of excess water, reducing run-off and flow rates, retaining soil and sediment (thereby protecting the downstream environment from flooding) or acting as a buffer to protect areas at risk of flooding.

This report refines and updates the Phase 1 work completed by CEM, Nottingham for Natural England in 2008, producing a conceptualisation of flood mitigation as an ecosystem service and identifying the key drivers. Following the Phase 1 approach, a Bayesian Belief Network (BBN) has been produced for flood mitigation, where the key driver is vegetation cover.

The generation of run-off is strongly influenced by a number of inherent physical characteristics, primarily the soils, topography and rainfall. These, combined with the effects of future climate change, are the most important factors influencing the provision of flood mitigation in the uplands.

Land cover and the way that the land is managed or used provides an opportunity to affect the pathways by which the rainfall subsequently moves over or through the soil profile and into the arterial drainage network for conveyance downstream. In this way, land use and management can play a significant key influence in flood mitigation, and although of secondary importance to climate, these drivers provide the opportunity for Natural England to influence flood mitigation on a local scale within the uplands.

Land use management and flooding is currently the subject of some considerable research under the Government's Making Space for Water strategy. Many projects identify a number of benefits to one or more ecosystem services, most especially water quality and flood mitigation. The current evidence, however, does little to support the impacts of land use beyond the local scale. There therefore remains a

real difficulty in mapping this ecosystem service both in terms of scale (local or catchment scale) and in the transferability of the results.

The difficulties of scale and transferability, even within the uplands environment, become more apparent when one attempts to ‘operationalise’ or provide data to support any mapping of the system, for example in using the Bayesian Belief Networks (BBNs). Nonetheless, recommendations are provided on how to take this mapping approach forward to investigate drivers and the impacts of land use changes.

Introduction

Ecosystem services

The concept of ecosystem services has been developed to aid our understanding of the human use and management of natural resources.

The Millennium Ecosystem Assessment (MA), a project initiated by the United Nations Environment Programme (UNEP) in 2001, set out to assess how human-made changes to ecosystems affected human welfare. It also sought to establish the scientific basis for actions needed to enhance the conservation and sustainable use of ecosystems and their contributions to human well-being. The findings, published in 2005, represent the most comprehensive assessment of the state of the global environment in this way to date. The MA grouped ecosystem services into four broad categories:

Supporting services, such as nutrient cycling, oxygen production and soil formation. These underpin the provision of all other 'service' categories.

Provisioning services, such as food, fibre, fuel and fresh water. These are the products provided by ecosystem services.

Regulating services, such as climate regulation, water purification and flood protection. These are the benefits obtained from the regulation of ecosystem processes.

Cultural services, such as education, recreation, and aesthetic value. These are the non-material benefits people derive from ecosystem services.

The regulating service of flood mitigation provided by and in the uplands of England is the subject of this report.

The English uplands

Although there is no statutory definition for the 'uplands', areas above the upper limits of enclosed farmland containing dry and wet dwarf shrub heath species and rough grassland are generally understood to be uplands. As such, upland areas contain many plant and animal communities that are only found in these areas and are nationally and internationally important for biodiversity, as well as being of significant landscape, archaeological, recreational, heritage, and natural resource value. They can also play a key role in climate change mitigation and adaptation, and the provision of a number of ecosystem services, the subject of this report. Agricultural activity has largely shaped the upland landscape that we value.

Upland Futures project – Phase 1

Natural England's Upland Futures project is a two-year initiative designed to 'develop a shared vision for England's Upland environment (in 2050) that is grounded in a firm evidence base and 'future-proofed' against forthcoming challenges and opportunities'[9]. As part of the Upland Futures project, Natural England commissioned an initial scoping study completed earlier in 2008 by Haines-Young *et al.* 'Upland Ecosystem Services – Phase 1'.

The aim of the Phase 1 study was 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 ecosystem services studied were:

Carbon storage and sequestration (Regulating service)

[9] http://naturalengland.communisis.com/naturalenglandshop/docs/NE99.pdf

Recreation (Cultural service)

Renewable energy (Provisioning service)

Water provisioning and flood regulation (both Regulating services) were also considered together in a 'more general way' within the study, noting that many of the systems had common direct and indirect drivers.

The Phase 1 study developed a series of Bayesian Belief Networks (BBNs) to depict the factors combining to deliver each ecosystem service, as well as the relationships between these factors. Further details on this approach are provided in Section 1.6 of this report. Notably, water quality and quantity were considered together for the development of an initial BBN in the Phase 1 study.

The purpose and aims of this project

This project has been commissioned to refine Natural England's approach and the information already developed in Phase 1, in order to build an improved understanding of upland ecosystem services. The findings will provide the basis for further work in this area, including spatial mapping of ecosystem services; understanding the implications of future scenarios; economic valuation of ecosystem services; and provide a focus for policy and land management change.

The ecosystem services identified for the second iteration of work were:

Carbon storage and sequestration;

Recreation;

Renewable energy;

Water quality; and

Flood mitigation.

Flood mitigation, the fifth of these ecosystem services, is the subject of this report. Other contractors have been commissioned to look at the other four ecosystem services noted above.

The project aims were three-fold:

Refine the service networks provided for water to ensure they reflect our best understanding of how different environmental systems work, illustrating the key components, processes, relationships, interactions, drivers and impacts of the system relating to flood mitigation.

Document the evidence concerning the nature and strength of the different relationships between the nodes and the probabilities within the nodes. An assessment of the confidence in the evidence for each relationship should be made, including an indication of the transferability of evidence in a particular spatial location to other parts of the English uplands.

Draw out the key conclusions to identify:

The most influential drivers of the system;

The changes that would result in the biggest environmental impacts (negative or positive); and

Comment on how the different drivers work in parallel.

In view of the short amount of time available to complete the work (5 days) and following a web conference[10] with the client and all contractors undertaking the assessments, the brief was altered, with the following key tasks agreed:

Refine or create the service networks for flood mitigation; and

assess the main drivers for change to the ecosystem service with a particular reference to how Natural England may use land management in the future to alter the provision of ecosystem services

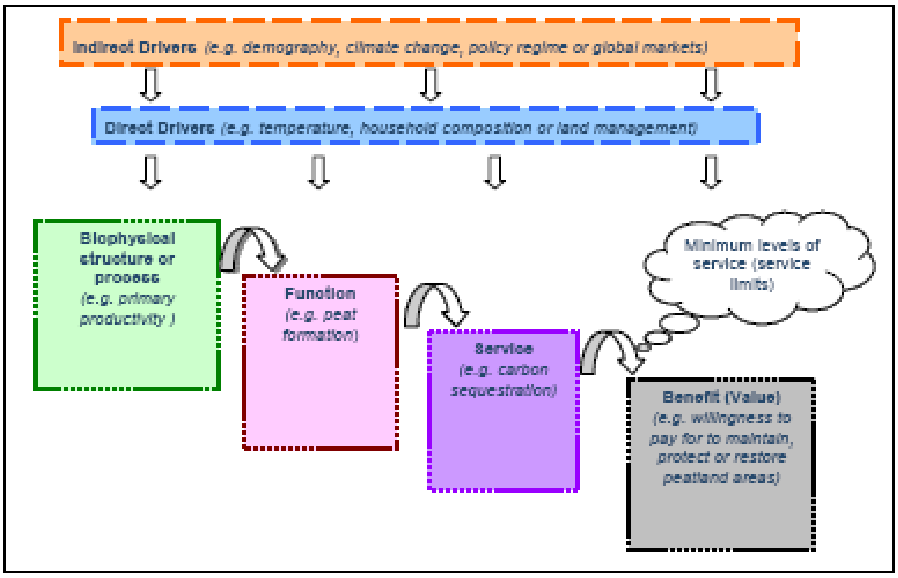
This will allow the 'co-ordinating contractor', CEM, Nottingham to draw together the outputs of all five ecosystem services into a revised report later in 2008.

Notably, as only the 'basic version' of BBN software (Netica) would be available to the contractors, the Phase 1 versions of the Bayesian Belief Networks (see section 1.6) would not be fully revised and recalibrated, but information provided on the nodes which make up such mapping diagrams.

Conceptual systems map

The current 'ecosystem service' paradigm (as identified in the Phase 1 study) 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. An example provided is carbon, which is taken up through 'primary productivity', the result of which is the ecological function 'peat formation', which delivers the ecosystem service of 'carbon sequestration', which in turn provides a benefit in terms of framing society's response to climate change. Impacting upon the ecosystem services and the relationships between them are a series of drivers: 'indirect' drivers, which include climate change and demography; and 'direct' drivers such as temperature, rainfall, and land management. Figure 1.1 illustrates this logic.

Figure 1.1 The logic underlying the concept of ecosystem services (after Haines-Young et al., 2006), as used for the framework for study in Haines-Young et al., 2008 (Phase 1 work)).



The difficulty lies in understanding the links between the structures, functions, and services shown in Figure 1.1 and trying to illustrate the complex relationships simply, in a way that realistically reflects reality.

[10] web conference held on 21 October 2008

The principle aim of the Phase 1 work was to expand the model shown in Figure 1.1 to create real systems maps for a number of ecosystem services in the uplands, based on best available evidence.

Bayesian Belief Networks

The Phase 1 study used the Bayesian Belief Network (BBN) approach to show the relationships between, and drivers of, the factors combining to deliver the ecosystem services. BBNs are a potentially useful tool for integrating knowledge about the biophysical, economic, social and policy drivers of change. In addition they provide a potential mechanism for integrating quantitative and qualitative information, including informed expert judgement. Within the Phase 1 study the BBN system was used to explore the relationships between drivers and factors influencing each service. This is not the only method of mapping and exploring such relationships. However, the BBN does provide a useful tool for stakeholder involvement and exploring the impact of change. What the BBNs do not do is provide a complete model of reality; they are simplistic conceptualisations which aim to portray the most important factors, in this instance for the provision of an ecosystem service.

Quick introduction to the Bayesian Belief Networks and software

Further background to the networks and mapping can be found in Part 2 of the Phase 1 report, which is reproduced with permission as Annex 1 of this report.

This power point presentation from British Colombia gives a readily accessible introduction to the concept.

http://www.forrex.org/program/con_bio/PDF/Workshops/Land%20Use%20Planning%20Workshop/Adrian%20Walton.pdf

The software to map Bayesian Belief Networks (*Netica*) can be accessed at http://www.norsys.com/ and the basic version is free to download.

Importantly, and as noted and for the reasons given Section 1.4, it is not within the remit of this report to produce new, recalibrated versions of the BBN. Instead, a mapping diagram of the nodes and relationships has been produced to reflect the provision of flood mitigation in the uplands, where vegetation cover is the key driver.

Flood mitigation as an ecosystem service of the uplands

The hydrology of uplands is noted for a combination of high rainfall and low evaporation which results in large volumes of stream run-off. In most places, rocks are impermeable while soils are thin or have waterlogged, peaty characteristics. This combination means that the run-off regime is invariably 'flashy' with high flood discharge and low baseflow.

One ecosystem service provided by the ecology and environmental management of the uplands is the modification of the system's storage and conveyance capacities to reduce the likelihood of flooding. Typically, this is achieved through the detention and storage of excess water, reducing run-off and flow rates, retaining soil and sediment (thereby protecting the downstream environment from flooding) or acting as a buffer to protect areas at risk of flooding.

The generation of run-off is itself strongly influenced by a number of inherent physical characteristics, primarily the soils, topography and rainfall, together with the characteristics of the land cover at the soil or ground surface. In addition, the way that the land is managed or used, both now and in the past, including cultivation techniques and livestock management systems, will affect the pathways by which the incident rainfall subsequently moves over or through the soil profile and into the arterial drainage network for conveyance downstream.

The key factors influencing the generation of run-off are usually considered to be a combination of the following factors:

Climatic conditions (e.g. rainfall intensity and duration, evaporation/evapotranspiration, hydrologically effective rainfall).

