Environment Agency

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Land use and environmental services

Resource Efficiency science programme
Science report: SC080014/SR1

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It's our job to make sure that air, land and water are looked after by everyone in today's society, so that tomorrow's generations inherit a cleaner, healthier world.

Our work includes tackling flooding and pollution incidents, reducing industry's impacts on the environment, cleaning up rivers, coastal waters and contaminated land, and improving wildlife habitats.

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- **Delivering information, advice, tools and techniques**, by making appropriate products available to our policy and operations staff.

Steve Killeen

Head of Science

Executive Summary

Introduction

This study has been conducted by Land Use Consultants (LUC) with GHK Consulting (GHK) for the Environment Agency (Project SC080014).

Within the context of an 'ecosystem approach', the study looked at the interaction between land use and four environmental services[1] of most relevance to the Environment Agency. These services are:

- regulation of water quality
- availability of water resources
- management of flood risk
- storage of carbon in soils

This study's primary purpose was to contribute evidence to the Environment Agency's policy on strategic land use across England and Wales. It focused on the overlaying of a large number of national spatial datasets supported by a review of research to understand the effects of land use and management on these services, singly and in combination, now and in the future. It took account of the implications of climate change, increasing development pressure and population growth and their combined implications for future land use and demands on natural resources.

The study draws large-scale strategic conclusions. It considers the types and scales of change to land use and management that will be required (up to 2020) to make major improvements in the condition of the services covered by the study.

Research method

The study mapped the current state of each service against defined environmental limits[2]; it analysed their relationship with land use and management[3]; and described the changes in land use required to ensure delivery of these services within the defined limits, taking account of future drivers of change.

Key findings on the state of the four environmental services across England and Wales

Regulation of water quality. Compliance monitoring under the Water Framework Directive (WFD) shows that 18 per cent of rivers are assessed to be in high or good ecological condition, 61 per cent in moderate condition and 21 per cent in poor or bad condition. Land use, and particularly land management activities, are a primary determinant of water quality, with diffuse pollution from urban areas and arable and intensive grassland farming a significant cause of poor ecological quality in rivers.

Compliance monitoring data for the chemical status of groundwater shows that 59 per cent of groundwater areas are classified as good status and 41 per cent are classified as poor status. The relationship between land use and groundwater quality is less

[1] Environmental services are the goods and services provided to, and valued by, society by natural systems. The term environmental services is closely related to, and in most cases synonymous with, that of ecosystem services but is preferred for this study because it is more inclusive.

[2] Environmental limit is defined as the level of delivery of an environmental service that is judged by policy makers to be the critical point beyond which any reduction in the service would be unacceptable or intolerable (see Haines-Young *et al*., 2006).

[3] The study distinguished between *land use*, which describes what land is used for, based on broad categories of functional land cover such as urban and industrial use and the different types of agriculture and forestry, and *land management*, which describes how land is used, based on different types of activity taking place within each category of land use.

clear because of the size of groundwater areas and the time lag between changes in land use and the response of the chemical status of groundwater.

Availability of water resources. The Environment Agency's assessment of the pressures and risks from abstraction on surface and groundwaters (compiled for the WFD) shows that around 15 per cent of surface water catchments and 21 per cent of groundwaters are considered to be at high or moderate risk of over-abstraction leading to low river flows. Land use and management is only one factor in the availability of water resources with rainfall patterns, drainage systems, the location of aquifers, and distribution of water demand all critical factors. Demand for water by households and businesses will grow with climate change and population growth, as will the need for farm irrigation especially in eastern England.

Management of flood risk. The study assessed flood risk at two levels: (a) the generation of floods from surface run-off of water across catchments as a whole, which leads to (b) the propagation of floods within river channels and across floodplains.

The concept of an environmental limit for flood risk is complex and there is no data in England and Wales that allows this to be mapped. However, the Environment Agency's sensitive catchment study suggests that areas of highest sensitivity for generation of surface water run-off are in Wales and western parts of England where rainfall levels are highest and, at a more local scale, on steep slopes. The Environment Agency's Flood Map identifies areas at risk of river and marine flooding, a situation that will worsen with climate change. The map shows that major areas on the east coast of England at risk of coastal flooding, while all major rivers in England and Wales have substantial floodplains in their middle and lower reaches.

While land use and management have a major influence on surface water run-off and flooding at a local scale, there is currently insufficient evidence to demonstrate this at a large catchment scale. Nevertheless, at the local scale there is a case for targeting land use and management to increase water infiltration, store flood waters, and reduce the speed of peak flood flows.

Storage of soil carbon. There is currently no fine-grained spatial data to measure levels of carbon flux in the soil, and therefore no way of mapping an environmental limit for soil carbon losses and gains. The study used data on the percentage of carbon in the first horizon of dominant soil types to map those areas of peat and organo-mineral soils with most soil carbon. Knowledge about the natural cycles of carbon flux in soils and the impact of different land uses and management on it is relatively weak, although land uses and activities (such as land drainage) that are detrimental to the conservation of peat soils are well known.

Key findings on the impacts of the main land use types

The study used the classification of major land uses used by the Centre for Ecology and Hydrology's Land Cover Map as follows:

Developed land covers only eight per cent of England and Wales but has the highest intensity of land use and high potential impact on services. It can be a major source of diffuse and point source pollution; public water supply is responsible for half of water abstraction from non-tidal waters; many urban areas are built within the floodplain and the high proportion of impermeable surfaces leads to rapid run-off which can exacerbate flooding downstream. The area of developed land is set to increase in the future.

Arable and horticultural cropping covers 27 per cent of England and Wales and can have adverse effects on all four services. Fertilisers and pesticides are major sources of diffuse pollution; though less than one per cent of total water abstraction is currently used for crop irrigation, areas of highest irrigation are in areas of lowest rainfall; surface water run-off is high with a combination of land drainage, low levels of soil organic matter, and soil compaction while the past removal of the best quality arable land from the functional floodplain has increased the risk of flooding downstream. Furthermore, the use of peat in the horticultural industry combined with arable and horticultural cropping over peat soils, result in very high levels of carbon loss.

Improved grassland covers 24 per cent of England and Wales, dominating wetter western areas. Nitrate and pesticide use are less than under arable but spreading of animal manure and slurry, use of sheep dip and leaching of nitrogen from ploughed grassland are diffuse sources of pollution. Water infiltration on permanent grassland can be high, aiding aquifer recharge and reducing surface run-off, except where high densities of grazing animals compact soils. As for arable, many areas of improved grassland have been removed from the functional floodplain through land drainage schemes. Soil carbon levels are usually higher than for arable but less than for semi-natural habitats including woodland.

Semi-natural grassland accounts for 16 per cent of England and Wales and occurs in large parts of the uplands and on small areas of less productive land in the lowlands. Where grazing densities are low and land is not artificially drained, this land use can contribute positively to the four services. It also contributes to other environmental services, particularly biodiversity and landscape quality.

Woodland covers nine per cent of the land area of England and Wales, with half of this being broadleaf, a third conifer, and the remainder mixed woodland. Woodland soils are generally undisturbed (except during commercial forestry operations). Woodlands, especially, broadleaved woodlands, can be a positive contributor to the four services, particularly water quality, flood risk management and soil carbon, and also to biodiversity and landscape quality. However, the high levels of water interception and evapotranspiration of trees can negatively impact water resource availability and the retention of carbon in wetland soils.

Dwarf shrub heath, fen, marsh and bog cover five per cent of the land area of England and 10 per cent of Wales and are primarily accounted for by the open moorlands of the uplands. Where these habitats are in good condition and have not suffered from overgrazing, they can make a vital contribution to all the services identified in this study, especially that of carbon storage. They have high value for biodiversity, contribute strongly to landscape quality and are often associated with rich historic landscapes. However, degraded areas of dwarf shrub heath and blanket bog (resulting from overgrazing, excessive burning or drainage) can pose a risk to water quality and the storage of water and soil carbon.

Conclusions of this study

A critical issue for land use policy is the extent to which targeted spatial interventions can deliver multiple benefits, addressing failures in more than one environmental service. Our analysis shows great potential for this. Nearly a third of England and Wales (30 per cent) is affected by the failure of, or challenges to, two or more of the services considered here. In these areas, changes in land use/management could achieve multiple outcomes. 'Hotspots' include many upland areas such as the Pennines and Snowdonia, as well as lowland areas such as the southern part of the Fens and the North Downs. There is a striking coincidence between many of these 'hotspots' and designated conservation areas – indicating their potential to deliver these services, but also the current levels of environmental stress they are under.

Regions such as the South East, that face the greatest challenge from climate change and population growth, already have extensive areas identified as having multiple priorities for intervention.

A. Concept of ecosystem services and use of environmental limits

The concept of ecosystem goods and services is highly relevant to core areas of the Environment Agency's work. This study shows that, where good spatial data exists (such as for water quality and resource availability), mapping current services against defined environmental limits offers a useful way of identifying areas where land use/management interventions must be targeted.

The use of the concept of ecosystem services, incorporating environmental limits as an objective methodology, can assist the development of the Environment Agency's integrated policy on land use, and will provide a common platform of evidence for comparison with the work of other national agencies.

B. Hierarchy of land uses affecting services
If the combined impacts of different land use types are viewed as a whole, it is possible to rank those that have the most adverse to the most positive effects on services. Developed land produces the most pressures and risks for services, followed by arable and horticultural cropping and improved grassland management. Conversely, dwarf shrub heath, fen marsh and bog can have the most beneficial effects on services (but see below), followed by woodland and semi-natural grassland.

However, this does not mean that developed land inevitably leads to failures in service delivery, nor that dwarf shrub heath is free from the risk of negative impacts. The way these are managed is critical, with management activities such as land drainage, overgrazing and poor targeting of agricultural inputs at risk of having negative impacts.

C. Policy interventions in land use and management
There are three categories of policy response based on the hierarchy of land uses. **Firstly**, in a few circumstances failure in a single service justifies large-scale land use intervention. These include replacing arable and horticultural cropping on peat soils with wet grassland or fen to halt the loss of soil carbon; and preventing urban or industrial development on flood and coastal plains. This study finds no evidence that changes across entire landscapes or regions are necessary to correct failures in individual services. But there is a need for targeted remedial action. Indeed, changes in land management are critical if changes in land use are to be avoided.

Secondly, there are a greater number of circumstances where the combination of benefits that can be achieved by a change in land use can warrant this change. For instance, replacing arable or intensive grassland with low input extensively grazed grassland can improve water quality, increase levels of aquifer recharge and attenuate flood run-off, as well as enhancing biodiversity and landscape quality and protecting buried archaeology. Such a change may be appropriate over many of the chalk and sandstone aquifers essential for public water supply, many of which already show signs of poor water quality, lack of resource availability and a sensitivity to flood generation.

Thirdly, many small-scale changes in land use and management are necessary to correct or help overcome failures in one or more services. These include the use of sustainable drainage systems (SUDS) to reduce the run-off of poor quality water from developed land, and the use of cross-contour buffer strips and appropriate soil cultivation techniques on arable and horticultural crops to reduce surface water run-off and diffuse pollution of water courses.

D. Importance of spatial targeting
If changes in land use or management are to benefit several services at the same time, it is essential that the location is carefully targeted. This requires knowledge of the pressures and responses of services at a fine spatial scale, with a means of making these interventions in the best locations. This involves engagement with land owners and managers to ensure measures are adopted where they will do most good.

E. How drivers of change will influence future service delivery
The next ten years and beyond will see increased pressure on ecosystem services. In many areas, policy interventions to correct current failures in services will need to become increasingly robust to overcome these growing negative influences.

F. Value of improvements to services

This study sets out a method for estimating the economic benefits of correcting failures in the four services covered here. While it has not proved possible, at a sufficient level of confidence, to calculate these values, qualitative assessments of the relative merits of intervention can be made. Targeted interventions to address surface water quality, flood risk and soil carbon will generate greater economic benefits than those for groundwater quality or provision of water resources. Interventions that improve more than one service will obviously be more cost-effective than those that address only one service.

G. Strategic approaches for delivering multiple benefits

This study shows the benefits of an integrated approach to land use policy. It requires mechanisms that recognise the synergies that are achievable through targeted interventions in land use and management.

In undertaking the Environment Agency's work on River Basin Management Plans and other measures, it is essential that full account is taken of the impacts of these activities on other policy domains and environmental services.

The two principal means by which public objectives for land use and management are delivered are the planning system (for developed land) and agri-environment and forestry schemes (for farmed and wooded land). Both of these already seek to address a range of environmental services but both will benefit from a greater understanding of the pressures facing the water environment and soil carbon.

The Environment Agency has an important role to play with its partners in advocating the use of environmental limits as an evidence-based approach to developing integrated land use policy. Furthermore, it will need to continue to work with its partners, particularly regional and local planning authorities (in relation to development control) and the Department for Environment, Food and Rural Affairs (Defra), Welsh Assembly Government, Natural England, Countryside Council for Wales and the Forestry Commission (in relation to agri-environment and forestry schemes) to ensure that the policies and programmes operated by these bodies are equipped to optimise the benefits to the suite of environmental services covered by the Environment Agency's remit.

Contents

1. Introduction

1.1. This is the final report of research commissioned by the Environment Agency and conducted by Land Use Consultants in association with GHK Consulting under contract SC080014.

Purpose

1.2. The overall aim of this study is to help develop a land use policy in England and Wales that:

- Resolves conflicts, identifies and respects environmental limits and maximises social, environmental and economic benefits from land at the same time.
- Recognises and values the delivery of environmental goods and services from land.

1.3. This study is an evidence review and analysis with the objectives of:

- Providing the evidence base for and to develop policy on strategic land use.
- Informing the land use debate and the future of land use policy.

1.4. The study covers the key environmental services provided by land that the Environment Agency has a responsibility for or considers a priority, and that are critical to the well-being of everyone in the UK. Based on a set of policy objectives - clean and adequate water supply, acceptable levels of flood risk and climate change mitigation - this study concentrates on the following key environmental services:

- regulation of water quality
- availability of water resources
- management of flood risk
- storage of carbon in soils

1.5. The study examines the functional and spatial relationships between these services, and their interactions with other environmental services, such as the conservation of biodiversity and landscape character and the provision of food and wood products. Most importantly, the study considers how land use and management influences the delivery of these services, in isolation and in combination. It considers the types and scale of changes to land use and management required (up to 2020 and beyond) to make improvements in these services.

Definition of terms

1.6. The following concepts are used throughout this report and are defined here.

Environmental services are the goods and services provided to, and valued by, society by natural systems, including both living ecosystems and natural resource cycles. The term ‘environmental services’ is preferred to that of ‘ecosystem services’ used by the Department for Environment, Food and Rural Affairs (Defra) and the Millennium Ecosystem Assessments as it acknowledges that many aspects of the natural environment, in addition to ecosystems, have the potential to provide goods and services vital for human survival and well-being. Nevertheless, the concept of environmental services is closely related to, and in most cases synonymous with, that of ecosystem services.