Land cover (e.g. vegetation type and age of habitat);

Land management (e.g. soil and crop management activities);

Soils (e.g. standard percentage run-off, infiltration, soil storage potential, bypass flow);

Topography (e.g. slope, shape); and

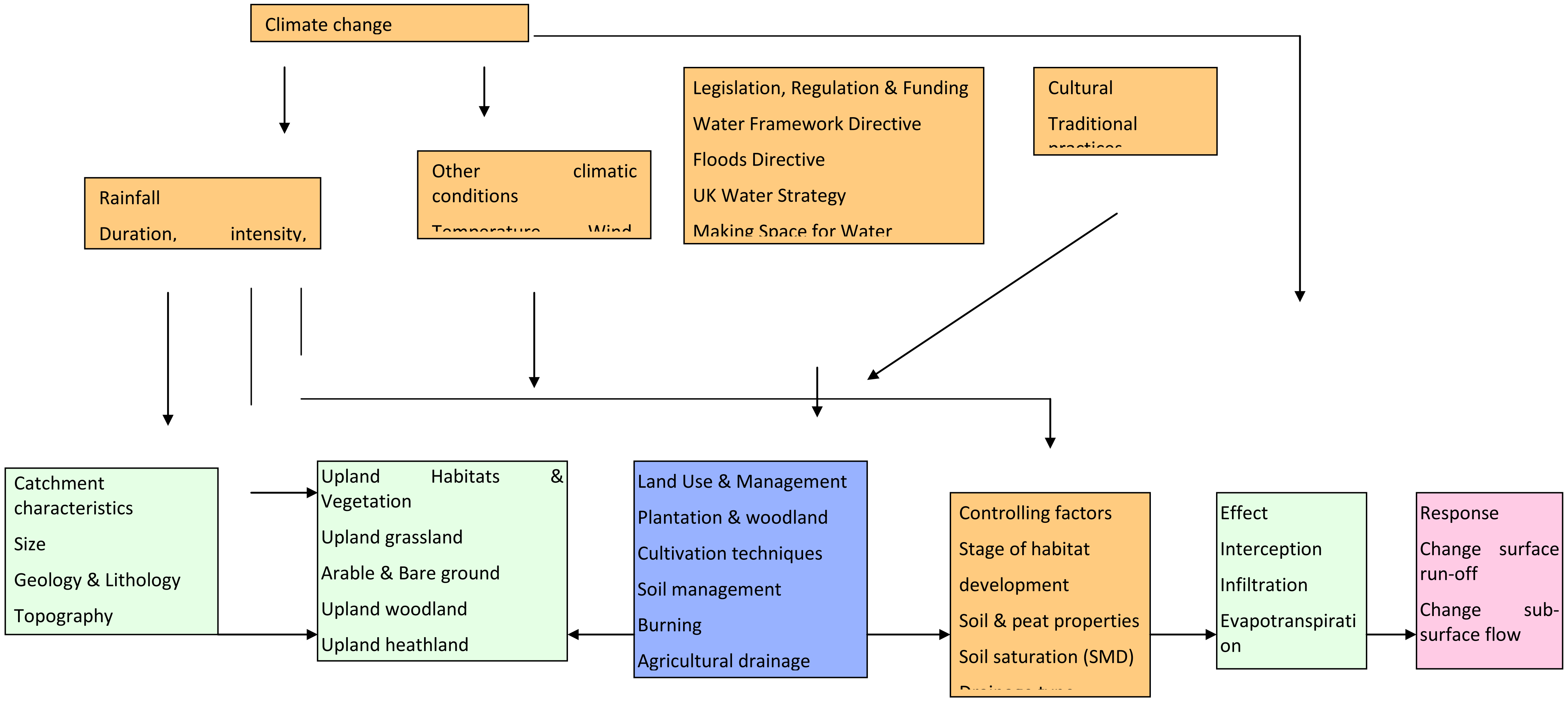
Drainage network (e.g. drainage density, hydrological connectivity).

Whilst all areas of land can play a part in absorbing and storing water (reducing run-off), slowing the speed at which it moves downstream and thereby mitigating floods, the difficulty is breaking down this complex process into component parts. In doing this one can then identify the most important variables, the relationships between those variables, and the how key drivers may impact upon them, both now and in the future. It is in this way that Natural England and others may play a role in proactively managing the uplands ecosystem to help maintain or enhance the services they provide.

Factors influencing flood mitigation

Figure 2.1 shows the conceptual model of the factors influencing flood mitigation in the uplands. This has been developed in Phase 1 and has been amended only slightly, or provided with further detail. The figure shows a much wider understanding of flood mitigation and the factors which influence it. The colour coding follows Figure 1.1, in identifying the direct and indirect drivers (orange and blue, respectively), the ecological structures and processes (green), functions (pink), services (purple) and potential benefits (grey).

Figure 2.1: CONCEPTUALISATION OF FACTORS INFLUENCING FLOOD MITIGATION IN UPLANDS



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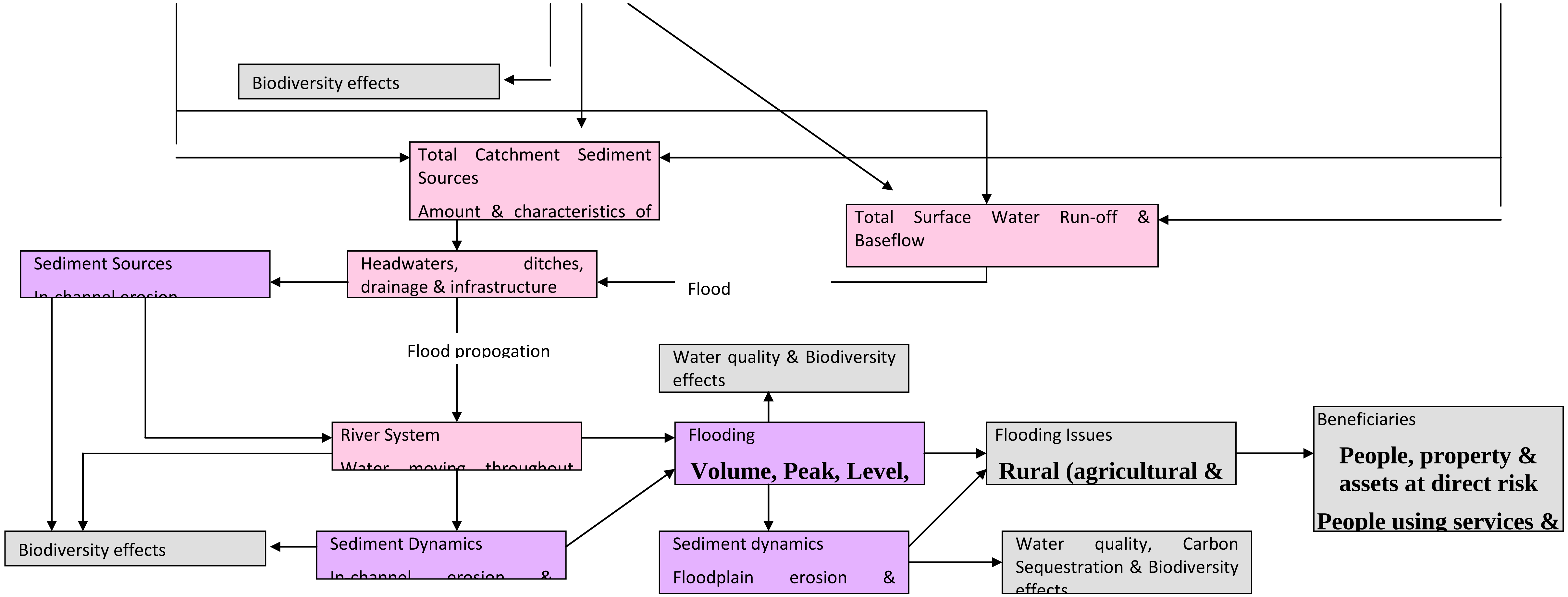
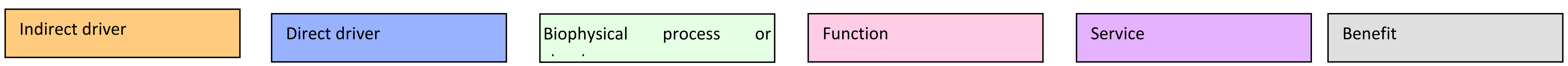


Colour coding is the same as that depicted in Figure 1.1



Factors influencing flood mitigation: Key drivers

The key drivers, both indirect and direct, influencing flood mitigation in the upland environment are therefore identified as:

Climate change

Rainfall

Other meteorological conditions

Legislation, Policy and Funding

Cultural factors

Built Environment

Upland habitats and vegetation

Land use and management

The Built Environment is an additional driver identified by this report.

Table 2.1 details these drivers and assesses their potential influence and current evidence for flood mitigation.

Climate, including future climate change and present meteorological conditions, and specifically rainfall, is likely to be the most influential driver. It is therefore detailed in Section 2.2.1 below.

Land use management, including vegetation and habitat type, is likely to be of second order importance to climate. Nonetheless, these are the factors where changes can be made on the ground through legislation, policy and funding. In this way, land use management and habitat or vegetation type could be considered the most important set of drivers for flood mitigation.

Climate change

Climate change is likely to be the most important future driver influencing the provision of flood mitigation as an ecosystem service, through the increased frequency and magnitude of flood events. The implications of future climate change are likely to be complex and highly uncertain, but the principle impacts to the UK are likely to be (Defra, 2005):

Warmer climate;

Higher summer temperatures becoming more frequent, and very cold winters becoming increasingly rare;

Winters becoming wetter, and summers drier;

Snowfall amounts decrease; and

Heavy winter precipitation becoming more frequent.

Although the resultant changes to flood risk will vary from catchment to catchment, and within catchments, the upland environment is likely to be more seriously affected by some elements of future climate change than other environments. For example, hotter drier summers are likely to cause more peat soils to dry out and more wild fires to occur on the moors; whilst wetter winters may mean increased soil erosion and downstream flooding.

Climate change may in itself precipitate changes to land use and management, especially agriculture (Defra, 2005a). Any associated changes to the type of crops grown, stocking densities and farming practices could have knock-on impacts on soil structure, vegetation cover, infiltration and interception rates. A change in land management could also help mitigate the causes and impacts of climate change in the uplands. For example, management to preserve peatland habitat has the potential to provide mitigation for the effects of climate change through carbon sequestration. SCaMP (Sustainable Catchment Management Programme) and Peatscapes upland conservation projects are providing evidence of this point.

Table 2.1 An assessment of the key drivers for flood mitigation as an ecosystem service

	Factor / Node	Detail	Potential impact on the provision of flood mitigation	Potential strength of influence of driver
Indirect driver	Climate change	Potential changes in climate of the uplands including: increased storminess and precipitation; increased levels of sediment; erosion; and hotter, drier summers, and wetter winters Interpretations of climate change model outputs: UKCIP08, and Defra FCDPAG3	Further stress on the environment through increased flood risk, combined with potential to reduce the ecosystem's ability to deliver flood mitigation, e.g. through hotter, drier summers drying out peat soils increasing run-off and making wild fires on moorland more common.	Climate is likely to be the most important factor in influencing the frequency and magnitude of flood events. However, potential for climate change mitigation and adaptation within the upland environment e.g. through carbon sequestration.
	Rainfall	Duration, intensity, frequency and timing	Hydrological response depends upon physical characteristics of catchment, vegetation and soil cover.	
	Other meteorological conditions	Temperature, snow, CO_2, storminess, wind, humidity, and cloud cover		
	Legislation, Policy and Funding	Key elements: Water Framework Directive (WFD) Floods Directive UK Water Strategy Making Space for Water Catchment Sensitive Farming (CSF) Environmental Stewardship	Potential enabling factor to elicit change e.g. land use change, funding for research initiatives to provide further evidence of the impact of land management on flood mitigation, or as a mechanism for a change in farming practices which reduces soil compaction and thereby increases infiltration rates.	Whilst there is potential for considerable influence through these and/or future policies, a number of these legislative instruments do not directly address flooding e.g. WFD, and CSF, and as yet there is no consistent approach

		Common Agricultural Policy Habitats Directive Floods and Water Bill PPS25 AMP5		across regulatory bodies or within the legislation, (despite the Pitt Review).
	Cultural factors	Traditional practices Visitor pressure Public education Loss of traditional land management skills	Potential to make a significant difference at the local scale e.g. trampling of ground and loss of vegetation leading to increased flood propogation.	Cultural factors are likely to be the least influential driver of the system.
Direct driver	Land use and management	Plantation and woodland Cultivation techniques Soil management Burning Agricultural drainage Moorland drainage and gripping Pasture and stock management Floodplain woodland Tree shelter belts	Evidence from recent research that changes can be made to all these land use and management systems to reduce rates of surface run-off and/or delays in downstream flood peaks at the local (hillslope). However, there is uncertainty regarding how local scale changes impact upon flood risk at the catchment scale.	Land use management including vegetation and habitat type are likely to be of second order importance to climate. Nonetheless, these are the areas where changes can be made through legislation, policy and funding. Therefore they could be considered the most important drivers

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	Upland habitats and vegetation	Upland grassland Arable & bare ground Upland woodland Upland heathland Hedgerows Upland fens and swamp Rivers, lakes and wetlands Blanket bog Wet woodland	A change in habitat or vegetation on a large scale has the potential to make a modest to a significant difference to flood propogation and generation. Therefore, strategic habitat change in appropriate locations would achieve the greatest impact for flood mitigation.	for flood mitigation.
	Built Environment	Reservoirs Roads Urban areas Roads and hard standing Hydropower	Potential to make a significant difference at local and catchment scale, either in terms of flood mitigation or flood risk, e.g. water supply reservoir would have a major impact in reducing flood risk in some upland catchments, whilst an increase in farm hard standing or road networks could significantly increase flood risk.	

Impacts of upland land management on the provision of flood mitigation as an ecosystem service

The impact of land use management on flooding is the subject of recent research as part of the Making Space for Water (MSfW) strategy on flood and coastal erosion risk management in England. A number of land-use projects HA6 (catchment scale) and HA7 (farm or local scale) are investigating the role that rural land use and land management can play in reducing flood risk. Many of their findings provide insight into possible changes that could be made to the upland environment to improve the provision of flood mitigation as an ecosystem service. The project outputs, combined with those of Defra FD2114 project to *Review of the impacts of rural land management on flood generation* (2004), provide an assessment of the most recent evidence and scientific thinking in support of the link between land use and flood mitigation. The Defra project was most recently updated by Atkins to guide the direction of future HA6 and HA7 and funding in this area (EA, 2007).

Table 2.2 provides a summary of the relationship between land use and management types (or in some cases practices) within the uplands and flood mitigation, including how flood mitigation is achieved: a reduction in flood generation or propogation downstream; an assessment of the current evidence to support that relationship; selected current research to support or investigate the assumptions; and an identification of possible wider benefits which can be achieved through ecosystem services.

Issues of scale and transferability

Whilst there is a significant theoretical basis underpinning the relationship between land use and flood risk, the results from HA6 and HA7 projects within the MSfW strategy (and other current research) show there is little monitoring evidence to demonstrate the effects. Where evidence exists, it is at the local scale. Effects at a large catchment scale are difficult to determine since they are the result of aggregating many local-scale effects which are themselves hard to quantify, and are also dependent on individual physical catchment characteristics. This does not, however, necessarily mean that there is no catchment-scale effect, but rather that the nature of the effect is very difficult to detect, and the effect will differ between catchments. Research is ongoing, and Defra have, for example announced funding in July 2008 for demonstration projects to continue to look at the link between land use management and flood risk.

This does pose two particular problems for this study. Firstly, the ability to conceptualise flood mitigation at a catchment, rather than local, scale, and then map the network within a BBN. Secondly, the transferability of any findings between and within upland catchments becomes more problematic.

Benefits to other ecosystem services

The possible wider benefits which can be achieved beyond simply flood mitigation reflect the close relationship between many ecosystem services. Many of the ongoing projects listed in Table 2.2 show wider benefits to three of the four other ecosystem services being studied in this phase of work: recreation, carbon storage, and especially water quality. Benefits in achieving biodiversity objectives and habitat restoration can also be realised.

However, the relationships between ecosystem services are not necessarily simple. Poor woodland management has for example been shown to have negative impacts on water quality, by increasing turbidity in streams enriching and contaminating the water (Forestry Commission, 2003). Also, a catchment approach to control sediment inputs into Bassenthwaite Lake in Cumbria has identified potential conflicts over land use whereby planting of new woodland for the purpose of erosion control potentially conflicts with ecological and landscape values of important moorland habitat (Nisbet, 2004).

Figure 2.2 Land use management and associated flood mitigation benefits, ongoing research and wider benefits

Land use and management type or practice	Flood mitigation	Assessment of current evidence to support the relationship	Ongoing or current research (selected)	Possible wider benefits by other ecosystem services
Plantation and woodland Tree shelter belts Floodplain woodland	Tree cover can provide a buffering function for water courses, by attenuation of overland flow limiting flood generation and reducing flood propogation of flood flows downstream.	Floodplain woodland must be strategically situated to achieve flood mitigation (as the resultant increased floodplain roughness may cause flood depths to increase upstream of the site), plus there is a noted risk of floating debris downstream causing blockages that locally increase flood risk.	Defra project SLD2316 Restoring Floodplain Woodland for Flood Alleviation to establish feasibility of floodplain woodland in case study catchments. Woodland creation included within Pontbren, Parrett and Ripon Mulit-objective projects.	Carbon storage and sequestration, biodiversity objectives, and improvements to water quality.
Burning	Controlled burning and wild fires lead to changes to vegetation cover, likely to have a negative impact	Limited evidence to suggest a positive relationship between flood mitigation and this land use practice.	Subject of limited current research in relation to flood mitigation.	Limited wider ecosystem service benefits.

	(especially if badly managed) on the provision of flood mitigation services.			
Moorland drainage and gripping	Restoring areas of eroded and exposed peat should improve infiltration of surface run-off especially in extreme rainfall events, and help reduce flood generation.	Uncertain as to whether long-term changes in peat hydrology resulting from past drainage can be reversed. Actual impact in any catchment has been shown to vary according to peat type, climate, catchment characteristics and the behaviour of the peat water table. Therefore it is important to understand the characteristics of the peatland system before restoration.	Ongoing research into peat hydrology in the United Utilities SCaMP project, Upper Wharfedale Best Practice project, and Peatscapes.	Opportunities to restore priority habitats, minimize carbon loss and improve water quality.
Pasture and stock management	Changes from arable to intensive grassland; and a	Run-off processes at the local scale vary spatially according to soil structure and soil	Ongoing research at Pontbren to quantify the impacts of upland	Similar to cultivation techniques in that improved

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	reduction in sheep stocking densities can limit flood generation by retaining water in the upper catchment. Reduction in flood propogation through flood storage e.g. where permanent pasture used to provide flood buffer storage.	vulnerability and have also been shown to vary year to year at the same location. Large-scale changes in grassland land use required to produce a relatively small reduction or delay in downstream flood peaks.	land management at plot, local and catchment scales. Yorkshire Dales Rivers Trust and Upper Wharfedale Best Practice projects looking at sheep stocking densities.	grassland management offers parallel opportunities to meet conservation, biodiversity and diffuse pollution objectives.
Agricultural drainage	Limiting flood generation by decreasing run-off and retaining water in the upper and mid catchment. Run-off generation varies according to soil properties,	Benefits are relatively well understood and proven at the local scale as a result of numerous small-scale process studies.	Nafferton Farm Proactive Run-off Management project, and Ripon Multi-objective pilot study.	Improved soil and ditch maintenance will have biodiversity benefits.

	rainfall, and drain and ditch maintenance. Additional water storage on farms dramatically reduce flows, and bunded areas reduce flows entering watercourses.		Parret Catchment Hope Farm	
Cultivation techniques and soil management	Limiting flood generation by retaining water in the upper catchment and delaying time for storm water to reach the floodplain. Changes to farm practices e.g. contour ploughing, buffer strips, under-sowing, uncultivated areas, reduced	Good quantifiable evidence for significant flood mitigation through run-off reduction at the local scale.	Changes from arable to pasture and best practice land management part of the Parrett Catchment project. Mercaston and Markeaton Brooks	Changes to cultivation techniques can provide the opportunity to address conservation, diffuse pollution and biodiversity objectives.

	grazing pressure through altered stocking densities. Changes in land use from arable to grassland along rivers and set-aside at margins and headlands Changes from arable to pasture and best practice land management leading to reduced surface run-off rates achieved through conservation tillage and better tyre pressurisation which increases infiltration.		Projects. River Poulter Project, Ripon multi-objective pilot and Upper Wharfedale project.	

BBN for flood mitigation

As acknowledged in the Phase 1 study, the conceptual model is complex and 'would require considerable effort to convert into a fully calibrated BBN'. Furthermore, since there are a number of common factors influencing water quantity and quality, Phase 1 study mapped both water quantity and quality in the same model.

A revised BBN covering the issues related to flood mitigation alone is shown in Figure 3.1. Water quality remains within the BBN as a node, as many of the processes and relationships have a particular impact upon diffuse water pollution.

The key driver for the BBN in Figure 3.1 is vegetation cover. This driver has been selected in consultation with the project team, and represents a key driver for the future of management of the uplands.

Nodes coloured dark green in the network are those considered most influential in this mapping scenario. As in the Phase 1 study, the assumption is that the network operates at the catchment scale. However, and to reinforce the points raised in Section 2.4, the relative importance of each of the nodes will change both between and within catchments in the uplands environment, as the physical characteristics change and the impacts of land use management. Therefore, Figure 3.1 can only represent a generalisation. The most important nodes will depend upon where the mapping system applies on the ground. This makes it difficult to comment upon the strength of the relationships between the nodes in addition to the identification of the key drivers identified in Section 2 of this report and those nodes coloured dark green in Figure 3.1.

The key changes to the BBN are as follows:

Vegetation cover (E1) – a more comprehensive list of vegetation type and habitat including arable, woodland, heathland, hedgerows, upland fens and swamp, rivers, blanket bog, wet woodland, as well as bare ground would need to be included.

Catchment conditions (F) and Catchment characteristics (I) are represented as two nodes in the diagram. However, in terms of 'operationalising' the network, these would have to consist of a number of further nodes, which does complicate the network, as follows:

Catchment conditions: Soil moisture and recent meterological conditions;

Catchment characteristics: Size, Geology & Lithology, Topography, Soil type, Drainage network, and the Built environment (including hard-standing, roads, etc.).