Environmental limit: This is the level of delivery of an environmental service that is judged by policy makers to be the critical point beyond which any reduction in the service would be unacceptable or intolerable. See paragraph 3.20 for definitions of the related concepts of environmental thresholds and environmental indicators.

Land use describes what land is used for, based on broad categories of functional land cover such as urban and industrial use and the different types of agriculture and forestry. The categories of land use used in this study are defined and described in Chapter 4.

Land management describes *how* land is used, based on different types of activity taking place within each category of land use. While this study is primarily concerned with the influence of land use on the delivery of environmental services, the way in which land is managed is often equally important, especially in terms of policy interventions aimed at landowners and managers. The relationship between land use and management is discussed in paragraphs 4.6 to 4.11.

Approaches to multi-functional land use

1.7. The Government places great importance on the natural environment, as set out in the Public Service Agreement (PSA 28) which details the Government's vision "*to secure a diverse, healthy and resilient natural environment, which provides the basis for everyone's well-being, health and prosperity now and in the future, and where the value of the services provided by the natural environment are reflected in decision-making."*

1.8. To secure a healthy natural environment, Defra aims to develop a more strategic approach and an integrated framework for policy-making and delivery. As part of this, further steps are being taken to embed an ecosystems approach in policy-making and delivery, based on a number of core principles set out in *Securing a healthy and natural environment: An action plan for embedding an ecosystems approach*[4]. The core principles set down in this plan are:

- Encourage a holistic approach to policy-making and delivery, with the focus on maintaining healthy ecosystems and ecosystem services.
- Ensure that the value of ecosystem services is fully reflected in decision-making.
- That environmental limits are respected in the context of sustainable development, taking into account ecosystem functioning.
- Encourage the use of decisions at the appropriate spatial scale while recognising the cumulative impacts of decisions.
- Promote adaptive management of the natural environment to respond to changing pressures, including climate change.

1.9. Defra has identified four benefits to policy development and delivery from following an ecosystem service approach. These are:

- More effective delivery of environmental outcomes.

[4] Defra (2007)d

- Better-informed decisions that take full account of environmental impact, helping the achievement of sustainable development.
- Better prioritisation and more efficient use of resources.
- More effective communications and greater awareness of the value of the natural environment and ecosystem services.

1.10. The benefits provided by environmental (or ecosystem) services range from the essentials for life, including clean air and water, food and fuel, to things that improve our quality of life and well-being, such as recreation and beautiful landscapes. They include natural processes, such as climate and flood regulation, that we often take for granted – and as is becoming increasingly clear with climate change, society damages these natural processes at its peril.

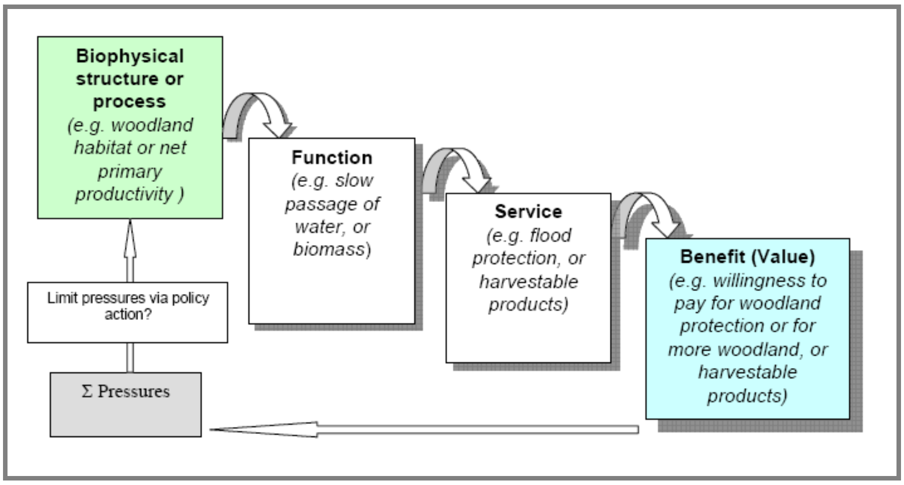
1.11. The Millennium Ecosystem Assessment (MA), which has been adopted in the Convention for Biological Diversity, developed a framework which groups environmental services into the four categories shown in Figure 1.1. The MA framework and its relationship to the services that lie within the Environment Agency's remit are covered in Chapter 3.

Figure 1.1: The Millennium Ecosystem Assessment framework.

Provisioning services	Regulating services	Cultural services
The products obtained from ecosystems such as food, fibre, fuel and water.	The benefits obtained from the regulation of ecosystem processes including carbon capture, air quality regulation, water regulation.	The non-material benefits that people obtain through spiritual enrichment, reflection, relaxation and aesthetic experiences.
Supporting services		
Such as nutrient cycling, oxygen production and soil formation. These underpin the 'provision' of all the other service categories.		

1.12. When considering the value that society places on environmental services, it is important to differentiate between services provided by natural systems, and the economic and social benefits that these generate. This relationship is shown in Figure 1.2 below.

Figure 1.2: The cascade from natural processes to human benefits implicit in the concept of ecosystem services[5].



[5] Diagram from: Haines Young *et al*. (2006)

2. Method

2.1. This research was conducted in four consecutive stages, as follows.

Stage A described the environmental services delivered by land use and identified the sources of data used to define the state, and environmental limit, of each of the four key environmental services.

Stage B quantified and mapped the current state of the four key services. This stage relied on existing GIS-based data using national datasets.

Stage C analysed future drivers of change affecting the four keys services and described the changes in land use required to ensure delivery of these services within defined limits. It examined the likely impacts of these land use changes on other environmental services.

Stage D reviewed the available evidence on which a headline economic valuation of the benefits of improved service delivery derived from land use change can be based. It also put forward estimates of the net economic benefit from society that can be achieved.

2.2. Fuller descriptions of key steps in the method, such as the selection of environmental limits are contained in the appropriate chapters in this report.

Project management and steering

2.3. The study was guided by a Steering Group of staff from the Environment Agency and partner organisations including Defra, Natural England and the Countryside Council for Wales. See the acknowledgements for the full list of Steering Group members.

Case studies

2.4. This research used two case study areas to provide finer-grained analysis of data on service delivery and land use than was possible at a national scale. This involved smaller scale analysis of national datasets (for instance increasing the resolution at which land cover data are distinguished); greater cross-comparison of datasets (for instance running detailed queries on the interaction between land use and water quality data at a finer spatial scale); and analysis of regional strategies and issues. The two case study areas are as follows.

2.5. ***The South East River Basin District.*** This provides an example of an area with:

- predominantly aquifer-based water resources;
- high levels of demand for water;
- projections for major increases in demand from new housing;
- relatively intensive agricultural land management with a high proportion of arable cropping and significant areas of horticulture;
- a length of coastline which is sinking and where parts are subject to inundation;
- some settlements with a relatively high level of flood risk;

- significant coverage of Sites of Special Scientific Interest (SSSIs) - such as chalk grassland and coastal marches, as well as the Rivers Test and Itchen and protected landscape (the proposed South Downs National Park and High Weald Area of Outstanding Natural Beauty (AONB)).

2.6. ***The Wye Catchment*** within the Severn River Basin District. This provides an example of an area with:

- predominantly surface-based water resources, particularly in the upper catchment;
- upland headwaters draining an area of deep peat that is in relatively poor condition (having been drained and overgrazed in parts);
- areas of conifer plantation exhibiting many of the problems associated with this land use (such as high levels of land drainage on steep soils, acidification of water);
- areas of relatively intensive livestock grazing (particularly sheep in upper catchment), again exhibiting many of the problems associated with this (such as soil compaction and erosion and diffuse pollution);
- areas in the mid-catchment with intensive cropping (particularly potatoes) on erodible soils, resulting in soil loss, increased flood risk and poor water quality;
- long lengths of river SSSI (the whole of the Wye and the Lugg, its major tributary), as well as covering parts of the Brecon Beacons National Park and Wye Valley Area of Outstanding Natural Beauty (AONB).

3. The selected environmental services and their environmental thresholds

Introduction

3.1. One of the overall objectives of this study was to "*critically examine the ecosystem approach and its relationship with the Environment Agency's areas of work*". In this study, the first task aimed to "*consider briefly how delivery of the [key ecosystem services that are the focus of this study] relate to the different types of land use policy and intervention, particularly in relation to the Environment Agency's areas of interest (for instance regulation, promotion of industry best practice, investment in infrastructure, etc)*".

3.2. This chapter:

- outlines the Environment Agency's remit;
- defines the four environmental services that are the principal focus of this study;
- considers the concept of environmental limits and how thresholds, limits and targets are used to assess the state of environmental services and to plan for policy interventions;
- considers each of the four environmental services in turn, examining the evidence on the state of each service, and selects the best environmental limit against which to consider the contribution that land use and management make to each service.

Environmental services in relation to the Environment Agency's remit

3.3. The Environment Agency was established under the Environment Act 1995, through which it adopted a wide range of powers and responsibilities from earlier legislation such as the Water Resources Act 1991 (water resource management), Land Drainage Act 1991 (flood defence), Water Act 1989 (navigation and harbour authorities), Control of Pollution Acts 1974 and 1989 and Environmental Protection Act 1990 (waste regulation).

3.4. Critically, the Environment Agency was given an overall duty, in relation to its statutory responsibilities and resources, "*to protect or enhance the environment, taken as a whole, as to make the contribution towards attaining the objective of achieving sustainable development*".[6]

3.5. The Environment Agency's corporate strategy *Creating a Better Place*, which covers the period 2006 to 2011, sets out its nine priorities. These are shown in Figure 3.1, and demonstrate the breadth of its remit.

[6] Environment Act 1995: Part 1, Chapter 1, Section 4.

Figure 3.1. The Environment Agency's corporate priorities.

Two over-riding goals:	• a better quality of life for people • an enhanced environment for wildlife
Three goals to protect and improve the environment:	• cleaner air for everyone • improved and protected inland and coastal waters • restored, protected land with healthy soils
Two goals to change the way people live and work:	• a greener business world • wiser sustainable use of natural resources
Two priorities to manage major risks to the environment:	• limiting and adapting to climate change • reducing flood risk

3.6. The Corporate Strategy also describes the roles that the Environment Agency will need to adopt to meet these priorities. These make clear that the Environment Agency acts as a regulator, an adviser, a communicator and, overall, as a champion of the environment to the Government in the context of sustainable development.

3.7. In the light of the last role, as a champion of the environment, the Environment Agency has an interest in the full range of environmental services. However, this study focuses on those services that relate to the Environment Agency's core remit as a regulator and adviser, particularly to the businesses and organisations responsible for land use and management. The policy areas that lie within this part of the remit are described below in Figure 3.2. In simplest terms, it is the protection and regulation of the natural resources of water, soil and air that are most central to the Environment Agency's work.

Figure 3.2. The Environment Agency's core responsibilities and policy areas.

- **Water quality in inland waterways and groundwater** – monitoring and enforcement of chemical and biological quality; advice and communication to reduce diffuse pollution, especially from agriculture.
- **Availability of water resources** – licensing of abstraction from rivers and groundwater, advice and communication on best practice (such as industrial and agricultural use).
- **Recreation on inland and coastal waters** - licensing of recreational fishing and boating.
- **Fisheries management** - the regulation of freshwater and marine fisheries.
- **Flood prevention and protection** – maintenance of flood defence structures and delivery of Defra's capital investment in flood defence. Work with Inland Drainage Boards on land drainage.
- **Climate change adaptation and mitigation** – advice and communication in relation to land and water use and management.
- **Industrial emissions to water, air and soil** (including noise pollution and contaminated land) – monitoring, enforcement and advice particularly to high risk sectors.
- **Biodiversity along rivers and in wetlands** – licensing of pesticide use and control of invasive species (regulation, advice and communication), as well as more general advice on enhancing water-dependent biodiversity
- **Resource efficiency, waste management and disposal by businesses** – regulation of hazardous wastes and advice and communication on best practice.

The key environmental services for this study

3.8. As noted in paragraph 1.4 the four environmental services considered by this study are:

- regulation of water quality
- availability of water resources
- management of flood risk
- storage of carbon in soils

3.9. Following the MA framework (paragraph 1.11) for ecosystem services, these four services are covered by: (a) the provision of fresh water (a provisioning service); (b) water regulation; (c) water purification (both regulating services); and (d) climate regulation (a further regulating service)[7]. The descriptions of these services based on the MA but modified by Defra are shown in Figure 3.3.

Figure 3.3. Description of MA ecosystem services most relevant to this study.

Service	Description
Fresh water *(a provisioning service)*	People obtain freshwater from ecosystems and therefore the supply of freshwater can be considered a provisioning service. Fresh water in rivers is also a source of energy. Because water is required for other life to exist, however, it could also be considered a supporting service.
Water regulation *(a regulating service)*	The timing and magnitude of run-off, flooding and aquifer recharge can be strongly influenced by changes in land cover, including alterations that change the water-storage potential of the system such as the conversion of wetlands or the replacement of forests with croplands or croplands with urban areas.
Water purification and waste treatment *(a regulating service)*	Ecosystems can be a source of impurities (e.g. in fresh water). However, they can help in the filtering out and decomposition of organic wastes introduced into inland waters and coastal and marine ecosystems and can also assimilate and detoxify compounds through soil and sub-soil processes.
Climate regulation *(a regulating service)*	Ecosystems influence climate both locally and globally. For example, at the local level, changes in land cover can affect both temperature and precipitation. At the global level, ecosystems play an important role in climate by sequestering or emitting greenhouse gases.

Source: Defra (2007). *Securing a healthy natural environment: An action plan for embedding an ecosystems approach.* PB12853. (Adapted from Millennium Ecosystem Assessment: Ecosystems and Human Wellbeing: General Synthesis)

3.10. Based on these descriptions, the four key services for this study and their relationship with land use can be defined as follows:

Regulation of water quality

- High quality water, from surface and groundwaters, is essential for the maintenance of healthy and naturally functioning ecosystems, and for public water supply. Variations in geology and soils mean that the precise chemical content of surface and groundwaters varies. Land uses and management affect the cleanliness of the water supply by introducing pollutants and aiding in their transportation. Pollution may be either diffuse

[7] The way in which individual services relate to the framework of types of service (Figure 1.1) is not always clear cut. For instance, although fresh water is classified by the MA as a provisioning service, it is also a supporting service.