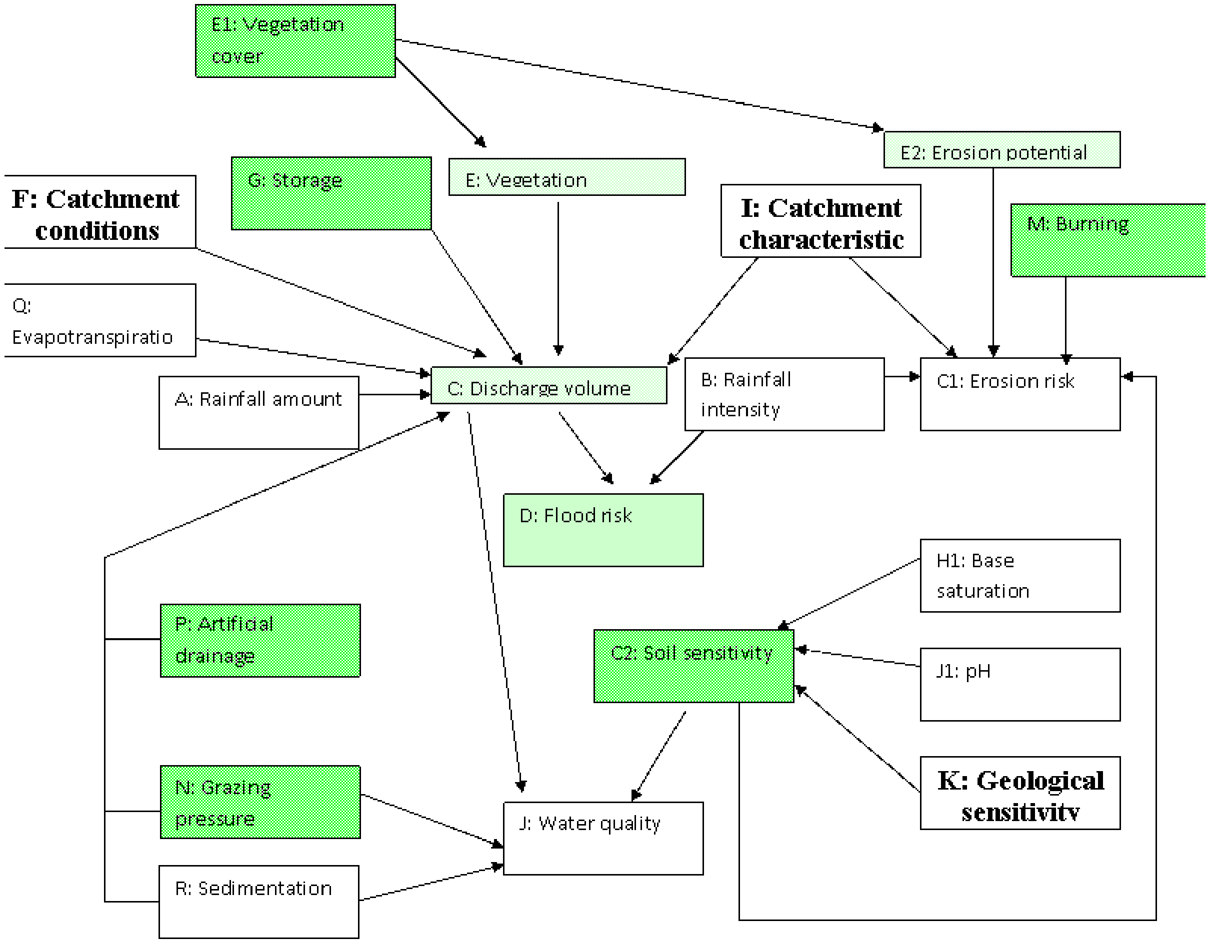
Burning (M) and Artificial Drainage (present and past) (P) will be important land use management practices for some catchments or local areas, and therefore these nodes have been added. Of course, in other catchments they will not be relevant.

Sedimentation – an additional node for in-channel sediment (R).

Evapotranspiration (Q) - has been added as a node as it will be important in influencing discharge volume at certain times of the year.

Storage (G) – represents an additional node to include reservoirs, wetlands and flood protection storage on farms.

Figure 3.1: BBN FOR FLOOD MITIGATION (WITHOUT CALIBRATION) WHERE THE KEY DRIVER IS VEGETATION COVER



Conclusions

The ecosystem service provided by the ecology and environmental management of the uplands is the modification of the system's storage and conveyance capacities to reduce the likelihood of flooding. Principally, this is achieved through the detention and storage of excess water, reducing run-off and flow rates, or acting as a buffer to protect areas at risk of flooding.

The generation of run-off is strongly influenced by a number of inherent physical characteristics, primarily the soils, topography and rainfall. These, combined with the effects of future climate change, are the most important factors influencing the provision of flood mitigation in the uplands.

Key drivers influencing flood mitigation are climate change, rainfall, along with other climatic conditions. These are likely to be the most important factors influencing the frequency and magnitude of flood events.

Land cover and the way that the land is managed or used provides an opportunity to affect the pathways by which the rainfall subsequently moves over or through the soil profile and into the arterial drainage network for conveyance downstream. In this way, land use and management can play a key influence in flood mitigation, and although of secondary importance to climate, these drivers provide the opportunity for Natural England to influence flood mitigation on a local scale within the uplands.

There remains a real difficulty in conceptualising this ecosystem service both in terms scale (local or catchment scale) and in the transferability of the results.

The difficulties of scale and transferability, even within the uplands environment, become more apparent when one attempts to 'operationalise' or provide data to support any mapping of the system, for example in using the Bayesian Belief Networks (BBNs).

This is not to suggest that BBNs are therefore not are useful tool for understanding ecosystem services, or more specifically, flood mitigation as an ecosystem service. These networks, as shown in the one produced in this report, can identify the factors most likely to influence the provision of flood mitigation. As such, they can guide funding, research and future decisions for land management in the uplands.

Recommendations

In order to take forward the BBN approach to mapping ecosystem services, it is recommended that a network is fully calibrated at the local scale using existing data on an ongoing project. Both the Phase 1 study and this report note the difficulty in 'operationalising' such a network. However, this is likely to be the cost-effective approach.

The accompanying Excel spreadsheet attempts to identify these spatial datasets.

In terms of valuing the ecosystem services provided for flood mitigation, good use could also be made of existing data, including costs of damage to properties, typical costs of flood walls and banks foregone, the costs of land management practices, etc.

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Recreation in the Uplands

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5th January 2009

Christine Reid
Natural England

Recreation in the Uplands

Introduction

The Access Company (TAC) was contracted for 5 days by Natural England's Upland Futures project to work with a group of other experts and model the main drivers and influences on upland ecosystems. The subject of our research was recreation in the uplands.

The Access Company are experts in access and recreation, with relevant qualifications and a great deal of policy and project delivery experience in the team. Wherever possible we applied known evidence and real data to the work and minimised our assumptions aware that the model has the potential in the future to significantly influence the quality and enjoyment of a nationally important landscape.

The requirements of the contract were to:

1. Develop an approach to:

    a. Test the assumptions made about how the system works
    b. Refine and improve the terminology
    c. Identify other evidence to support the work, and comment on the quality and relevance of the quoted material
    d. Identify any conflicts in the evidence
    e. Refine the probabilities identified in each of the nodes

2. Document the evidence about the nature and strength of the different relationships between the nodes and the probabilities within the nodes. Assess the confidence in the evidence for each relationship, including an indication of the transferability of evidence obtained in a particular spatial location to other parts of the English uplands.

3. Draw out key conclusions using the networks interactively, exploring the impacts of changing different variables (alone and in combination), to identify:

    a. The most influential drivers of the system
    b. The changes that would result in the biggest environmental impacts (positive and negative)
    c. How the different drivers work in parallel.

Section 1. The Approach

The Upland ecosystem services: Phase I Report[11] provided a system map (Figure 4.1) and two subsequent recreational sub-models (Figures 4.2 and 4.3) which were the basis for our study of recreation. We had some reservations about the representation and assumptions in these original models however and explored what existing evidence from other sources could be used to anchor assumptions and inform the evolution of further models.

The most recent and helpful evidence available to us was that collected recently for Natural England as part of the review of National Trails[12]. The national survey (collated by market research company TNS in 2008[13]) captured the opinions of a representative sample of the English adult population and explored recreation need, motivations, barriers and triggers for behaviour change. The evidence focused on recreational walking but we have a confidence that many of the given values are transferable to a wider recreation model and can be adjusted to be made relevant to Upland areas as walking is known not only to be the most popular national recreational activity it is by far the most popular recreation activity in upland areas too.

Behind the survey work informing the model is a complex segmentation model which ensures equality in the way the population is sampled. The English population here has been divided into 17 segments by marketers and is illustrated in Figure 1 in relation to those active or inactive in recreation.

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[11] Haines-Young, R., Potschin, M.; Rollett, A. and Tantram, D. (2008): England's

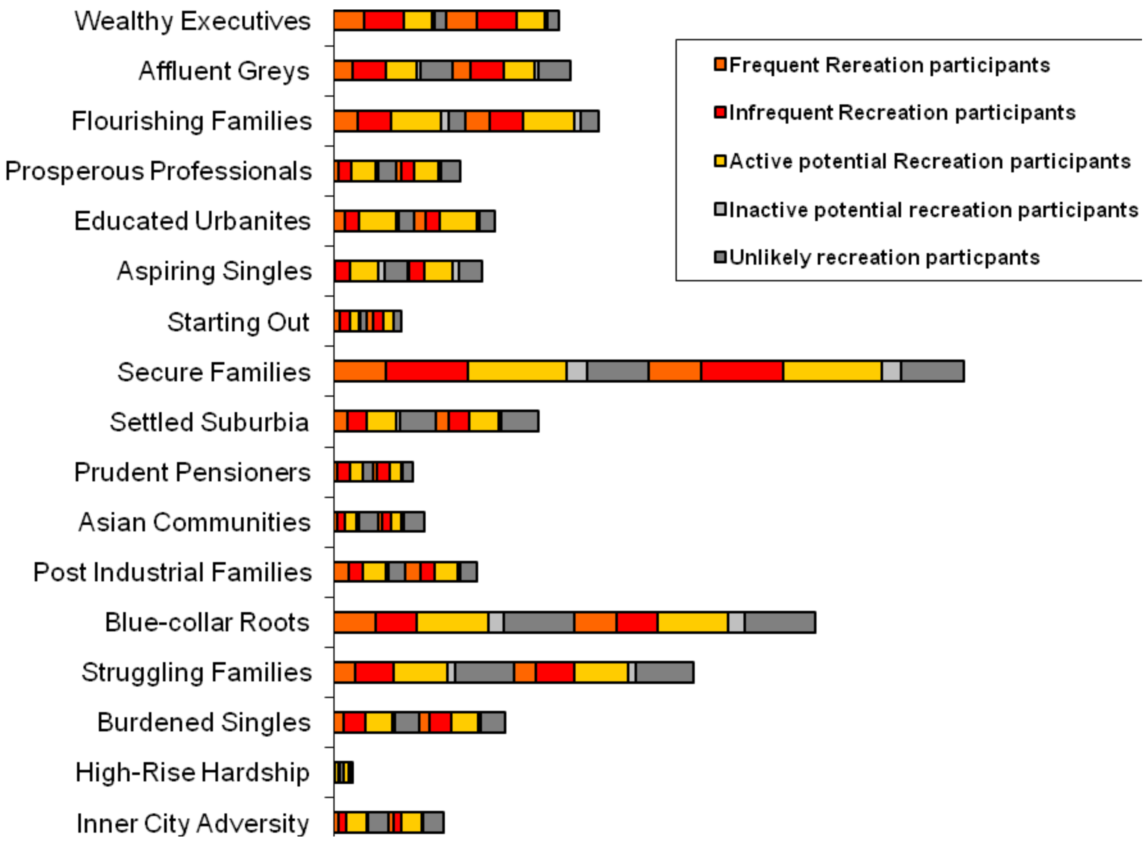
Upland ecosystem services: Phase I. Final Report to Natural England, 114 pp.

NE Project Code: FST20/79/023

[12] Full findings and report yet to be published – contact Peter Ashcroft, Natural England

[13] Internal NE report - The Market for Strategic Recreational Routes TNS UK Ltd, August 2008

Figure 1. Recreation walkers by segment relative to market size in England.



Such segmentation tools have the potential to refine the data so that communities living in and near to upland areas can be mapped against national trends and their specific values and motivations captured. The existing national dataset however is too small (n1700) to be confident that the reduced sample size would be representative of upland community values. It is recommended however that further research is considered to improve understanding of who is attracted (and potentially attracted) to visiting these areas for future target marketing.

Figure 2. The recreation model based on existing evidence.

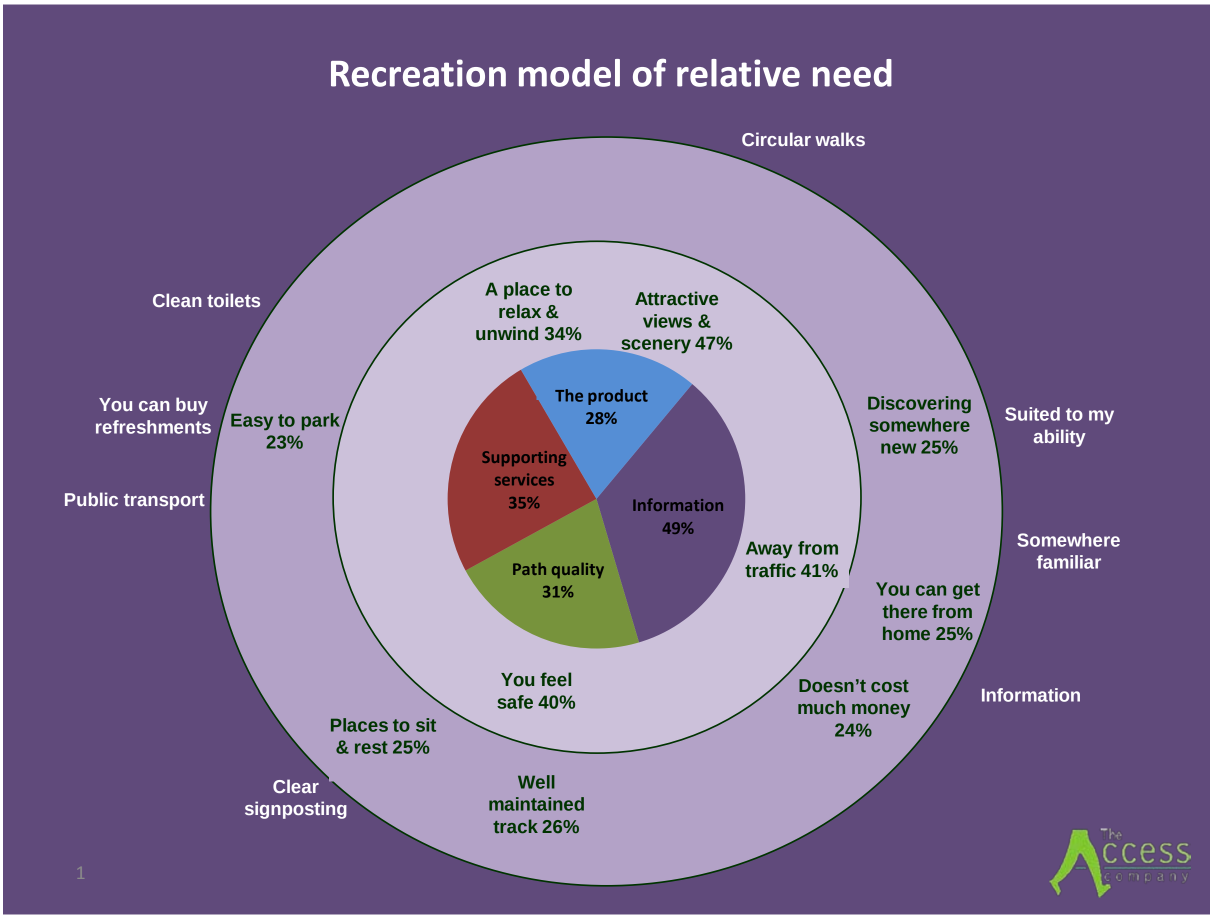


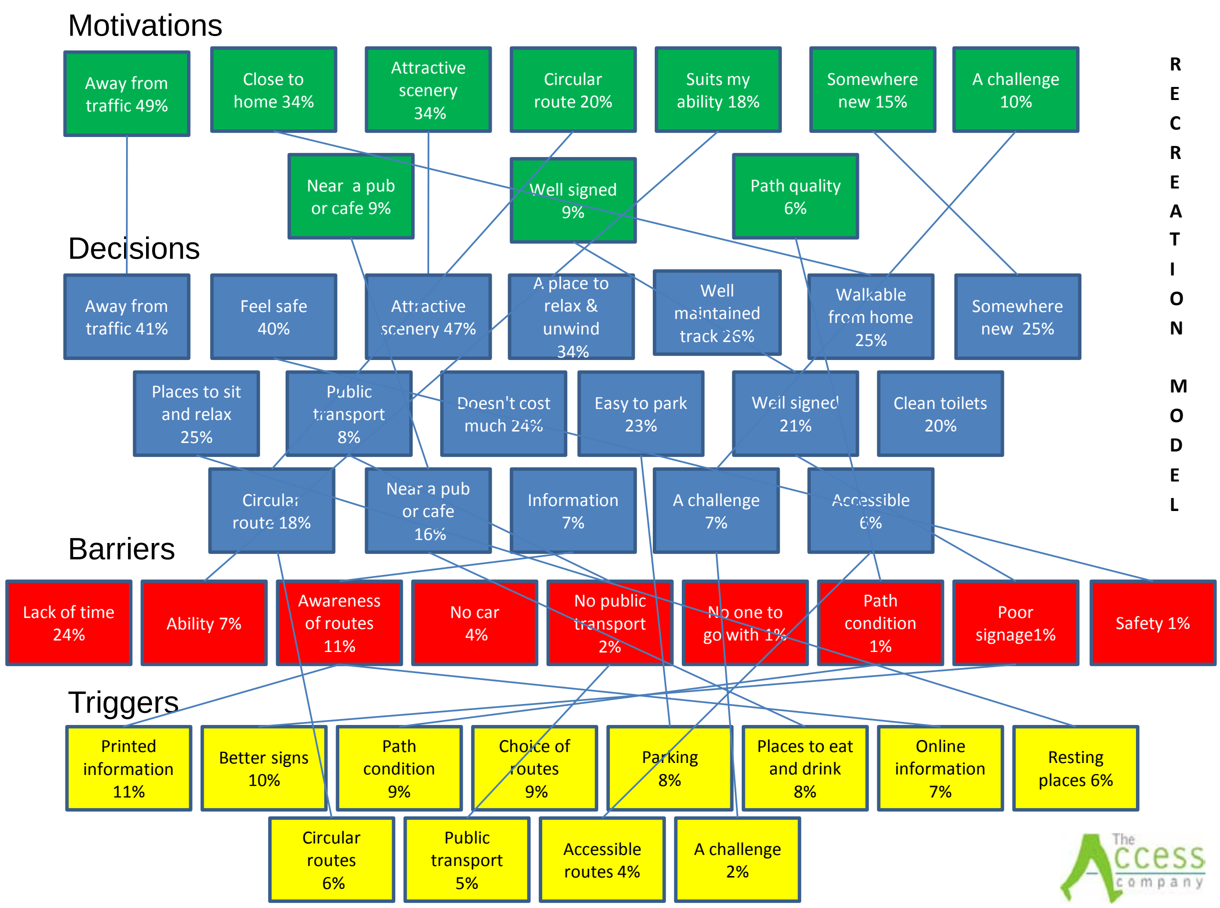
Figure 2 presents the existing national recreation evidence in concentric spheres of importance. The survey evidence identified 4 headline factors as key to recreation participation which are relatively equitable and include: the need for reliable, accurate and relevant information; the need for an attractive and inviting 'product' (used to describe the environment al context including landscape type); the need for services to support a chosen activity; and the need for a place and the recreation infrastructure provided to be looked after and managed.

Evidently 'a place away from traffic' (which has some relevance to the upland recreation model 'tranquillity' factor), 'attractive scenery', and being 'close to home' are given as the three most important factors determining recreation participation.

Despite the apparent high number of people saying that more information would make them recreate more, looking into the data in more depth reveals the common sense conclusion that, while information is important, it cannot alone make someone want to go to place – it is the quality and attractiveness of the place which does that.

Aware that the applicability of the recreation model relies on understanding the complex interrelationships between the variables and their influence on different segments of the population we explored the detail of the evidence to see how each known factor relates to others and informs the upland system understanding. Figure 3 provides a relationship model therefore using the same evidence in the first step towards this.

Figure 3 Recreation need interrelationship links.



The above relationship model adopts the system approach as provided usefully by the Upland Report. Additionally we have included a hierarchy categorising factors into those which motivate; are used to make decisions; are given as barriers; and those which are known to be triggers to overcoming any given barriers. The hierarchy illustrates the relationships between decisions which lead to participation. On exploration themes emerge which we have drawn out more in Figure 4.

Figure 4. Recreation Model by area of need and relationships

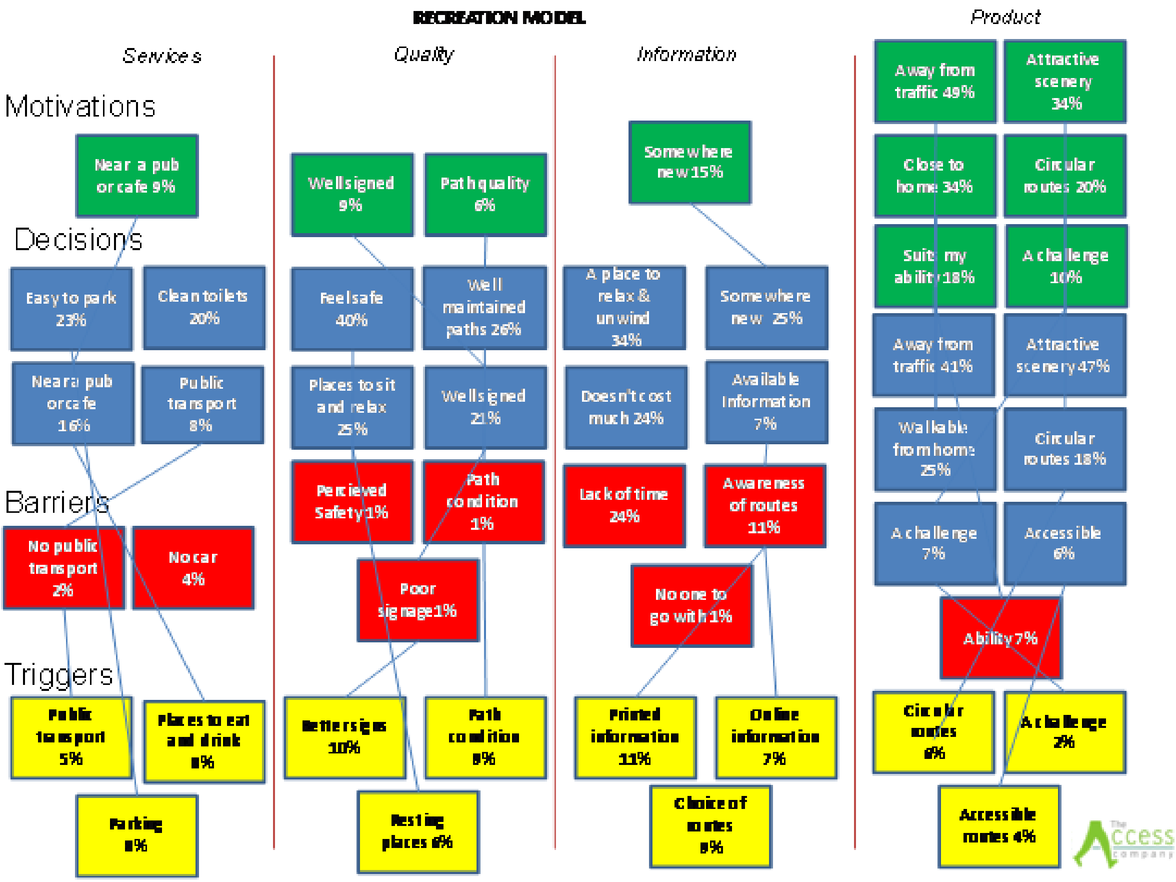
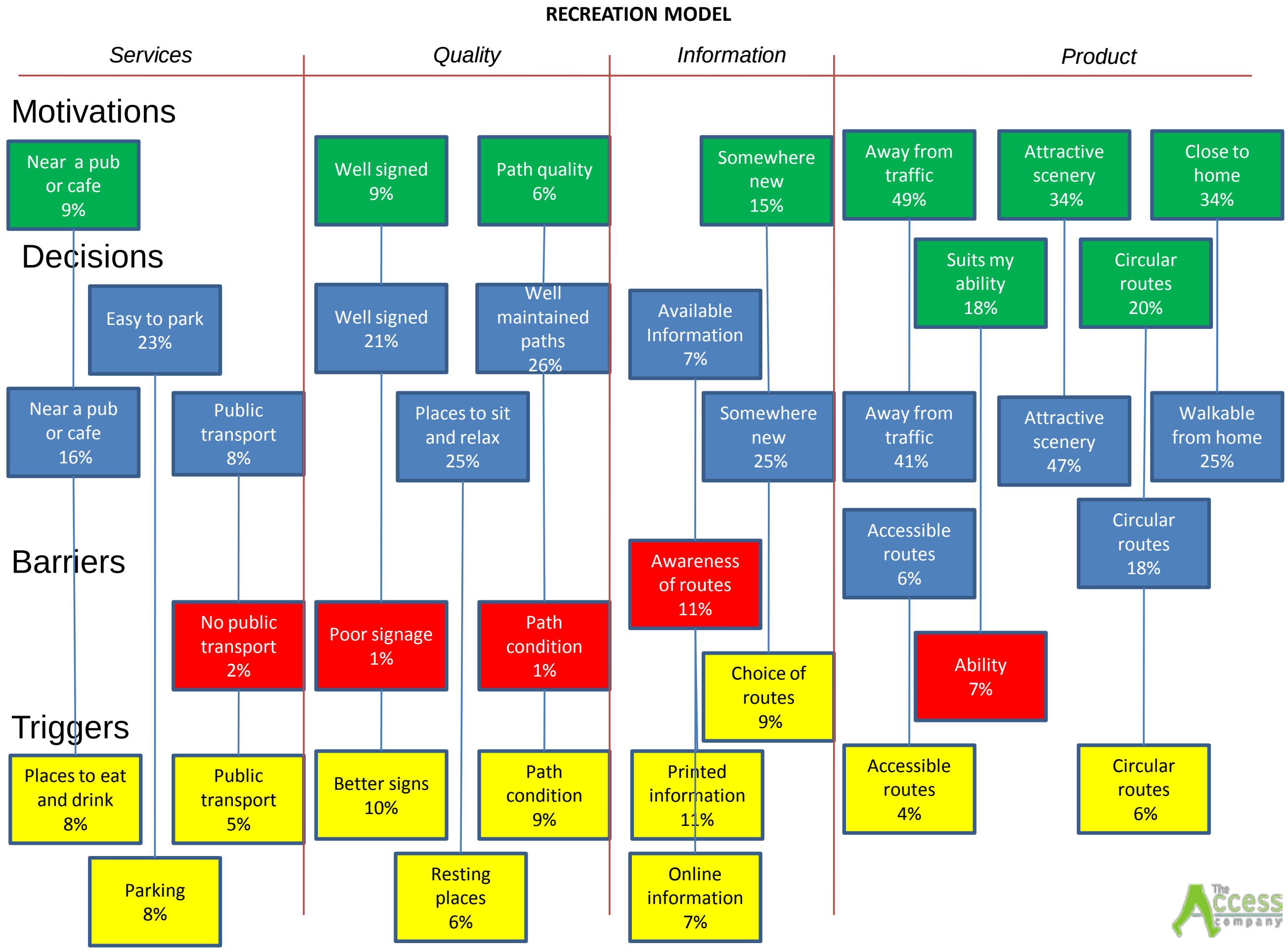