(as from agricultural run-off) or point source (as from industry), biological or chemical.

Availability of water resources

- As with water quality, the amount of water held in surface and groundwaters is important to maintain naturally functioning ecosystems and to supply us with water for drinking and other domestic uses, for industry and crop irrigation. Increasing demands for water have led to growing levels of water abstraction from both rivers and aquifers, leading to increasing fluctuations in water levels and low flow conditions in many rivers affected by abstraction. Different land uses demand varying levels of water as an input, and equally they vary in terms of their impact on the water supply elsewhere, for example by increasing or reducing levels of infiltration and aquifer recharge.

Management of flood risk

- Flooding from rivers and the sea is a natural phenomenon, with seasonal inundation an important requirement for some habitats. However, many urban areas are located in or close to floodplains. Understanding and managing flood risk is vital if homes and industrial assets are to be protected from flooding. Varying land uses can affect flood risk within a river catchment by influencing the levels of run-off and infiltration experienced. Equally, more engineered land management strategies can affect the likelihood of floods occurring as well as influencing their eventual impacts, for example by storing water or by acting as a flood defence.
- Flooding develops in two ways and it is helpful to consider these separately, particularly as their relationship with land use and management is quite different. Firstly, the potential for flooding is *generated* across catchments as a whole, based on the way in which rainfall is intercepted by vegetation and soils and infiltrates into the soil and groundwater or runs off into surface water drainage systems. Secondly, flooding is *propagated* in river channels and floodplains through a combination of river flow, high water tables and ability of water to flow to the sea. This environmental service is therefore considered in these two parts.

Storage of carbon in soils

- The threat posed to the global climate by the rising concentrations of carbon dioxide in the atmosphere is focussing attention on natural stores of carbon. Understanding the stability of organic carbon stored in soils, that exists in flux with carbon dioxide and which may be quickly released to the atmosphere, is particularly important. The way that land is used and managed is one of the key factors, in combination with the local climate and underlying geology and topography, influencing the levels, and flux, of organic carbon held in soils.

Defining environmental limits

3.11. Working within environmental limits is one of the guiding principles of the UK's Sustainable Development Strategy and is recognised by the International Convention on Biological Diversity as a core component of the ecosystem approach.

3.12. The concept is based on two key notions:

- First, that the environment is irreplaceable, has intrinsic value and, through the provision of environmental or ecosystem services, provides necessary life support systems.
- Second, that there are limits to the capacity of the environment to accommodate change beyond which unacceptable change will occur.

3.13. As stated in a recent study for Defra "*Environmental limits are most usefully defined in terms of the point or range of conditions beyond which the benefits derived from a natural resource system are judged unacceptable or insufficient*".[8]

3.14. There is a growing body of research into the theoretical basis for environmental limits[9] which is outside the scope of this report. However, there are few examples where the concept has been applied in practice to prioritise policy interventions. One exception is the use of water quality and resource monitoring data to define acceptable levels of these services to meet the requirements of the Water Frameworks Directive. The following points are pertinent to the approach followed in this study.

Environmental limits in the context of the pressure-state-response model

3.15. It is helpful to think of environmental limits in the context of the pressure-state-response model. This is a way of thinking about how the state of an environmental service (such as the provision of high quality water) responds to increasing pressure (such as from rising nitrate levels). Figure 3.4 shows that this response may be linear (the quality of water declines at a uniform rate), it may be non-linear (the decline is faster at some levels of pressure than others) or it may change dramatically at a given threshold (the state of the service may suddenly collapse, having been 'tipped' into a radically different regime).

3.16. Such is the complexity of natural systems that responses that appear linear from a distance almost certainly involve non-linear or threshold relationships at a finer scale. Nevertheless, some environmental assets show a relatively linear response to pressures (such as the quality of groundwater in chalk aquifers responding to pesticide applications) while others exhibit one or more threshold responses (climate models suggest this is the case for global temperature responding to rising carbon dioxide levels).

[8] See Haines-Young *et al*. (2006)
[9] See for instance: Turner *et al*. (2007)

Figure 3.4. Environmental limits and thresholds in the context of the pressure-state-response model.

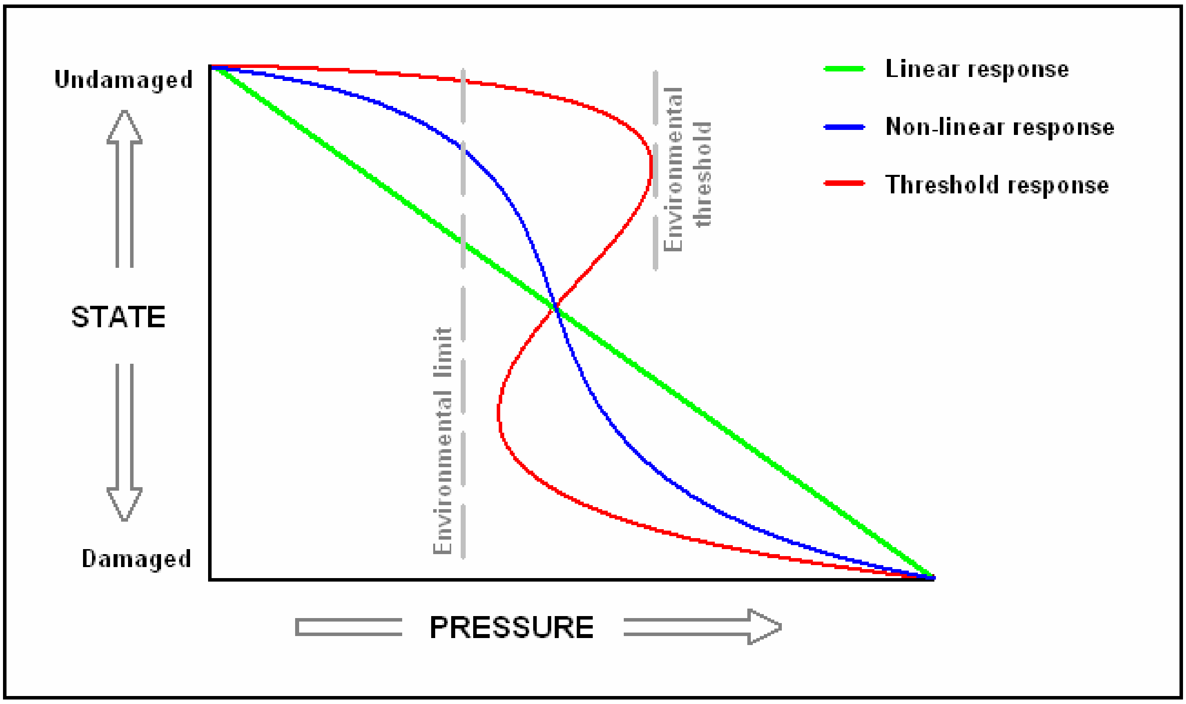


Figure adapted from Haines-Young *et al.* (2006).

3.17. Figure 3.4 is clearly an idealised model; environmental assets and natural resource systems in the UK (as in most of the world) have been modified for millennia by human-induced pressures. Most of these pressures have increased dramatically during the last century. How environmental assets will respond to increased pressure is often difficult to predict. An asset that may have responded in a linear way until now may adopt a threshold response in future. Predicting future responses to complex natural systems requires a high level of understanding of how these systems function. Imperfect knowledge is often a constraint on the setting and measurement of environment limits.

Distinguishing between environmental limits and thresholds

3.18. In the pressure-state-response model shown in Figure 3.4, the level of pressure at which the response tips into a completely different type of behaviour can clearly be identified. This is shown as the ‘environmental threshold’.

3.19. In many cases this is difficult to define and, as a consequence, limits are more often a policy construct that reflects the human values and benefits derived from natural assets and services. Here environmental limits are set by policy makers as a trigger for intervention.

3.20. In the case of services that exhibit a threshold response, it is particularly important to define an environmental limit so action can be taken to reduce the pressure before the critical threshold limit is reached. In the case of services with linear and non-linear responses, the level of the environmental limit will be set with a greater regard to what is considered an unacceptable level of delivery of the service. The environmental limit can be thought of as the point of ‘damage containment’, where the reduction in the net benefit delivered by the service is no longer acceptable or tolerable.

3.21. Setting environmental limits therefore needs to be based both on a sufficient scientific understanding of the natural systems supporting the environmental service and on the public benefits derived from that service. Where there is doubt about the way that environmental limits should be measured, or the level at which they should be set, the precautionary principle should be adopted.

Measuring environmental thresholds and limits

3.22. Environmental limits may be measured directly but are more usually measured through proxy indicators (such as populations of farmland birds as a measure of biodiversity). The choice of which metric to use depends on:

- there being robust evidence linking the indicator to the desired environmental outcome;
- the cost of collecting the data;
- the ease with which the limit can be communicated to policy makers and the public.

3.23. It is often the case that a combination of different metrics is used to create a combined indicator. This is the case for 'good ecological status' measured under the Water Framework Directive (see paragraph 3.32).

3.24. It may not be possible to set or monitor an environmental limit for an environmental service. This may be because there is insufficient knowledge about the way natural systems operate and, in particular, how pressures cause responses to the service. This is currently the case with carbon flux in soils. Or, while it may be possible to establish an environmental limit, there may not be a suitable source of data to measure it. This is currently the case, at a national level, with flood risk management. These issues are further explored later in this chapter under the relevant environmental services

The role of environmental limits and targets in public policy

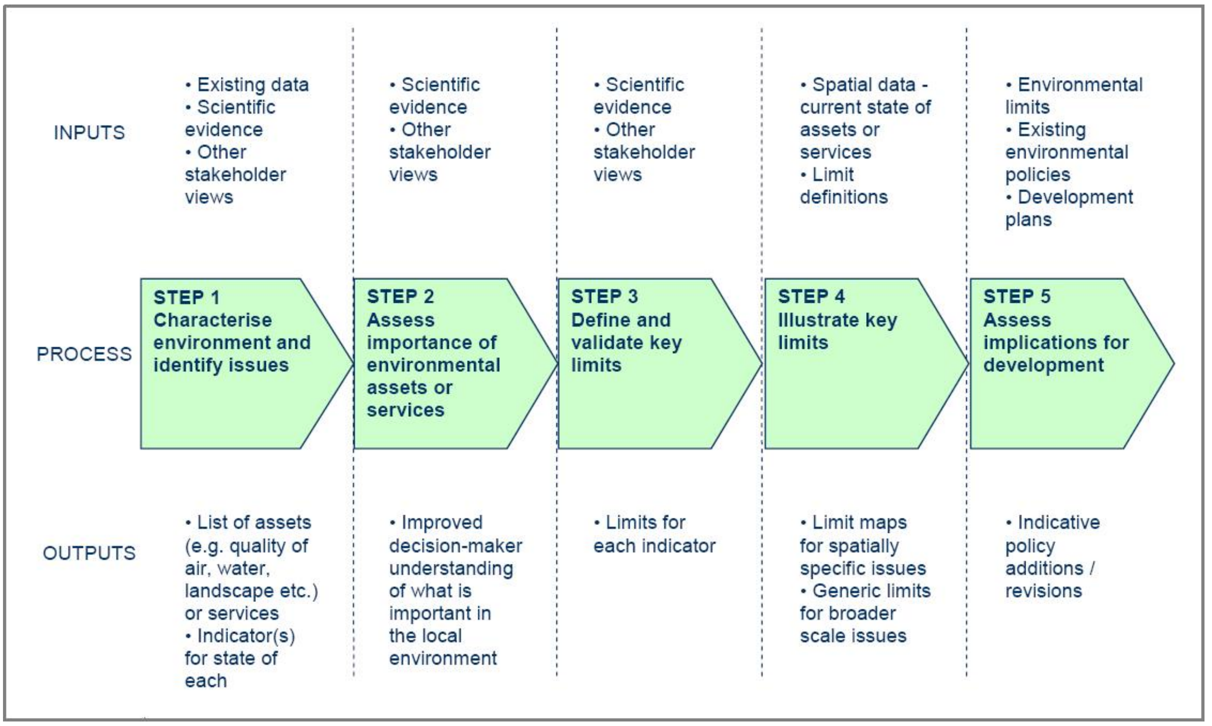
3.25. Just as environmental limits provide a 'bottom up' trigger for intervention, public policy also relies on 'top down' targets. These are usually based on an assessment of achievable improvement in the state of an environmental service, rather than a recognition of the threat posed by a pressure. An example is the target set by Government for 60 per cent of new housing to be built on previously developed ('brownfield') land to reduce the impact of development on the countryside. [10] A key goal of public policy should be to bring environmental limits and targets together.

Approaches to defining environmental limits

3.26. This study followed the approach to defining and measuring environmental limits that was developed for the East of England Regional Assembly in the Haven Gateway.[11] This used a five-step approach: (1) defining the issues that need to be addressed; (2) assessing the importance of environmental services; (3) defining and validating the environmental limits; (4) measuring current practice against these limits; and (5) assessing the policy implications.

[10] Planning Policy Guidance Note 3: Housing.
[11] EERA (2008)

Figure 3.5. Five-step method for applying environmental limits to spatial planning.



Source: EERA, 2008. *Environmental Capacity in the East of England: Applying an Environmental Limits Approach to the Haven Gateway*. Report by Land Use Consultants, January 2008

3.27. In the remainder of this chapter, each of the environmental services covered by this study is considered in turn. For each, the existing and potential indicators are described and an environmental limit is set. The current delivery of each service is assessed and mapped across England and Wales and evidence on recent trends in their delivery is described.

Regulation of water quality

3.28. The advent of the Water Framework Directive (WFD) has changed the way that water quality is assessed by the Environment Agency,[12] replacing the earlier General Quality Assessment (GQA) of water quality. Under the WFD an important distinction should be drawn between compliance monitoring of the current state of the water environment (used here to assess water quality) and modelled forecasts of pressures and risks on water quality and quantity described later in this report (for instance paragraph 3.39).

3.29. The WFD applies to all surface freshwater bodies (including lakes, streams and rivers), groundwaters, groundwater-dependant ecosystems, estuaries and coastal waters out to one mile from low-water. The WFD requires monitoring of water quality to make empirical assessments of the ecological and chemical status of all controlled water bodies and groundwaters. Where water quality is classified as being below the required levels, measures must be introduced to address the identified pressures and risks. This provides the concept of ‘good ecological status’ and ‘good chemical status’ as environmental limits triggering policy interventions.

[12] The WFD came into force across the EU on 22 December 2000, and was introduced into UK law in 2003.