Figure 4 has further categorised need vertically therefore, as well as horizontally, using the headings of services, product, quality and informaiton as described in Figure 2. At this point the main motivation factors which make people want to go outdoors for recreation can be seen to be product related, despite the fact that 49% of people say information is the most important factor.

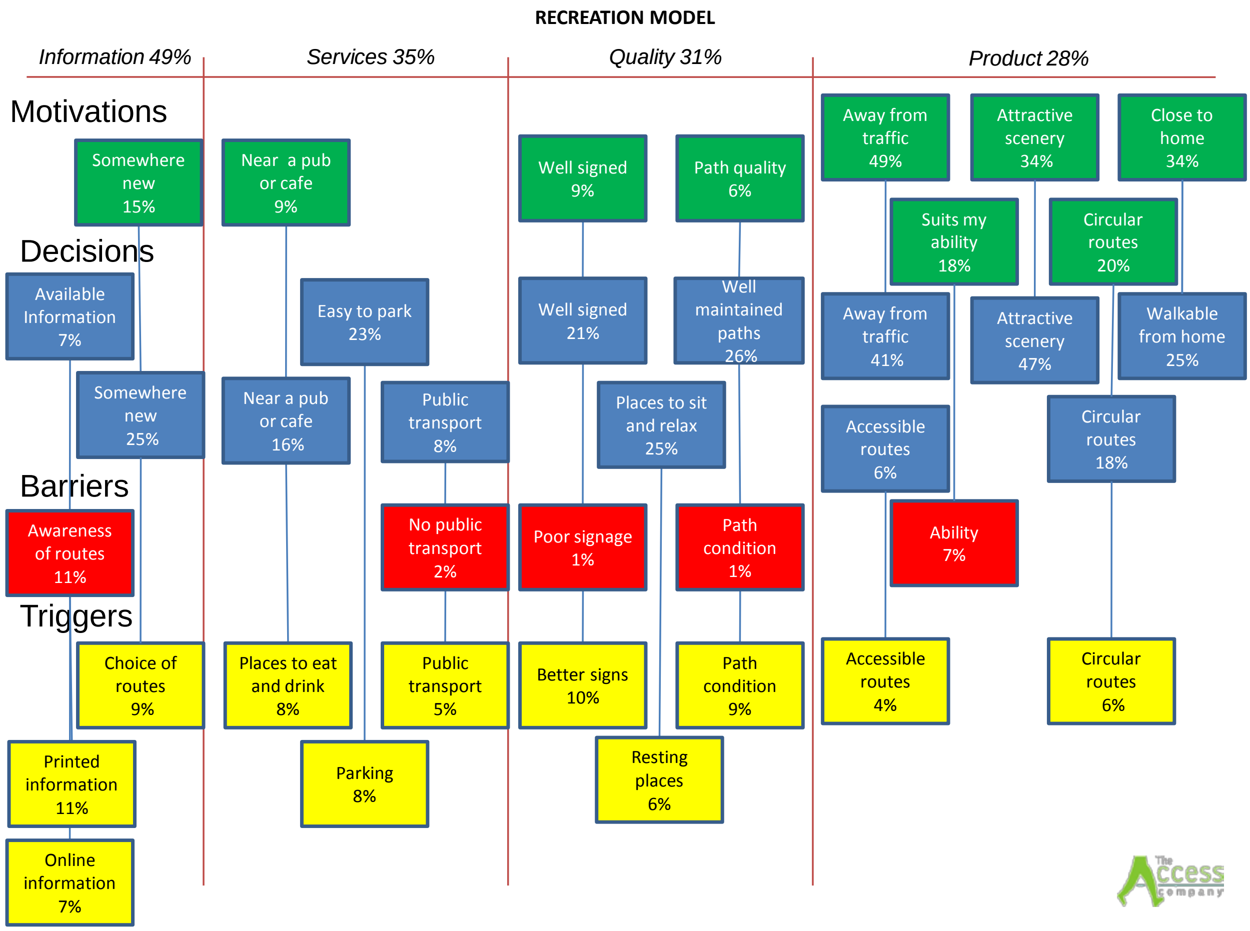
To simplify the relationships between factors we refined the model to produce Figure 5.

Figure 5 Recreation Model by area of need showing simplified connectivity in decision making



In this model we have refined the way direct relaionships are shown and removed less significant and issolated factors to help improve clarity and relevance of a systems based approach. For example, 'a lack of time' as a given barrier to participation cannot be altered by any outside influence, and has no relationship to any of the motivtaions or decision making factors, so has been removed.

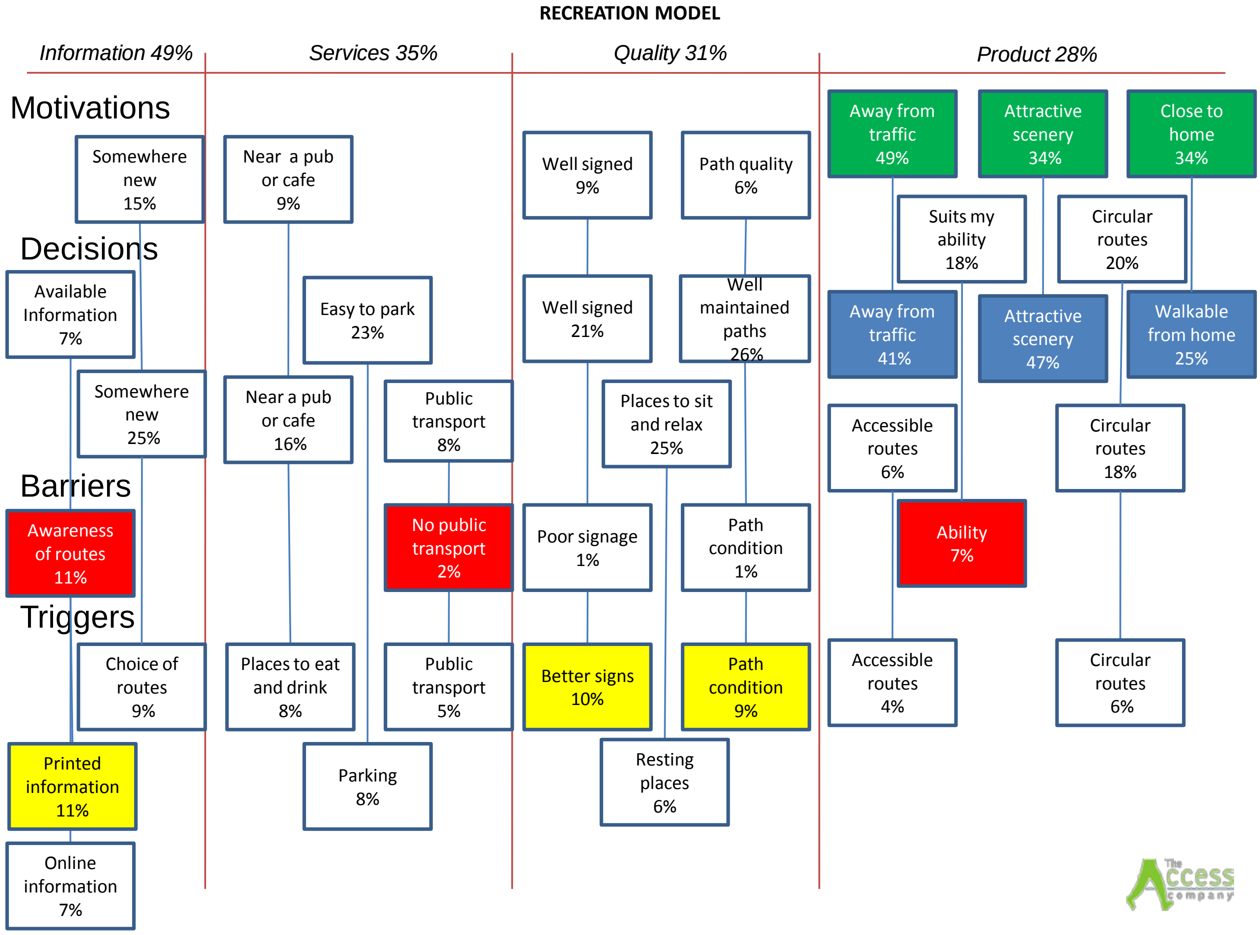
Figure 6 Recreation Model by area showing relative priority



In Figure 6 we rearranged the columns in order of significance so that the system can be read from left to right based on given values of significance. However again it is clear that the system favours the importance of the product in the complexity of the relevant factors despite the values given to information.