3.30. WFD monitoring is risk-based, focussing on where there is likely to be a problem, and classification is based on a far wider range of assessments than the GQA. It uses a principle of where the poorest individual result drives the overall classification (and as a result WFD results will appear poorer than GQA results). The Environment Agency selects sampling points where it considers that a problem may occur and samples are taken for the parameters most likely to show signs of damage to ecological and chemical status. This inevitably produces a deliberate bias in the way the WFD data portrays water quality which needs to be borne in mind in the context of this report. In practice, assessments are driven mainly by incidents of point source pollution and low-lying but persistent levels of diffuse pollution (such as from agricultural sources of nitrate and phosphate) are less likely to be reflected in the status given to each water body.

3.31. Under the WFD separate assessments are made of surface water bodies (rivers, lakes and coasts/estuaries) and groundwater. For the purpose of this study, WFD data on rivers and groundwater are considered the most relevant to studying the impact of land use and management on water quality.

Classification of rivers

Existing and potential indicators of surface water quality

3.32. For surface waters, separate classifications are made of ecological and chemical status. For each of these, a large number of metrics, covering differing quality elements, are used.

- Ecological status classification consists of assessments of biological quality (such as fish and macro-invertebrates), of compliance with environmental standards for supporting physico-chemical conditions (such as dissolved oxygen and ammonia) and of compliance with environmental standards for concentrations of pollutants (such as zinc and cypermethrin). For high status water bodies, an additional assessment is made to ensure that hydromorphology is largely undisturbed.
- Chemical status classification for surface water bodies assesses the levels of priority substances (such as aldrin and dieldrin) and priority hazardous substances (such as atrazine and benzene).

3.33. Stretches of river considered artificial or heavily modified (for instances for navigation, recreation, water storage or flood protection) are classified according to their ecological potential measured against the same indicators for other surface water, but applying a lower environmental limit since it is recognised that these stretches will never be able to achieved good ecological status.

3.34. Classifications of ecological and chemical status are made for each stretch of river (with the lowest classed element determining the overall classification). Ecological status is classified into five classes (high, good, moderate, poor and bad) and chemical status is classified into two classes (good and fail).[13]

3.35. Draft data have been prepared for ecological and chemical status of most river stretches in England and Wales and these data have been used as the basis for draft management plans for each River Basin District (RBD) published for consultation in December 2008. Finalised data (for the first round of river basin

[13] The methodology is explained in more detail in Environment Agency (2008)g

planning under the WFD) will be published by the Environment Agency later in 2009.

Environmental limits for surface water quality

3.36. These two overall classifications provide a rigorous way of assessing river water quality based on meeting the national and European policy objectives of the WFD. These data were used to establish the environmental limits for river water quality in this study.

3.37. The draft results for ecological status in England and Wales show that (for the 86 per cent of river stretches, by length, that have been assessed):

- eighteen per cent of rivers by length are in good or better condition;
- sixty-one per cent are moderate;
- seventeen per cent are poor;
- four per cent are bad.

3.38. Figure 3.6 maps the spatial distribution of these rivers.[14] It shows a complex picture, with the different classifications widely distributed across England and Wales and rivers of good and poor ecological condition often occurring close to each other. All parts of the country and RBDs have stretches of good, moderate, poor and bad quality river, although the Anglian RBD shows the least variation with large lengths of river classified as moderate. Stretches classified as good and high tend to occur in the headwaters of rivers, particularly in upland areas. However, it is not necessarily the case that river water quality deteriorates downstream. For instance, there are river stretches in the headwaters of the River Test in the South East RBD that are classified as bad,[15] and in the headwaters of the River Ithon (a tributary of the Wye above Builth Wells) that are classified as poor, but where dilution with water entering the river lower down mean that a higher classification is achieved in the middle and lower reaches of the rivers.

3.39. The data for individual elements of ecological condition is not yet sufficiently complete to enable the underlying reasons for the overall ecological assessment to be mapped spatially. However, work completed by the Environment Agency modelling the pressures and risks facing rivers (known as the River Basin Classification 2) can be matched against the ecological classification to indicate likely causes arising from identified risks and pressures. Figure 3.7, which covers the Wye catchment, only shows those catchment geographies of rivers that are classified as of poor or bad ecological status and it colours them according to the risk of low pH. This shows that acid waters are likely to be the cause of bad ecological status in the River Ithon and poor status in the Wye between Rhayader and Builth Wells. The link between low pH and land use is explored further in Chapter 6.

3.40. Using the same approach of comparing pressures and risks data with poor river water quality, Figure 3.8 suggests that, in the South East RBD, high nitrate levels on the Kent Downs, in parts of the Test Valley south west of Andover and

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[14] The Environment Agency has developed a method for relating the condition of each stretch of river to its associated catchment geography (allowing spaces between stretches of rivers to be 'filled in') and this is used to relate river water quality to the surrounding land use later in this report.

[15] A major paper mill is located at Overton close to the headwaters of the Test.

on the Selsey peninsular south of Chichester may be responsible for failures in water quality.

3.41. Published data on the chemical classification of rivers are much more patchy (with two-thirds of river stretches by length not assessed). There are two classes in the assessment, which are good condition and failing to achieve good condition. Of the stretches assessed, 65% have been classified as in good condition and 35% failed to reach good condition

3.42. Figure 3.9 maps these data and shows a similar overall pattern to that for ecological status, with failures of chemical quality in upper stretches being mitigated by dilution with higher quality water as it moved down river.

Classification of groundwater

Existing and potential indicators of groundwater quality

3.43. Under the WFD groundwater areas are distinguished on the basis of the underlying geology based on different aquifer types, primarily chalk and sandstone. These areas are relatively large and in some cases cross between different RBDs. Under the WFD, groundwater quality is assessed under a single heading of chemical quality although a number of metrics are used to make the classification. These include the general chemical status, the presence of saline and other intrusions, the impact of surface water chemical and ecological status and the Drinking Water Protected Area status. Each groundwater area is classified as good or poor chemical status.

Environmental limits for groundwater quality

3.44. Again, these data were used in this study to establish the environmental limits for groundwater quality.

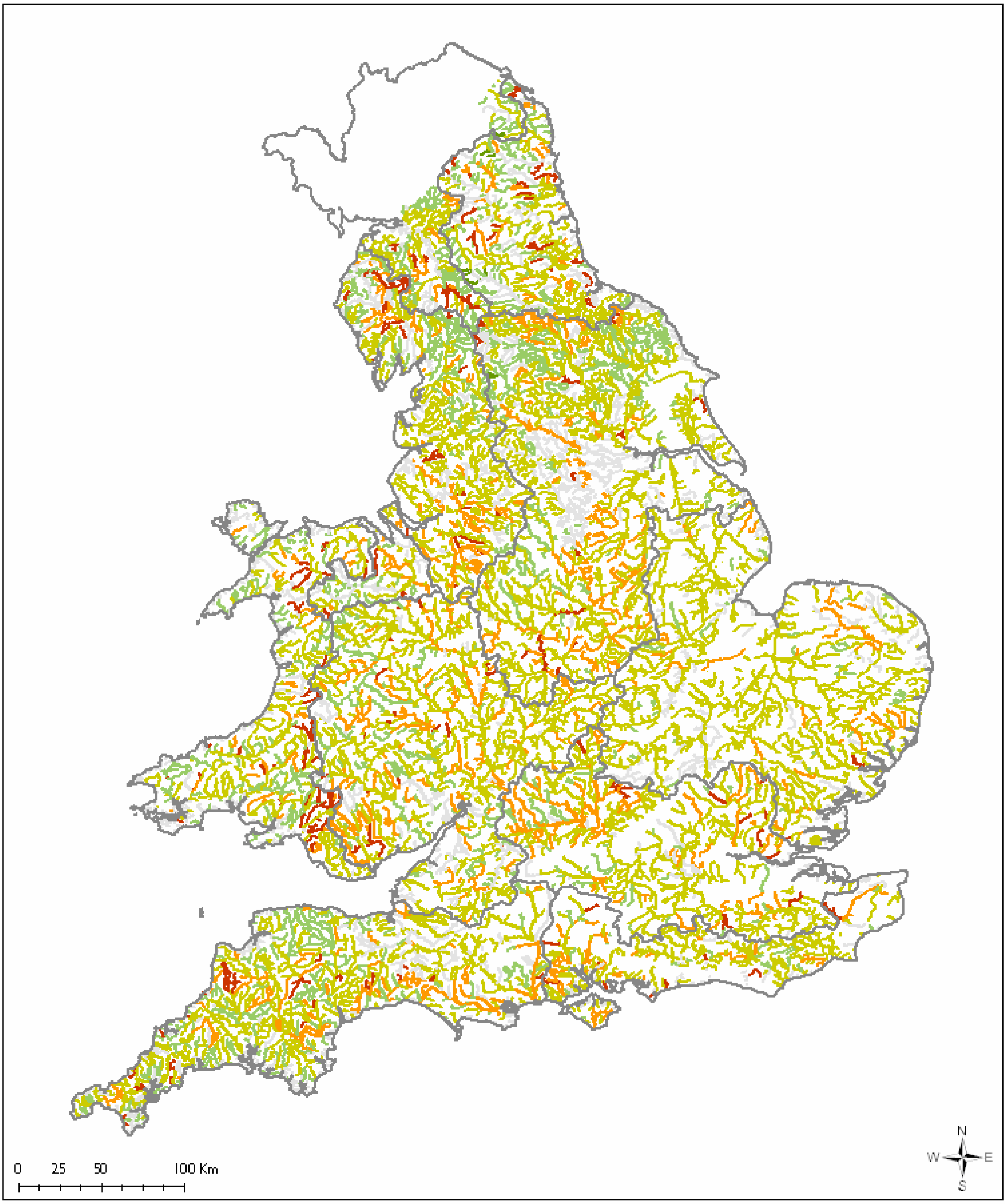
3.45. Figure 3.10 maps the classification of groundwater across England and Wales. It shows that large swathes of groundwater across all RBDs are not compliant with good chemical status, with the distribution largely following underlying geology, as might be expected.

3.46. Groundwater areas that lie outside the environmental limit of good chemical quality include those that are aquifers (such as the South Downs and underlying chalk of East Anglia) and those which are not (such as the granite intrusions of Cornwall and south Devon and the clay vales of Cheshire and south west Lancashire).

3.47. It is interesting to compare the classification of groundwater areas with chemical status of the rivers that flow over them. There appears to be no clear correlation between the two. For instance, the River Ribble is failing to achieve good chemical condition over a groundwater area that is achieving good status, while the River Exe is classified as having good chemical status but the groundwater in the catchment is assessed as poor status.

3.48. This lack of connection may be because groundwater quality failure is not an issue that is addressed in the chemical classification of rivers (for instance relating to Drinking Water Protected Area status or intrusions from mine workings or marine salinity) or it may be because changes in river water quality have not yet been reflected in groundwater quality (for instance high levels of priority substances in rivers have not yet percolated through to the groundwater).

Figure 3.6. Overall ecological classification of rivers in England and Wales.



Ecological classification of rivers across England and Wales

Source: Environment Agency compliance monitoring

Date: 30th January 2009

WFD Rivers Classification [ECOL_CLASS]

- High
- Good
- Moderate
- Poor
- Bad
- Not yet assessed

Figure 3.7. Risk posed by low pH in areas of poor and bad river ecology classification.

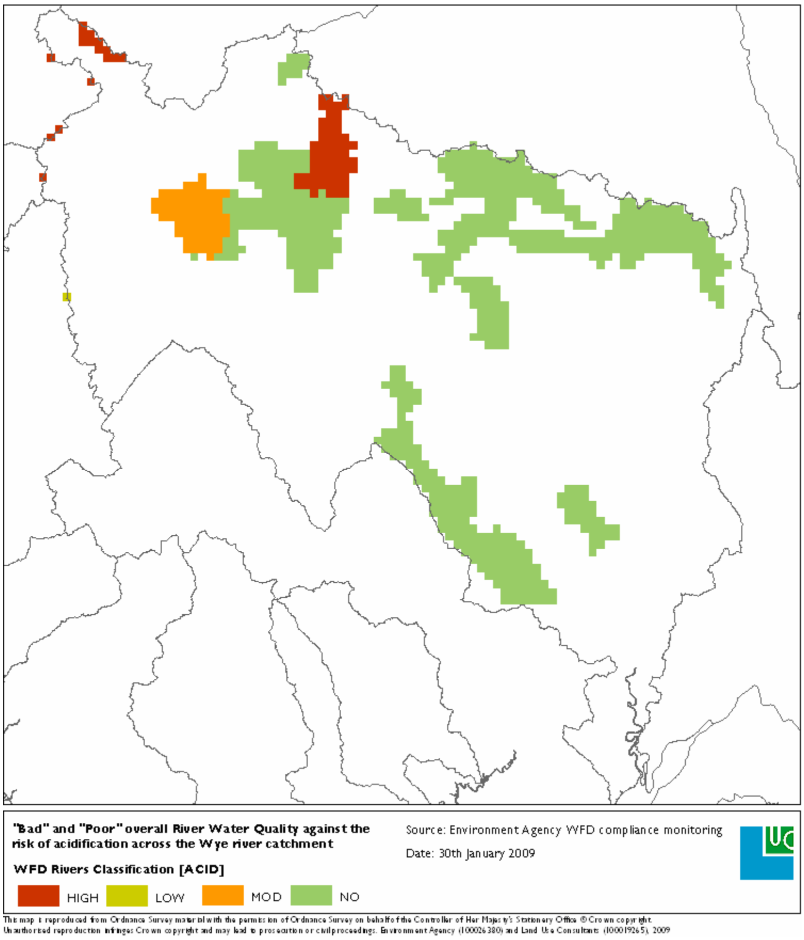


Figure 3.8. Risk of nitrate in areas of poor and bad river ecology classification.

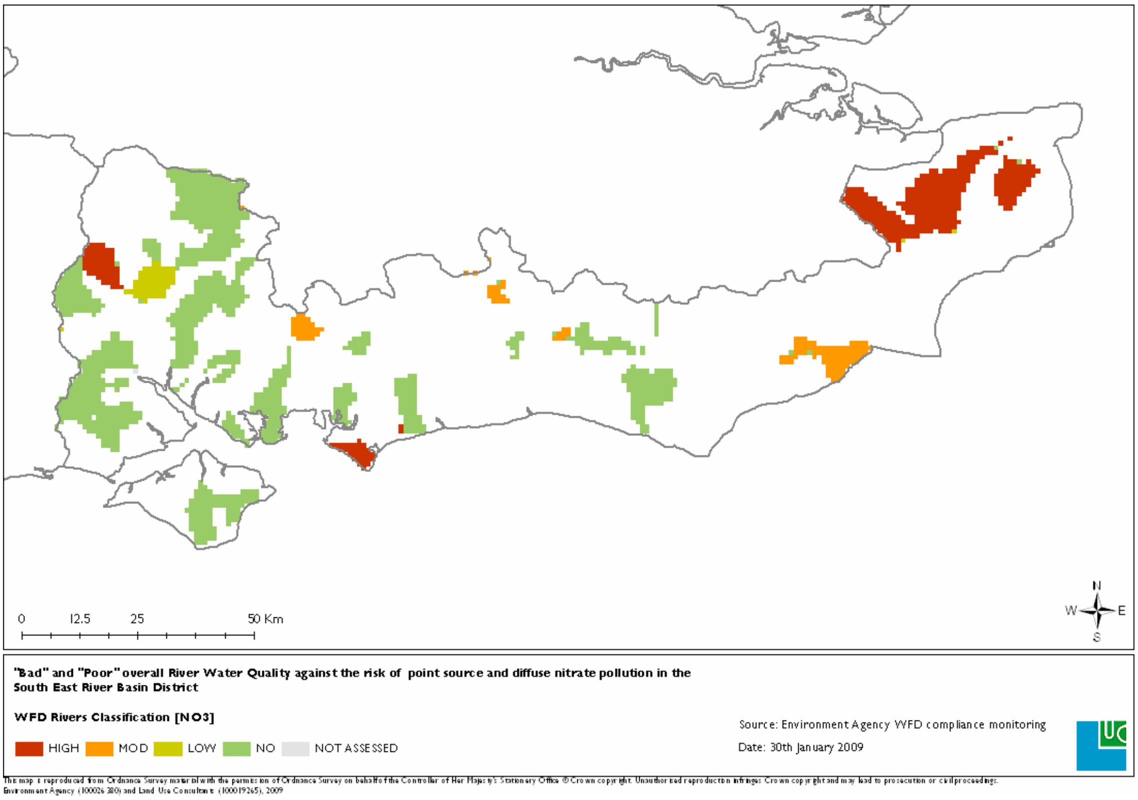


Figure 3.9. Overall chemical classification of rivers in England and Wales.

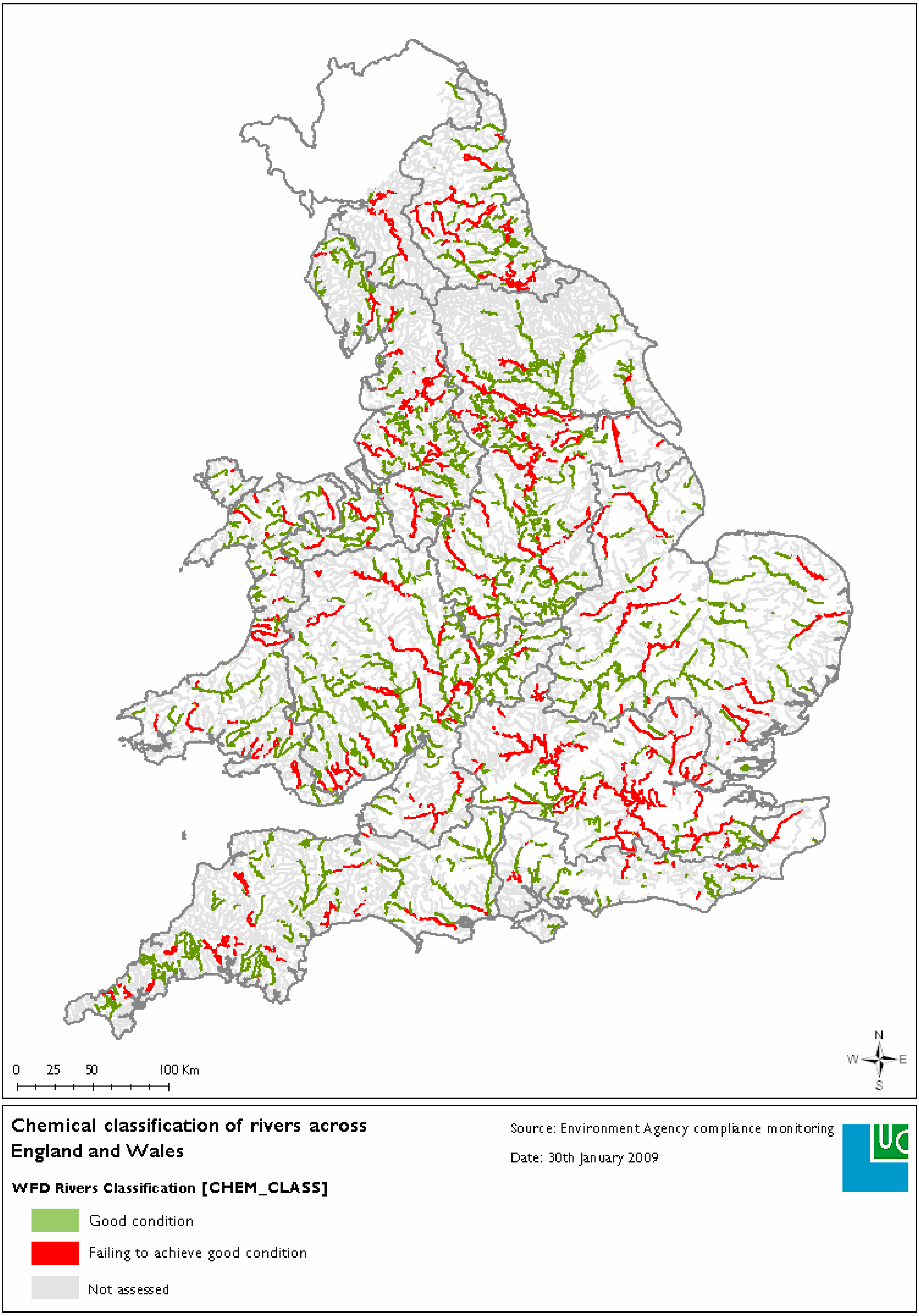
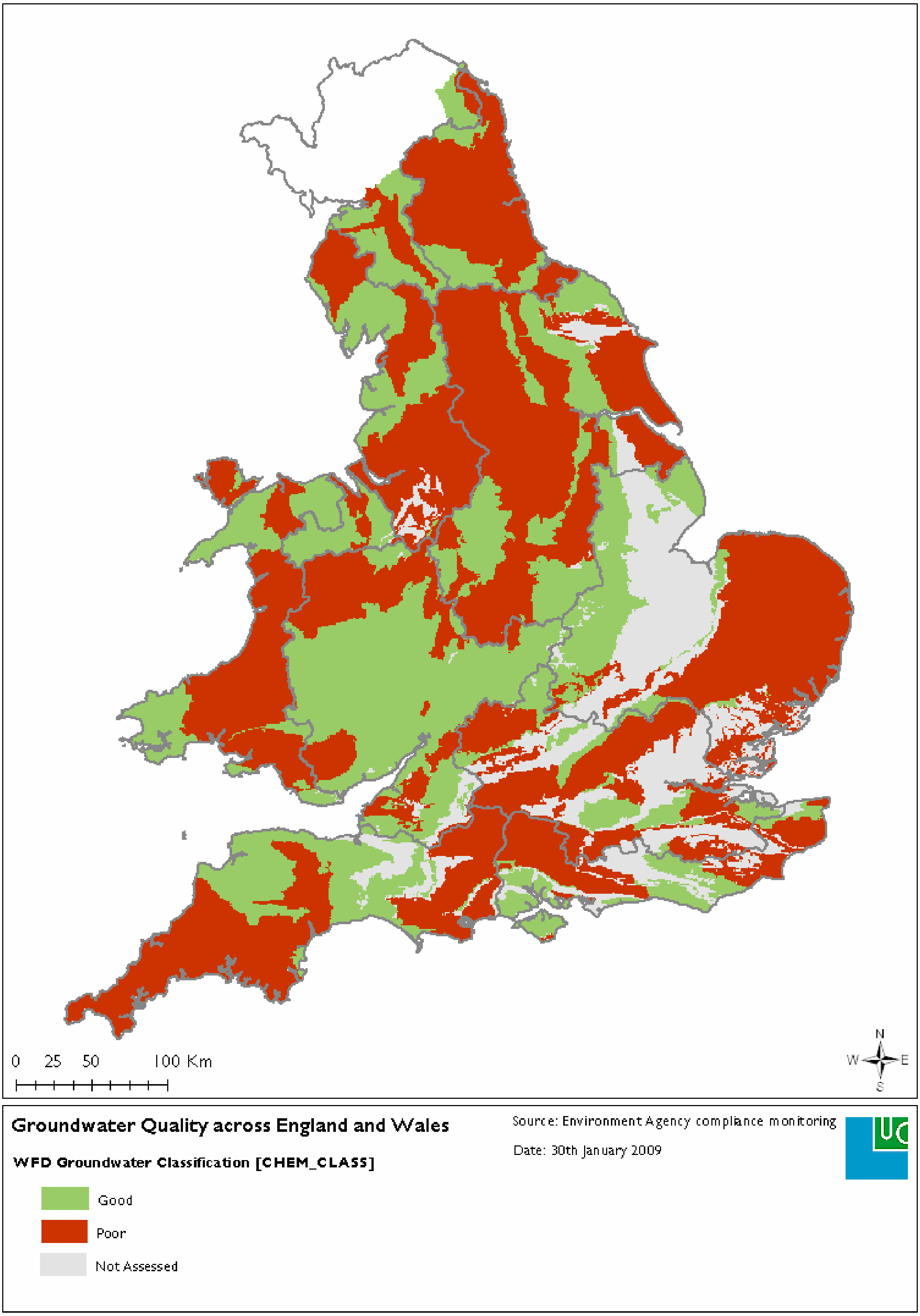


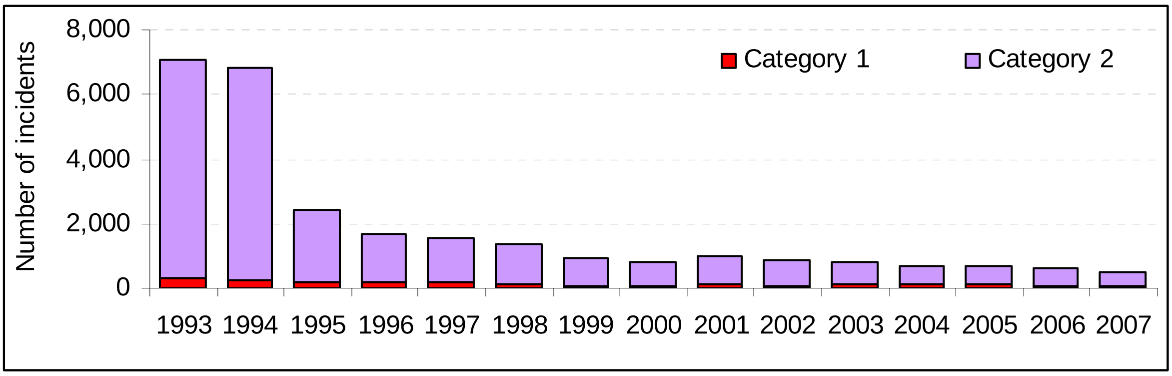
Figure 3.10. Overall chemical status of groundwaters across England and Wales.



Recent trends in the quality of surface and groundwaters

3.49. There is insufficient historical WFD compliance monitoring data to be able to track trends in water quality using this method. However, the previous General Quality Assessment datasets and the Environment Agency's records of pollution incidents show an improving trend in water quality. The number of serious pollution incidents fell dramatically in 1995 and there has been a gradual downward trend since then (**Figure 3.11**).

Figure 3.11. Number of serious water pollution incidents in England and Wales 1993 to 2007.



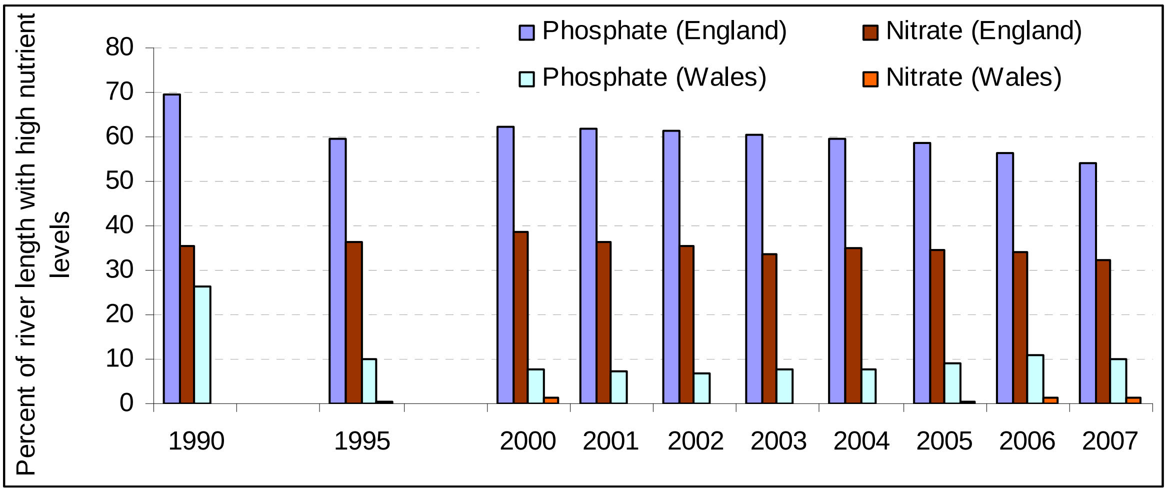
Source: Environment Agency Environmental Indicators. www.environment-agency.gov.uk/research/library/data/34281.aspx

3.50. In 2007, the largest identifiable sources of serious water pollution incidents was sewage (19 per cent of serious incidents) followed by industry (17 per cent) then agriculture (12 per cent). The relative importance of sewage has largely remained constant whereas industry and agriculture have both fallen as a proportion of identifiable sources. However, these figures relate to point source incidents of pollution and they mask the fact that diffuse sources, where the cause cannot be pinpointed, have grown as a proportion of pollution incidents.

3.51. Agriculture is considered to be a major source of diffuse pollution, with pesticides, nitrates and phosphate of particular concern. Figure 3.12 shows that a high proportion of rivers in England have high levels of nitrate and phosphate and that, while levels of phosphate show a long-term decline since 1990, there has been little change in the level of nitrates.