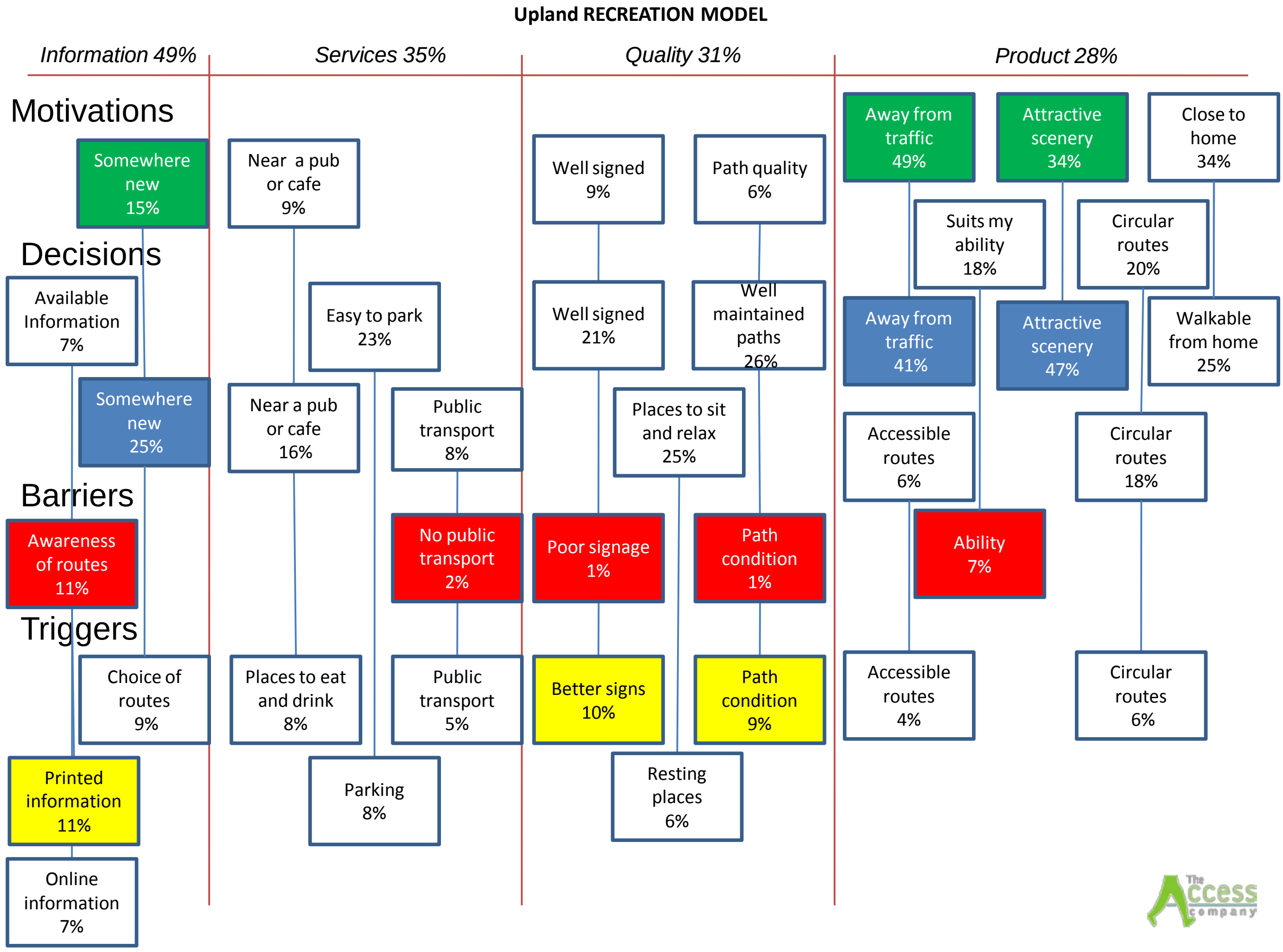
In Figure 7 the recreation model has been redrawn to show the most important relative values at a national level.

Figure7. The most important given values influencing recreation participation



Despite an extensive search no reliable information appears to exist for informing the adaptation of the national recreation data to Upland ecosystems. In an attempt to adapt it ourselves however Figure 8 amends the model to demonstrate the factors which are most important for upland recreation.

Figure 8 Recreation Model adjusted for upland values showing relative importance



The Upland model adaptation has assumed that not many people live in upland areas (and therefore they are not as readily accessible) and that upland areas are inherently traffic free and attractive. From previous marketing work their attractiveness includes a sense of space, big skies and views of horizons but more detailed work would be needed to understand more specific adaptation of the recreation system model to upland (or any other) landscape area.

Interestingly the dominant importance of the product in all these models appears to contradict Curry (2008)[14] who argues that the supply side is not a key factor in outdoor recreation. We would however agree with him that the consumer preference is a vital factor, and that the wide availability of other recreation pursuits has resulted in a decline in the number of people participating in outdoor recreation

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[14] Curry, N.R. (2008): Leisure in the landscape: rural incomes and public benefits.

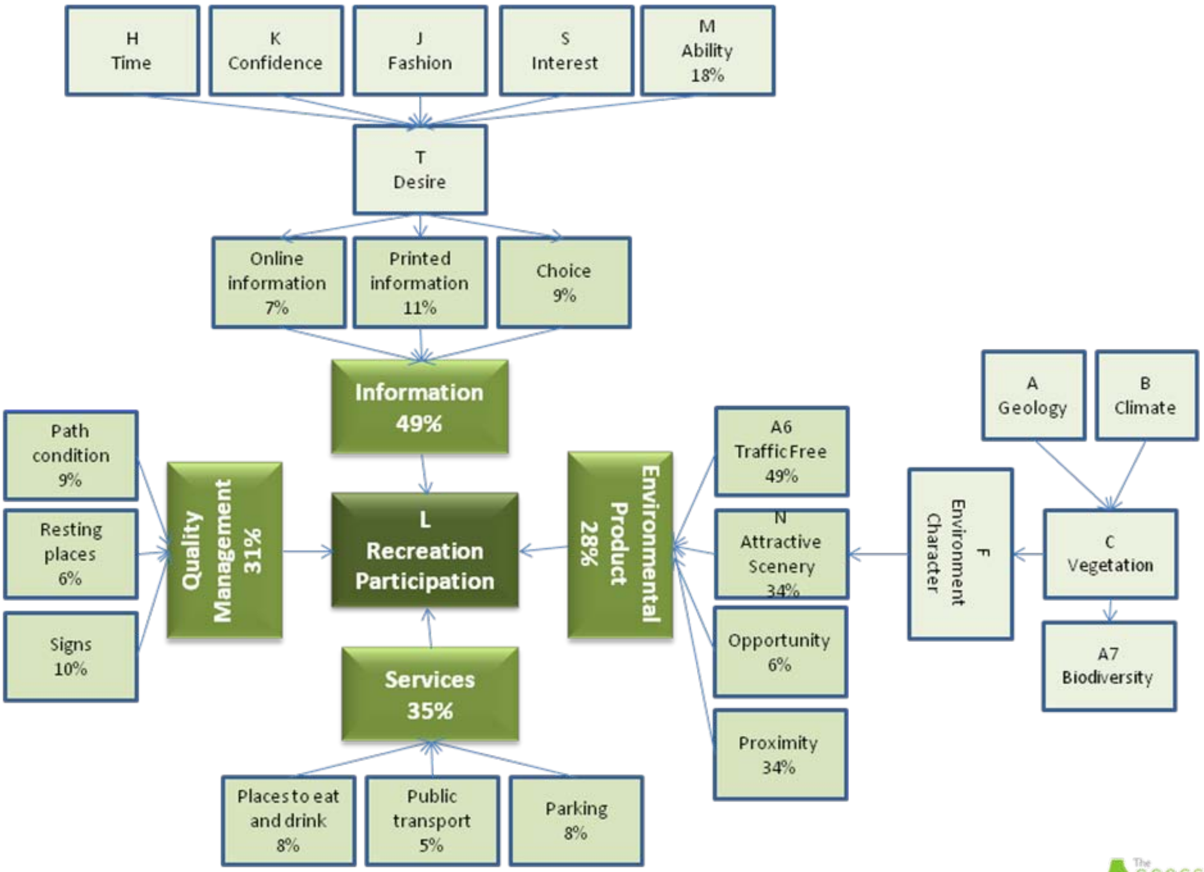
Drivers of environmental change in uplands (eds Bonn, A., Allott, T.E.H.,

Hubacek, K. & Stewart, J.). Routledge, in press.

To relate this evidence base to the given Upland model we reviewed the given factors and assumptions categorising them to where we had a confident anchor to data.

The same letters for individual factors are used in Figure 9 as those used originally in Figures 4.2 and 4.3.

Figure 9 Recreation Participation Model



The values given in this model, from the same source data, identify that 35% of people need supporting services and facilities to be available before deciding to visit an area and that of all the different types of services 8% of people want places to eat and drink and a place to park and 5% need connecting public transport. 28% of people overall are influenced by the nature of the environment/the product and in particular 49% of people are looking for traffic free recreation experiences, 34% in attractive landscapes and for 34% of people the fact that these experiences are within 30 minutes of home is important. The quality of the management is important to 31% of people – most significantly 10% of people want to know that there are signs, 9% good paths and 6% rest areas. Having the right information at the right time and in the right place is recognised by 49% of people as the most key factor to recreation participation.

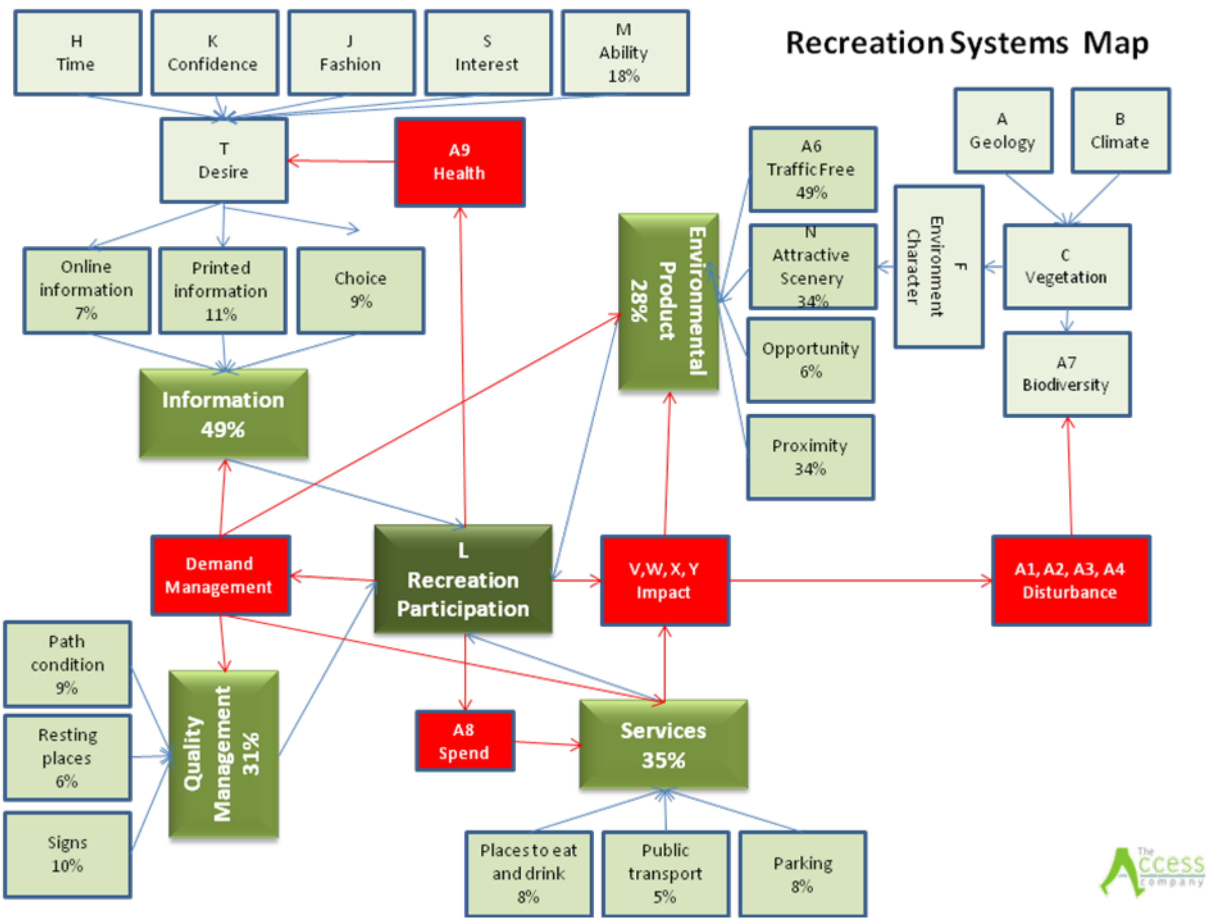
We are confident that a relationship between geology and climate, which in turn influence vegetation, biodiversity and environmental character, can all integrate with the model to help define the attractiveness of a landscape without necessarily attributing a value to these elements at this stage.

Furthermore there is logic that informing an individual's choice of where to go and what to do is their own ability, the amount of time that they allow for such activities, the influence of fashion and culture, their own levels of interest and confidence. We have annotated these elements to the model, again without known values, to connect to information.

Clearly upland landscapes could be seen as attractive and inviting to some and potentially threatening and unappealing to others - this data isn't known but it is our estimate that upland landscapes will appeal to approximately 6% of the population although less than 4% will feel confident enough to choose to take part in recreation there.