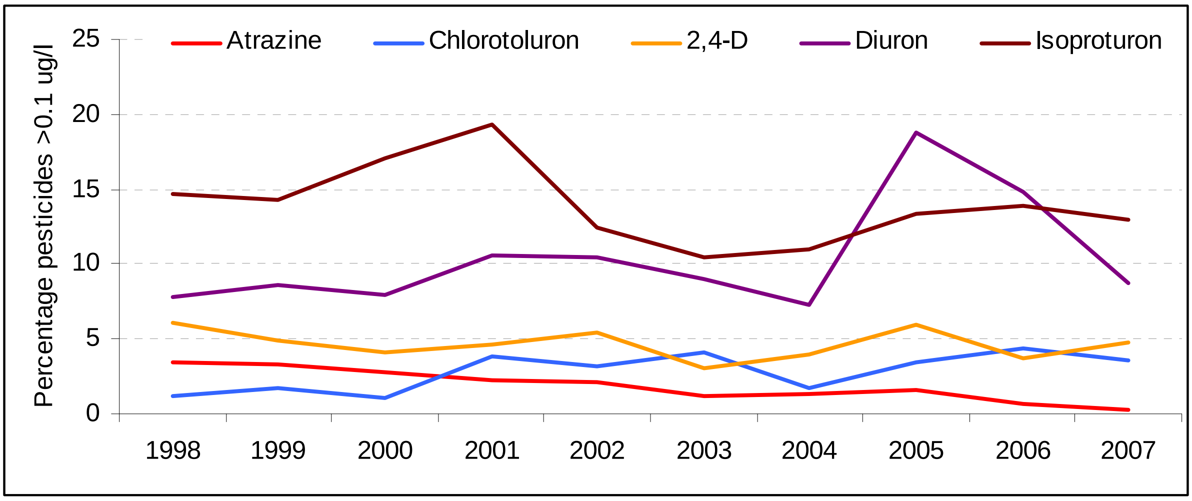
3.52. Figure 3.13 shows the trend data for a selection of pesticides since 1998 demonstrating that while the levels of some (such as atrazine) have declined, others (such as diuron) have risen in recent years, probably as a result of rainfall levels and soil conditions during the peak periods when these chemicals are applied.

Figure 3.12. Percentage of river lengths with high phosphate and nitrate levels in England and Wales 1990 to 2007.



Source: GQA monitoring data reported as Environment Agency Environmental Indicators. www.environment-agency.gov.uk/research/library/data/34281.aspx

Figure 3.13. Levels of selected pesticides in surface waters 1998 to 2007.



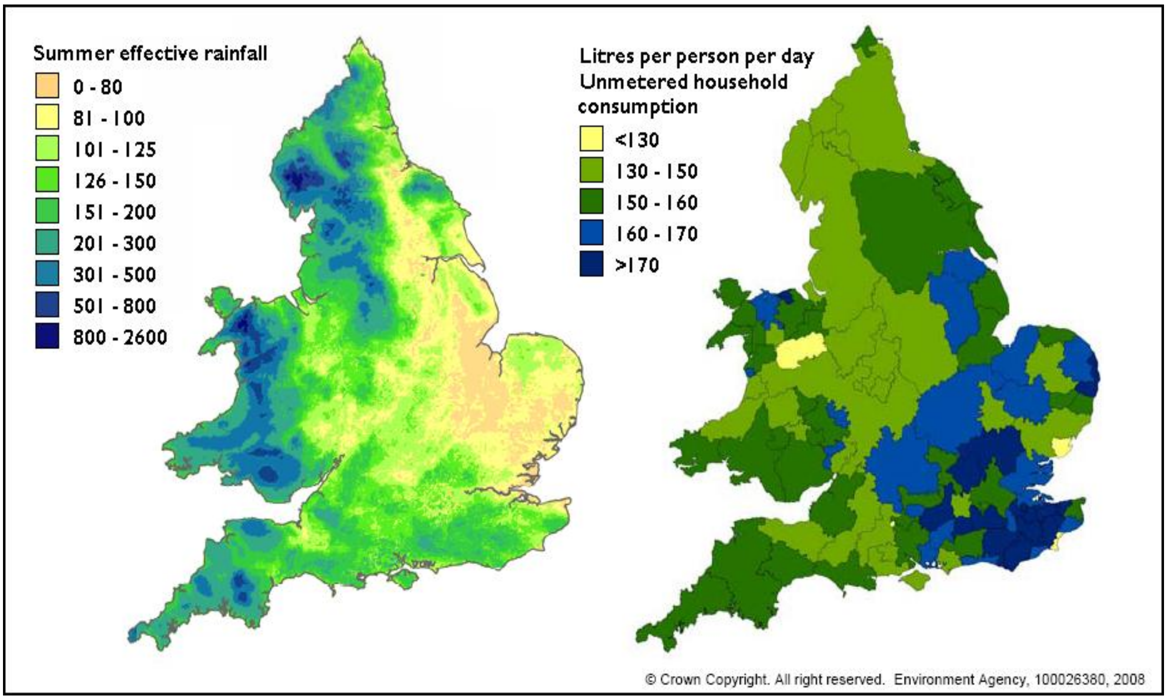
Source: GQA monitoring data reported as Environment Agency Environmental Indicators. www.environment-agency.gov.uk/research/library/data/34281.aspx

Availability of water resources

Existing and potential indicators of water resource availability

3.53. A recent report by the Environment Agency summarises the current state and future pressures on water resources.[16] This states that, excepting prolonged periods of dry weather, there is sufficient water in England and Wales to meet the needs of people and wildlife. However, there is a significant and growing imbalance between those parts of the country that receive highest levels of effective rainfall[17] but where demand is lowest, and those parts of the country where the opposite is true. Figure 3.14 shows that the water resources available from rainfall are greatest in Wales and the south west and north west of England whereas demand is highest in the south east and east of England.

Figure 3.14. Comparison of distribution of effective summer rainfall and unmetered water consumption.



Source: EA, 2008.

3.54. One way of measuring the balance of available freshwater to demand is the water exploitation index. Over England and Wales, the index shows that about 10 percent of available freshwater is abstracted. But in south east and eastern England, the level is more than 22 percent, exceeded elsewhere in the EU only in Cyprus, Malta, Spain and Italy.

3.55. Around 60,000 million litres of water are abstracted per day in England and Wales which is an amount that has remained relatively constant since 2000. About ten percent is abstracted from groundwater, with most of this being used for public water supply; 40 per cent is abstracted from tidal waters, most of which is used by electricity generators; and about half is abstracted from non-tidal surface waters, about half of which is used for public water supply and the

[16] Environment Agency (2008)4d
[17] 'Effective rainfall' is the rainfall that runs off to rivers and streams or percolates to groundwater and excludes rainfall that is immediately returned to the atmosphere through evaporation.

other half for industry and other uses. If abstraction from tidal waters is excluded, the amount abstracted for public water supply has remained static since 2000 whereas the amount used by electricity generators has declined significantly and water used for other industrial uses has declined since 2003. Volumes abstracted for crop irrigation have remained relatively constant (agricultural use of water is covered in more detail in Chapter 7).

3.56. The Environment Agency's Catchment Abstraction Management Strategies (CAMS) consider how much freshwater is reliably available, how much water the environment needs and the amount of water already licensed for abstraction. This shows where water is potentially available for abstraction from both surface and groundwater sources and where there is a need to reduce the amount of water abstracted, or licensed for abstraction.

3.57. In March 2008 the Environment Agency completed the first cycle of CAMS and in June 2008 it published *Managing Water Abstraction: Interim update to explain the future CAMS process*. This provided the first comprehensive baseline on water abstraction for all catchments in England and Wales and shows considerable pressures on surface and groundwater resources throughout England and Wales, not just in the drier south east and eastern England. The CAMS status is based on the amount of abstraction that can occur during seasonal periods of low flow without damaging river needs, primarily ecological integrity but also amenity, navigation and other human uses. The results show that, overall:

- a third of catchments have water available for abstraction;
- over a third have no water available for abstraction at low flows;
- eighteen per cent are over licensed (but where not all licenses are being used);
- fifteen per cent are over-abstracted.

In other words, only a third of catchments have water available for abstraction the year round.

Environmental limits for water resource availability

3.58. Separate assessments are made of the availability of water in surface and groundwaters and these data are taken into account in WFD assessments of ecological status of water bodies (see paragraph 3.32). Advice from specialist Environment Agency staff to this study was that modelled data on the pressures and risks arising from water abstraction in surface and groundwaters is currently the most appropriate measure of environmental limits for availability of water resources (see paragraph 3.28); these data are used in this study to define environmental limits for water resource availability. This reflects expected risks from abstraction rather than currently measured levels. Furthermore, the approach taken treats rivers and groundwater in isolation when in reality water supplies for the sub-region's people and its environment are supported by a complex system of river transfers, groundwater augmentation and reservoirs.

3.59. This modelled data indicates that for surface water catchments:

- five per cent of England and Wales is considered to be at high risk of over-abstraction and low river flows;
- nine per cent at moderate risk;
- eighteen per cent at low risk;
- 66 percent at no risk.

3.60. WFD pressures and risks assessments suggest a more favourable position (with two-thirds of surface water catchments being at no risk) than CAMS (which also cover groundwater, showing that only a third of catchments have water available for abstraction). This is because CAMS cover groundwater as well as surface waters.

3.61. Using this modelled data, Figure 3.15 maps the risks to surface water resources from abstraction and flow pressures across England and Wales (based on the pressure and risk assessments prepared for the WFD). In broad terms it shows a high concentration of areas at high and moderate risk in the south east and east of England, particularly in chalk catchments. Wales, the south west, and northern regions of England have relatively few such areas.

3.62. For groundwaters, a greater proportion of England and Wales is considered to be at risk than for surface water catchments:

- four per cent of England and Wales is considered to be at high risk;
- eighteen per cent at moderate risk;
- 66 per cent at low risk;
- thirteen per cent at no risk.

3.63. Figure 3.16 maps the risks to groundwater resources from abstraction across England and Wales (again based on the pressure and risk assessments prepared for the WFD). The patterns of risks reflect the underlying geology, particularly those strata that are primary aquifers, and the major centres of population. The highest level of risk, and therefore the areas lying furthest from the environment limit, are across the North Downs south of London and the Chilterns and North Essex chalk north of London, the Stour and Worfe catchments (the Worcestershire Middle Severn groundwater area) west of Birmingham, the Wirral south of Merseyside and the Idle-Torne groundwater area lying between the South Yorkshire conurbation and the river Trent.

3.64. The relationship between water resource availability and land use is explored in Chapter 7.

Figure 3.15. River water resource availability measured as the risk arising from abstraction and flow pressures.

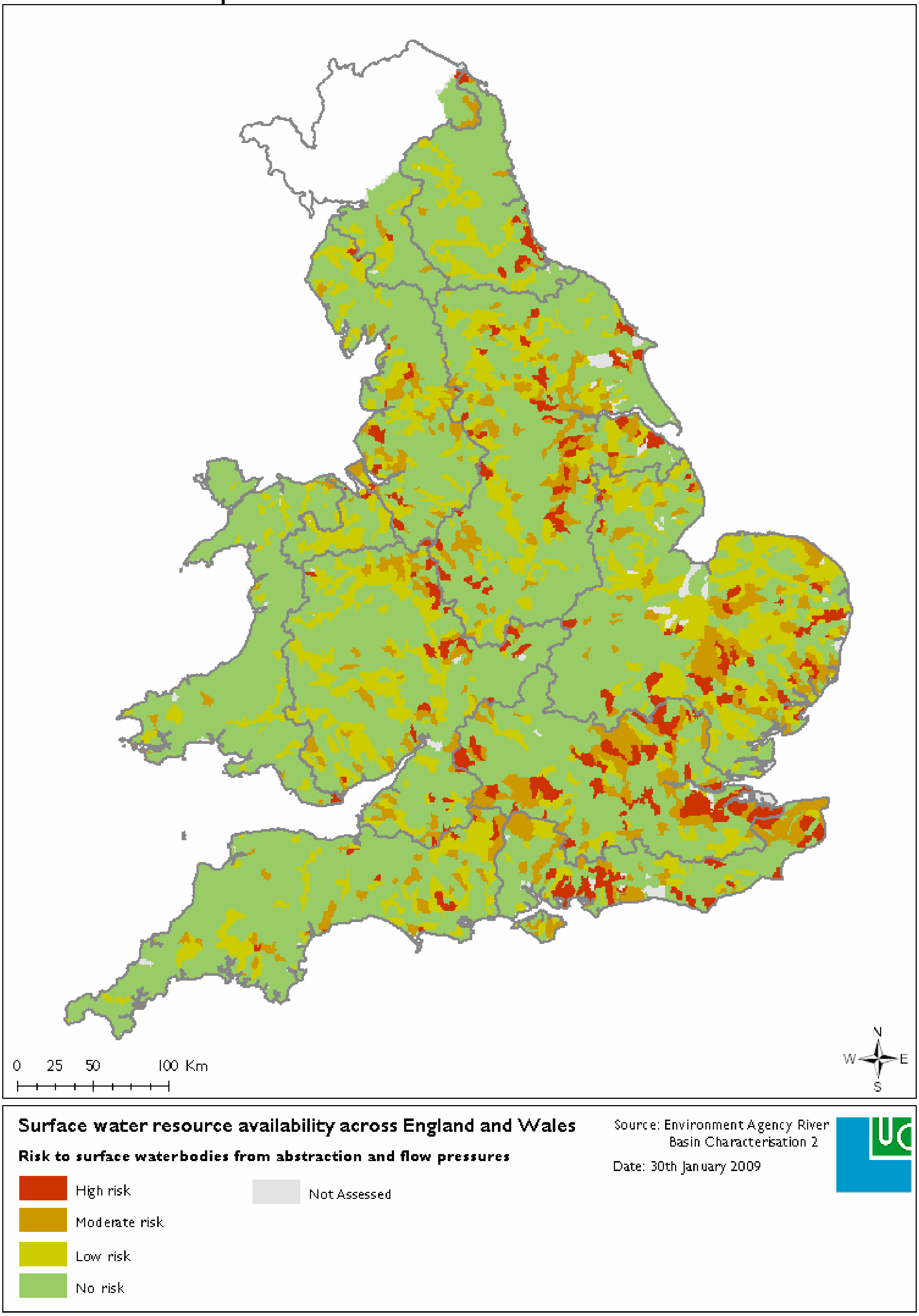
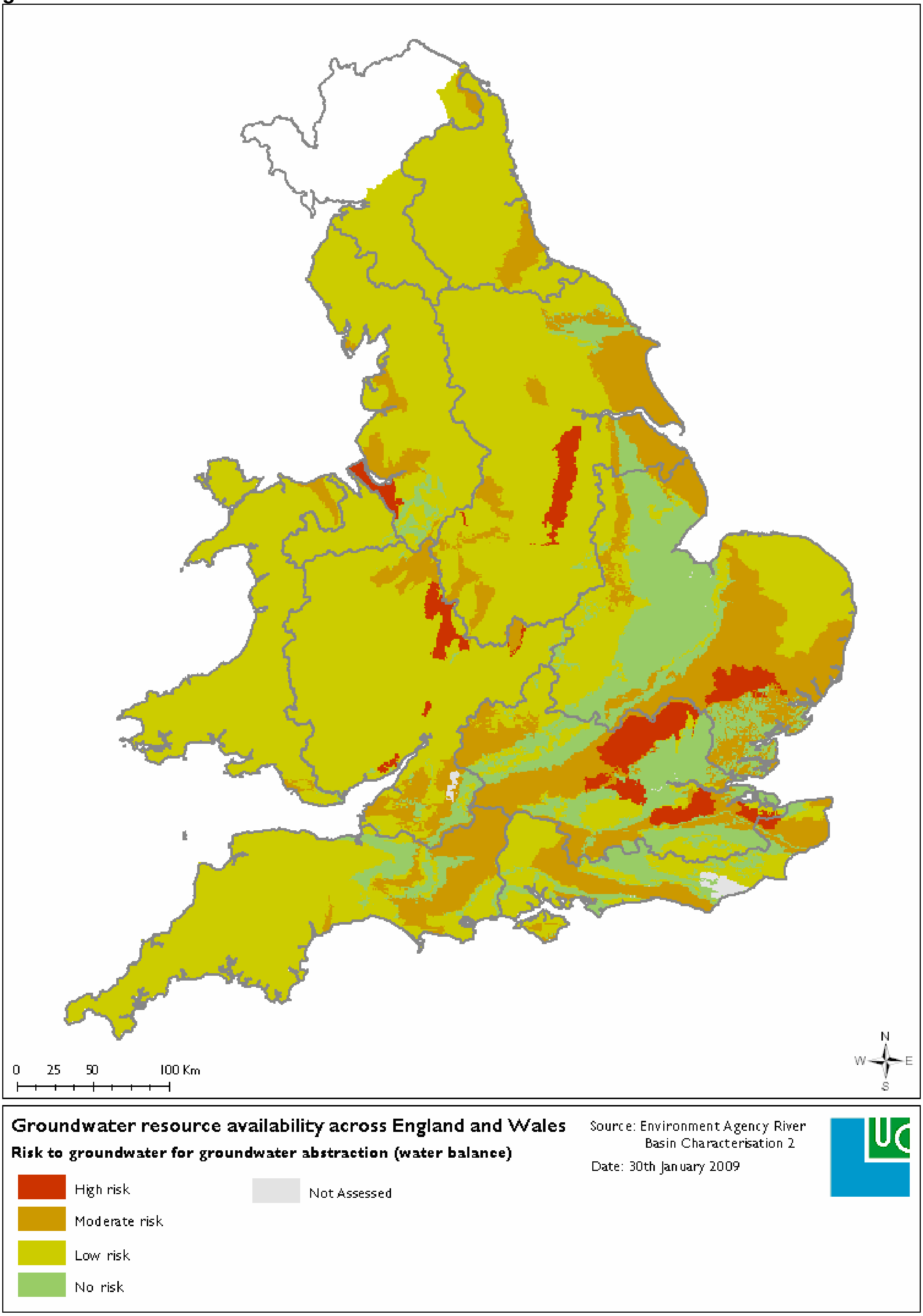


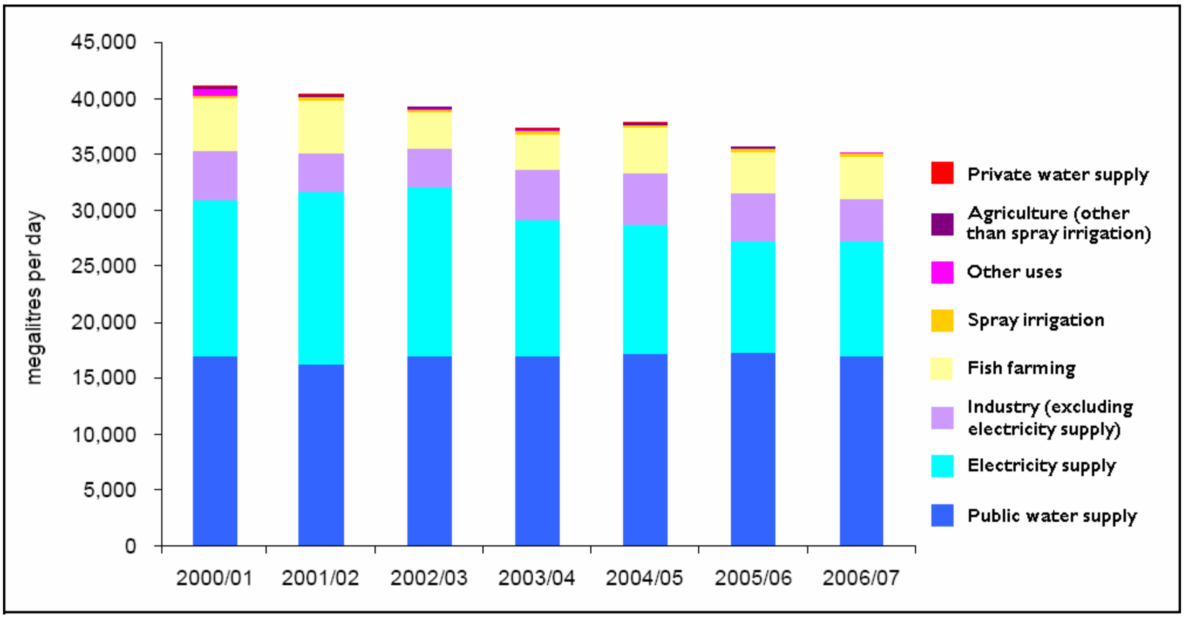
Figure 3.16. Groundwater resource availability measured as the risk arising from groundwater abstraction.



Recent trends in availability of water resources

3.65. As noted above, amounts of water abstracted for industrial uses has declined in recent years but the amount abstracted for household consumption has remained relatively constant (Figure 3.17).

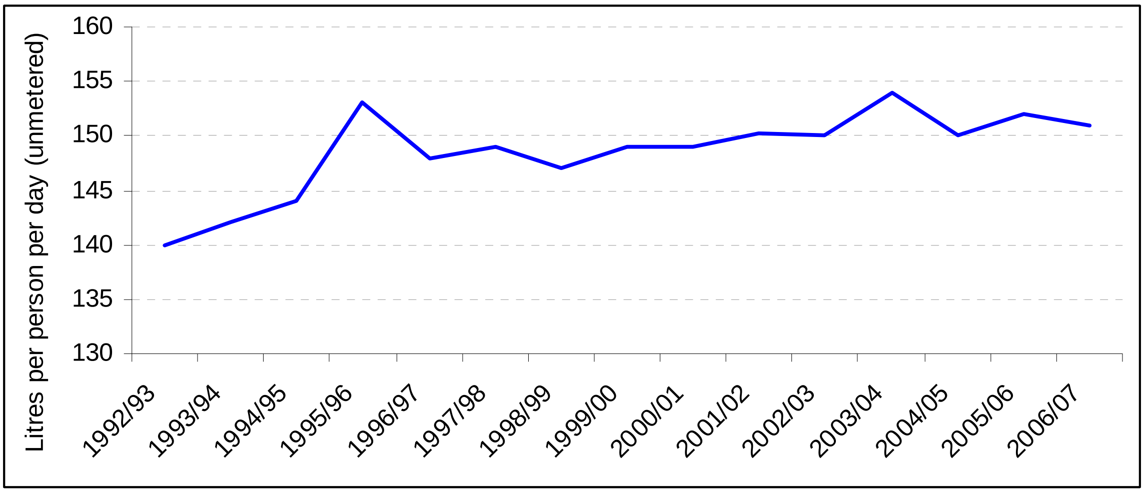
Figure 3.17. Uses of water abstracted from non-tidal waters in England and Wales, 2000 to 2007.



Source: Environment Agency, 2008

3.66. However, this overall figures hides the fact that household consumption has risen since 1992, although at a slower rate since 2000 (Figure 3.18). In contrast the amount of water lost through leakage in the main distributions system fell during the period 1994 to 2000 (but has remained relatively constant since then). There have also been significant regional trends, with highest levels of demand for household consumption being in the south east, which, as noted above, has the highest water exploitation index. As noted further in Chapter 5, government targets for future house building are likely to exacerbate this trend.

Figure 3.18. Household water use in England and Wales 1992 to 2007.



Management of flood risk

3.67. Around five million people in two million residential properties live in flood risk areas in England and Wales and over £200 billion worth of assets are at risk of flooding.[18] The major floods in recent years have raised public attention to the issue. The floods of 2007 that affected Yorkshire, the Humber, the Midlands and the South West (Gloucestershire) flooded 55,000 properties and resulted in the largest loss of central services since World War II - almost half a million people were without mains water or electricity, a dam breach was narrowly averted and emergency facilities were put out of action.[19]

3.68. As noted earlier, the level and type of flood risk depends on the way rainfall and other forms of precipitation are intercepted across the whole catchment (flood generation) and on how flooding itself develops in river channels and floodplains (flood propagation). The pressures and responses of these are different, and separate approaches to monitoring the state of the mechanisms in play, and their environmental limits, are required.

Flood generation

Existing and potential indicators of flood generation

3.69. The generation of floods across catchments as a whole is dependent on the amount and periodicity of precipitation, coupled with a range of factors that determine the rate at which water is intercepted by vegetation and soils and moves into river systems or groundwater. These factors include the slope, soil type and land cover. Highest levels of flood generation occur after intense rainfall and/or snow melt, on steep slopes where water runs over impervious or waterlogged soils and into river systems. Lack of vegetation cover, compacted soils, hard services and well-developed drainage systems can all increase the rate of flood generation.

3.70. Monitoring such a large number of pressures, which can vary widely in space and time, is complex. Research for the Environment Agency in 2007 as part of *Making Space for Water* (HA6 and HA7), known as the Sensitive Catchments Study,[20] modelled the pressures on surface water run-off across England and Wales. It developed separate layers of data at a resolution of one km^2 for levels of precipitation, slope, soils and land use. These layers were combined to provide an overall measure of sensitivity of land use leading to surface water run-off in each one-km tile, distinguishing between high, moderate, low and very low sensitivity. The study excluded developed land, but the large extent of impermeable services means that developed land is highly sensitive to surface water run-off, contributing to a risk of flooding. This combined sensitivity is mapped in Figure 3.19.

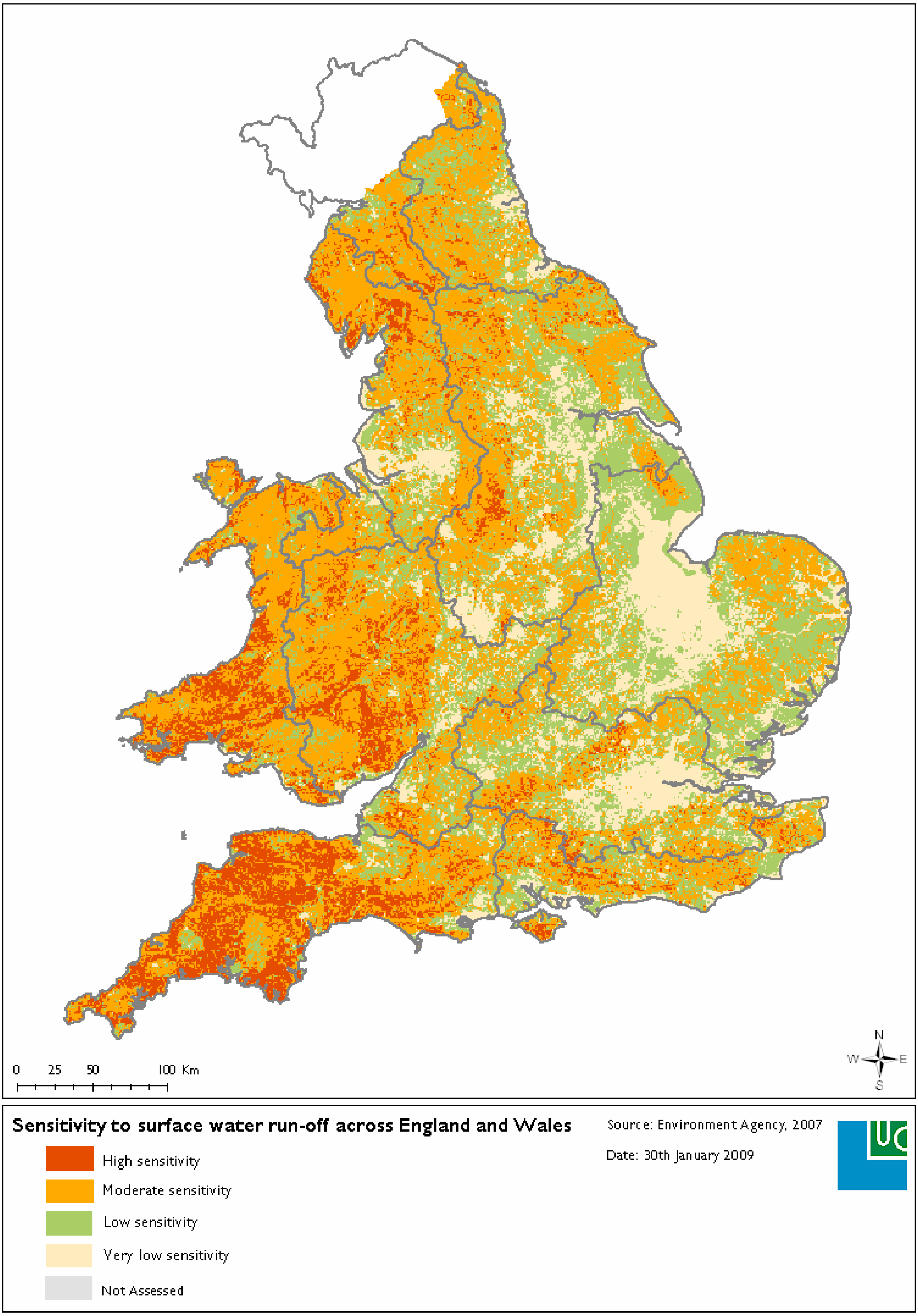
Environmental limits for flood generation

3.71. This relatively simple method did not seek to establish an environmental limit in relation to a threshold (for instance the point at which run-off overwhelms drainage systems) or a policy target. Nevertheless, it provides evidence-based data at a relatively fine scale that identifies the combined pressures for surface water run-off, which may, depending on the capacity of drainage systems and rivers to carry water away, lead to high risks of floods. For this study, high and moderate combined sensitivity are assumed to represent levels of surface water

[18] Evans *et al.* (2004)
[19] Pitt, M (2008)
[20] Environment Agency (2008)b

run-off that are highly likely to generate flooding. However, these data do not enable an environment limit for the risk of flooding to be defined or monitored.