In an attempt to extend our confidence with the recreation system model in one final diagram we have attempted to illustrate the outcome relationships of recreation participation in Figure 10.

Figure 10 The outcome relationship of Recreation participation



Uncomfortable that the original model suggested only negative impacts from recreation participation we have identified 5 outcome categories for the recreation model. These include health, spend, demand management, impact and disturbance. Disturbance and impact identify the same 8 annotated variables from Figure 4.2 in the Upland Report model and can be seen to have a relationship to several areas of the participation model. In detail disturbance is logically an outcome of impact but impact can be either direct from visitors or indirect as a consequence of the facilities and services provided for them and used as part of the experience.

It is relatively easy to appreciate the relationship between participation and an individual's health both in terms of their mental and physical well being. Overtime these can influence a desire to want to participate more (or less).

The economic activity is illustrated in the model as neither a cost nor benefit but a recognised factor that has a clear influence on the level of services provided.

To explain the more complex variable labelled 'demand management' in the model by this we mean that recreation participation itself can create a demand for more management, more provision of information and services and a better quality product/environment in a demand/supply model.

We have no evidence to add more detailed values at either a national level or for upland recreation specifically to adapt Figure 10 in any more detail but believe that this makes a significant contribution to understanding the factors and relationships between them which impact recreation participation and the outcomes of such actions too.

Section 2 The nature and strength of the relationships between factors

We agree however with the basic principles underlying the systems map in Figure 4.1, that there are few measurable outputs relating to recreation, and that participation rates and health benefits are the most important and most useful measures.

The report states that "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 whatever 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." We equally found that fitting our knowledge of recreation to the model was difficult due in part to the varied nature of humanity – and to the different preferences and drivers of different groups.

Tranquil and attractive areas for example are known to attract people, generally speaking but we have no evidence to say what is 'attractive' – we do not know if people prefer managed heather moorland, or rough limestone grassland, or woodland as each of these may appeal to some people and not to others. Therefore a change in land management such as planting woodland may result in an increase in use for some people, and decrease for others. We know many of the people who choose upland for recreation do so because of their 'wilderness' qualities, and these people like the low level of recreation management, with unsurfaced paths and sparse signage – the very things that deter other from going there.

The systems-map (Figure 4.1) 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).

Despite this model being a simplified one used a basis for more detailed work we felt it did not represent our understanding of upland recreation. We divided the model into 4 sections relating to participation, transport, disturbance and biodiversity. We concentrated our attention on the participation side, as there is little or no evidence to support the others.

The section we categorised as 'biodiversity' includes nodes B, D, A, E, F & A7. While it is clear that climate, vegetation, geology, and management impact on the upland environment type, and the biodiversity interest it is not clear how these affect or are affected by recreation. The model implies that recreation leads to disturbance (nodes A1, A2, A3, A4) all of which are negative factors. We would argue that recreation in the upland is not necessarily at the detriment of biodiversity, for example there is anecdotal evidence to suggest that areas with high levels of recreation are less prone to serious fire damage than those with fewer visitors as people are more likely to spot and report or tackle small fires before they spread. In addition there are benefits of recreation to upland areas which are not shown in the model, for example, the income from visitors which comes as a direct result of their presence is of particular importance to remote rural areas, as was demonstrated in the foot and mouth crisis. This is represented figure 4.1 in node A8, but this does not link to anything. We believe there are links between the financial benefits of recreation and biodiversity , often though grant payments to improve the management of areas as a result of, or in part because of, the number of people using them. A good example is the Moors for the Future project which would not have received funding if the area was not so well visited, other examples include the large areas of upland owned and managed by the National Trust – again this would not happen if no-one visited them. Resources are also allocated to areas adjacent to upland routes, an example being the Pennine Way National Trail which has received millions of pounds to restore the damage caused by erosion (caused by recreation and overgrazing), money which has been spent on the path and on restoration of the moorland vegetation, but has also lead to the develop of moorland management techniques, and raised awareness of contributory factors such as grazing pressure.

The third section of Figure 4.1 covers transport (nodes V, Z, Y, W, X). Again it is not clear how these factors relate to recreation. There will be an inevitable impact of people accessing upland areas, the majority doing so by car, which will impact on tranquillity. A key element which appears to be missing from the model is the impact of demand management, which is used to mitigate the impact of visitors, and again can bring about financial and other benefits through car park revenue, or for example through tourist use of locals services to keep them viable.

The participation side of the model is the area where we concentrated our efforts.

The following paragraphs look at the relevance and significance of each node in turn :

Node C - increasing affluence. The relationship between increasing affluence and outdoor recreation is not clear. Whist increasing affluence opens more opportunities for travel and alternative recreation opportunities, there is also a relationship between increasing affluence and increased leisure time. Many people who now spend their main holiday abroad have short breaks and weekend trips to the countryside – the growth in people Munroe bagging, or climbing the British 2000s is a good example of this phenomenon.

Node G – Demographics. There are clear links between demographics and recreation, the general perception is that people walking or taking other forms of recreation are more likely to be older, often fit retired couples. However our research shows that all age and social groups participate in outdoor recreation.

Table 1 – Demographic profile of walking, cycling and horse riding participants (%)

Base: All respondents

	Adult Population %	Leisure walkers %	Dog walkers %	Off-road cyclists/ MTB %	Horse riders %
Sex					
Male	**48**	46	42	62	30
Female	**52**	54	58	38	70
Age					
16-34	**32**	28	31	42	60
35-54	**35**	40	41	47	30
55+	**33**	31	28	10	9
Socio-economic Group					
ABC1	**57**	61	58	69	71
C2DE	**43**	39	42	31	29
Children in household					
Yes	**31**	32	31	43	44
No	**69**	68	69	57	56
Area of residence					
Urban	**85**	83	79	81	82
Rural	**15**	17	21	19	18

Notable variations in these profiles include the following:

- *Leisure walkers* – compared to the population in general, slightly more likely to be aged 35 to 54 and in the ABC1 socio-economic groups;
- *Dog walkers* – a similar demographic profile to the population as a whole but slightly more likely to live in a rural area;
- *Off-road cyclists/ mountain bikers* – more likely to be males, aged under 55 and in the ABC1 socio-economic groups;
- *Horse riders* – more likely to be females, aged 16 to 34 and in the ABC1 socio-economic groups.

The graph shown earlier in Figure 1 illustrated the relative market sizes for 17 market segments nationally and clearly demonstrated that all types of people are both frequent (orange bands - ie once a week or more) and infrequent (red bands - ie less than once a month) recreation participants. While wealthy executives and affluent greys are significant users as would be expected, families are also significant users of routes, and all sectors have some people participating in outdoor recreation. It should be remembered that the data is specifically for walking and at a national level so while we feel it is helpful to be informed and to apply this evidence to this modelling our confidence to a specific upland model at this stage is poor without further research.

There is a lack of similar research for the uplands, although some visitor research is carried out by the Moors for the Future project and a small number of other organisations this tends to be carried out on-site. We are not aware of any surveys carried out to determine what the general population think of the uplands, and to investigate how they use them.

Node H – time available. When asked why they haven't used a recreational route in the past 12 months 24% of respondents said they didn't have time. Lack of time is a factor in participation, but equally people who really want to go will make time. While time is obviously a factor for some we felt it was not a useful factor to use in the model as it is completely outside of the control of anyone – altering model to see what would happen if there was more time might be an interesting academic exercise, but in reality we cannot make more time, and even if everyone had more time they may well choose to use it in a different way.

Node J – Fashion and technology. We are aware from research over the last 20 years that 'the outdoors' is a marketable commodity and as such an industry of clothing and equipment manufacturers have built a fashion desire which they sell to fulfil. Few people market 'the uplands' as such we feel that few people would find them easy to locate, describe or name however the drive for more 'out of the way' places, where people can 'get away from it all' is increasingly fashionable and likely to be an important factor in favour of the Upland model at this particular time.

Node K – confidence and knowledge. This factor is important in upland recreation, many people do not feel confident about their own abilities and are reluctant to enter a potentially hostile environment which they are unfamiliar with. Messages about mountain safety reinforce these feelings. Reasons given for not using promoted routes include 'not suited to my ability' and 'too challenging', however the converse is also true as when asked what would make people use routes more often people said 'more remote, more challenging routes' as well as 'more routes suited to my ability', and 'more circular routes'. This is an aspect which can be altered through management – friendly welcoming signage can be used to encourage less confident visitors where appropriate, although this is likely to have the effect of deterring the more experienced users.

Node M – accessibility. Accessibility can mean many things – from how easy the site is to reach by car or by public transport (being 'close to home' is a key factor in where people choose to go), as well as how accessible the route is, relating to how good the surface is, the quality and design of countryside furniture etc. This factor relates to our work as we have evidence that being close to home is important, being 'easily accessible' is however a vital determinant for the 40% of the population limited by some personal ability or that of someone they care for such as small children or the elderly.

For many people the uplands are not seen as 'accessible' in any form, with a range of real and perceived barriers including the physical distance for where people live and the difficulties of getting there by any means other than the private car, but more significantly the fear of getting lost, lack of confidence of where to go and fear of not being fit or experienced enough act as barriers to many. Work has been done in both Scotland[15] and Wales[16] to increase the accessibility of National Nature Reserves (NNRs) through detailed access auditing, and site improvements, and through provision of clear information on the limitations, and attractions, of each site. However despite this valuable work the geography, gradient and remoteness serve as a real barrier to many people. We are not aware of any follow-on research which has been carried out to see if more people are visiting NNRs in these 2 countries.

Section 3 - Key Conclusions

The recreation model is heavily influenced by the complexity of different people demanding different recreational experiences from different environments. The interrelationship of these variables has only just started to be looked at nationally by Natural England in recent months and though interesting and revealing cannot yet be relied upon to provide definitive evidence for a specific and detailed national landscape modelling tool. It is recommended however that further market research is commissioned to focus on the values of upland landscapes and the specific recreational factors which interrelate to influence the local environment. This contract should be

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[15] The Access Company working for Scottish Natural Heritage, internal reports published 2006/7

[16] The Access Company working with the Countryside Council for Wales, internal report published 2007

considered as part of a wider contract exploring other landscapes at the same time to improve the value of the research investment.

The quality, tranquillity and general attractiveness of the landscape is undoubtedly key to people's recreation participation. Being able to predict where these places are or getting accurate and reliable information on such values however is seen as both difficult and confusing nationally. It is likely that Upland areas, which are well serviced by public transport and food and drink places, that are looked after by local managers to a consistent high standard and which are away from traffic and accessible from nearby cities are going to be popular and have the most potential to become even more popular in the future. We are not sure what percentage of upland areas could be categorised as such (estimate 15%) but recommend that this exercise is considered as a follow up phase of work.

Recreational participation has the potential to negatively impact on the quality of the experience that attracted people there in the first place if the values understood (and to a degree assumed at this stage) in the model are not secured and managed. Decisions to allow road widening for instance to accommodate more visitors will clearly have a negative impact on peoples demand for areas away from traffic and decisions to drain, plant or fence upland areas could potentially take away from their current attractiveness. Understanding the values behind recreation behaviour (and participation) in more detail therefore is paramount and could allow positive management choices which benefit both visitors and the environment. A community attracted by the tranquillity of an upland area for instance has every possibility of being made more aware of a wider biodiversity which in turn may stimulate a secondary interest in bird watching for example and a greater respect and concern for the environment.

It is not clear from the model what the estimated capacity issues are for certain landscape choices if they have been estimated in relation to management decisions, visitor numbers etc but this might be a useful piece of follow up work. In other landscape areas their recognition and appreciation by a loyal community of supporters has proven useful if not necessary to ensure their status is maintained and secured. A valued landscape needs to be defined and the threat understood and made treatable with the right support.

The Upland recreation model work has the potential to evolve the traditional 'man and environmental impact' systems have been used for the best part of 30 years to oversimplify land management decisions with too little consideration as to the consequences on those who live in, visit and value the landscape. Understanding people, their behaviour and influences is not a neat science to easily be accommodated but the commitment to explore it being led by Natural England and this team and their support for an evidence based approach means that there is every potential for more sustainable and successful integrated landscape management model in the future.