Figure 3.19. Sensitivity of land use to surface water run-off across England and Wales.



3.72. Figure 3.19 shows that the areas of highest sensitivity for surface water run-off occur in Wales and the western parts of England where rainfall levels are highest and, at a more local scale, on valley and scarp slopes. Areas of peat soils such as occur on the Cambrian plateau in central Wales, the South West uplands and along the Pennines tend to have moderate to low levels of sensitivity to run-off reflecting the absorptive properties of peat and the organo-mineral soils of the uplands. Sensitivity to run-off is generally lower on the eastern side of England. Moderate to high sensitivity occurs on the higher ground, steeper slopes and arable dominated landscapes of the chalk and limestone outcrops of the South Downs, North Wessex Downs, Chilterns and Cotswolds and Yorkshire Wolds. Low-lying areas such as the Fens, Humberhead Levels and Somerset Levels are shown as having very low levels of sensitivity for run-off but are clearly at greatest risk from flood propagation.

Flood propagation

Existing and potential indicators of flood propagation

3.73. Flood propagation occurs when water from river systems, the water table and from high marine tides meets in river channels and floodplains. The level of flooding is influenced by the periodicity of these three sources of water (extent to which peak flows from different rivers meet at a confluence and, in the lower reaches of rivers, the extent to which these occur at high tide). The morphology of river channels and floodplains is also an important factor, with physical obstructions and roughness of land cover (such as hedgerows, woodland and dense crops) all acting to slow the passage of flood water and flood propagation. In addition, flood defence structures will have been constructed to protect sensitive properties and remove valuable farming areas from the floodplain.

3.74. The Flood Map was developed by the Environment Agency in 2004, and has been updated regularly since, to help planning authorities take account of flood risk in spatial planning and development control (as required in England by Planning Policy Statement 25 on Development and Flood Risk, PPS 25). The model predicts the risk of flooding from rivers or the sea based on detailed surveys of topography and river and tidal flows and, where detailed surveys are not available, on national generalised modelling of the topography. In total, 80,000 km of watercourse and the entire coastline of England and Wales have been modelled to produce the data for Flood Map.

3.75. The Flood Map covers the whole of England and Wales and uses the zones specified in PPS25 to show the areas subject to three different levels of flood risk. PPS25 requires local planning authorities to use their Strategic Flood Risk Assessments to identify the 'functional floodplain' which lies within the highest flood risk zone and comprises land where water has to flow or be stored in times of flood. This area is not mapped on the Flood Map. The three flood risk zones used in the Flood Map are defined in Figure 3.20 below.

Figure 3.20. Flood zones defined in PPS25 and used in The Flood Map.

• Zone 1	Little or no risk with an annual probability of flooding from rivers or the sea of less than 0.1%
• Zone 2	Low to medium risk with an annual probability of flooding of 0.1-1.0% from rivers or 0.1-0.5% from the sea.
• Zone 3	High risk with an annual probability of flooding of 1.0% or greater from rivers or 0.5% or greater from the sea.

3.76. Flood zones are based on annual probabilities of flooding. Thus it is possible (but unlikely) that a flood with, for example, an annual probability of one per cent will occur two years running. The zones show the flooding that would occur without the presence of defences.

3.77. The Flood Map is supported by the results from the National Flood Risk Assessment 2004 which provides an indication of the probability of flooding for a range of events, taking account of the presence of flood defences and their condition.

3.78. The Flood Map is represented in Figure 3.21 with Zone 3 shown as a high risk of flood propagation, Zone 2 as a moderate risk and Zone 1 as a low risk.

3.79. Figure 3.21 shows that the main areas at risk of coastal flooding are the Wash and Fens of Lincolnshire and Cambridgeshire, Lincolnshire Coast and banks of the Humber Estuary, Norfolk Broads, Thames Estuary (south Essex and north Kent marshes), Romney Marsh, the Somerset and Gwent Levels and the Lancashire Coast around Morecombe Bay. Several major centres of population such as London and Hull are at risk of coastal flooding.

3.80. Almost all the major rivers in England and Wales have substantial floodplains in their middle and lower reaches. Examples of rivers with large floodplains are (moving clockwise around the country) the Trent, Nene, Great Ouse, Thames, Medway, Arun, Avon (Dorset and Wiltshire), Severn, Usk, Dee, Ribble and Eden. Many towns located in or on the edge of large floodplains are at risk of flooding during periods of extreme rainfall. Towns and cities that have been inundated in recent years include York (the Yorkshire Ouse), Hull (the Humber), Lewes (the East Sussex Ouse), Tewkesbury (the Severn) and Carlisle (the Eden).

Environmental limits for flood propagation

3.81. The concept of environmental limits does not lend itself easily to flood propagation. Frequency of flooding in itself is no indication of acceptable flood risk management since it is appropriate (and desirable) that some areas should be encouraged to flood frequently so as to reduce the risk on other areas with important economic, social or environmental assets. The zones in the Flood Map do not, therefore, directly translate into different levels of environmental limit. The distinction between areas where flooding is tolerated and where it is unacceptable are not recorded on the Flood Map or the National Flood Risk Assessment. Local planning authorities are expected to identify the functional floodplain, where priority should be given to flood storage in development control decisions in Strategic Flood Risk Assessments (one of the statutory development plan documents supporting Local Development Frameworks). To date, most local planning authorities have not completed Strategic Flood Risk Assessments.

3.82. At the same time, Catchment Flood Management Plans (CFMPs) are public documents prepared by the Environment Agency in close consultation with partners. They provide an agreed (but not statutory) basis for investment in flood management throughout England and Wales. CFMPs seek to describe the factors that contribute to flood risk within each catchment, such as how the land is used, and they recommend the best ways of managing the risk of flooding within the catchment over the next 50 to 100 years. CFMPs have been drafted and recently undergone a process of consultation. But again, they do not define environmental limits with regard to flood propagation.

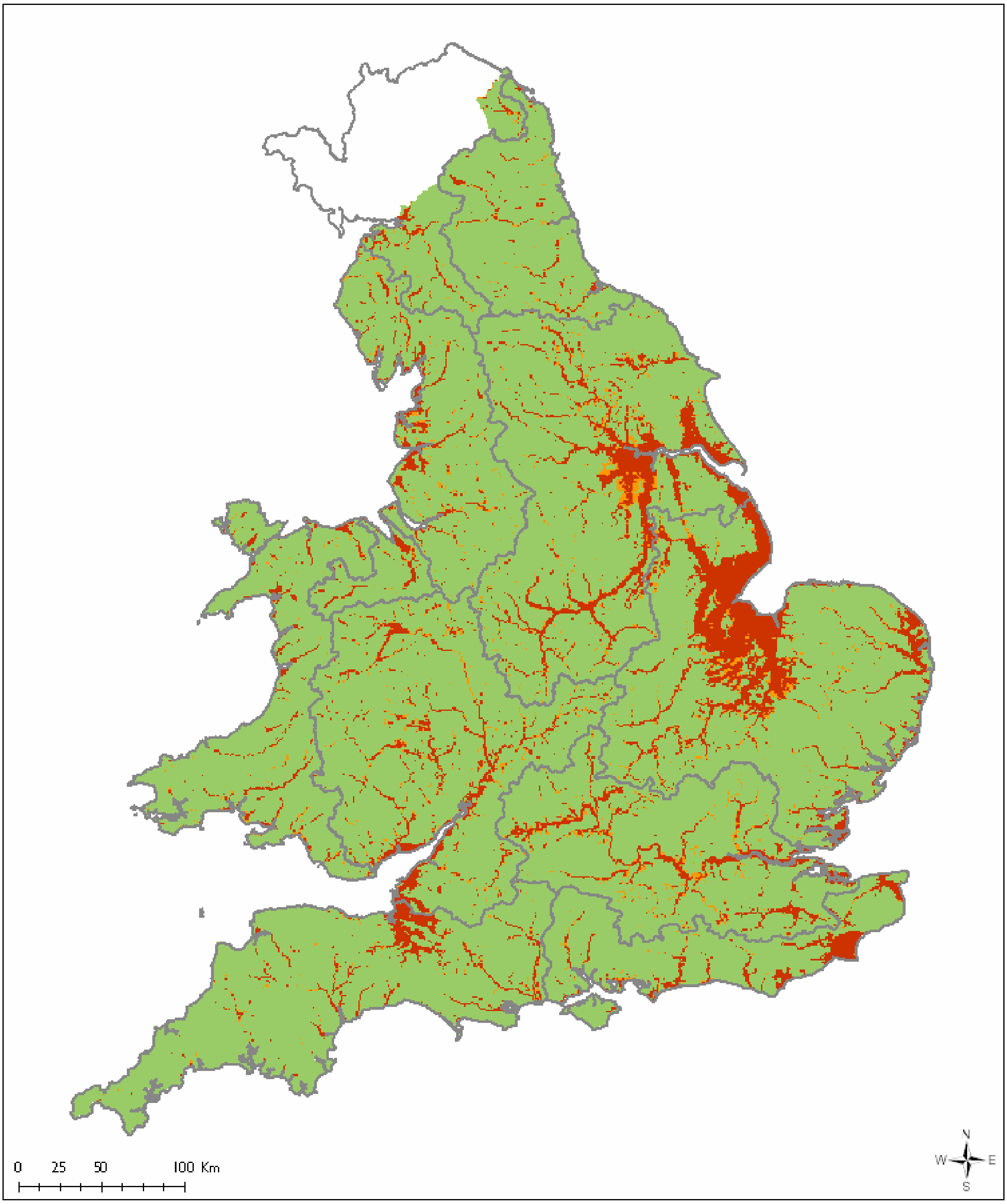
Recent trends in flooding

3.83. The wide annual variation in rainfall, and the presence of long-term cycles in the climate, mean that it is difficult to be certain about trends in flooding. On the one hand, three of the seven rivers covered by the Environment Agency's environmental indicator of flooding show a statistically significant increase in frequency of peak river levels over the last few decades. However, there is evidence that flooding comes in cycles and that at least 70 years of data is needed to give a reliable estimate of trend. The River Severn has the longest dataset (80 years) and this shows no significant long-term trend in flooding. Figure 3.22 shows the trends in flood peaks in four selected rivers, two of which show significant increases and two which do not. It is important to emphasise that land and water management are likely to have had a significant influence on these data. The increasing flood peaks are likely to be attributable to the influence of land use change between the 1930s and 2000s[21] and water resource management, including water transfer schemes between catchments, are likely to have affected river flows (such as the Wye[22]).

3.84. Flooding at the coast and in the lower reaches of rivers occurs in response to high tides and surges in sea levels. Sea levels in the South East of England have been rising for many centuries as the land sinks as a result of the isostatic response of the land surface following the last ice age, leading to increasing risk of flooding from the sea in these areas, as shown by the increased frequency of use of the Thames Barrier to protect London. This is now being exacerbated by sea level rise associated with the effects of climate change.

[21] Personal communication. Hillary Miller, CCW.
[22] Personal communication. Simon Neale, Environment Agency.

Figure 3.21. Risk of flood propagation across England and Wales.



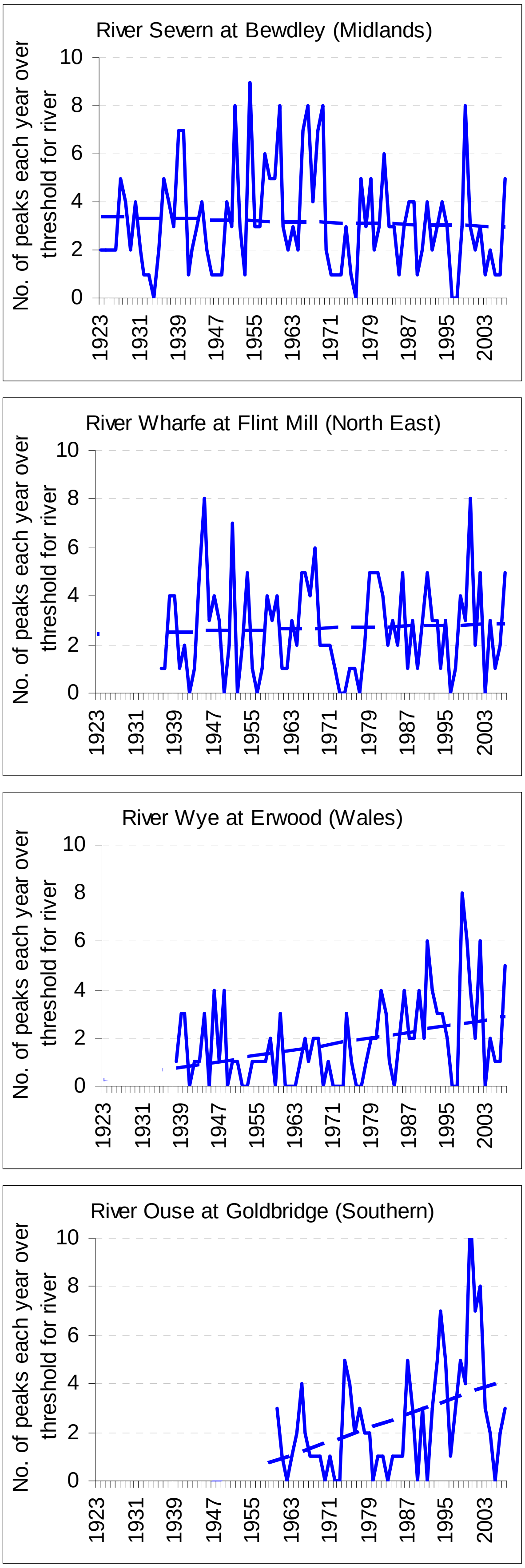
Risk of flood propagation across England and Wales

Source: Environment Agency Flood Map

Date: 30th January 2009

- High risk (An annual probability of flooding of 1.0% or greater from rivers or 0.5% or greater from the sea)
- Medium risk (An annual probability of flooding of 0.1-1.0% from rivers or 0.1 - 0.5% from the sea)
- Little or no risk (An annual probability of flooding from rivers or the sea of less than 0.1%)

Figure 3.22. Frequency of river levels exceeding thresholds in four selected rivers.



Source: Environment Agency Environmental Indicators: Flood levels in England and Wales. The data shown are the number of peaks in a year over a threshold that is specified for each river. The threshold is the level which is exceeded on average three times a year over the period 1980 to 2000.

Storage of carbon in soils

3.85. Carbon is the major chemical component of organic matter, which in soils increases its ability to bind chemicals, buffer the release of pollutants, regulate the supply of nutrients, improve soil structure and make soil more resistant to the effects of drought and erosion.[23] In addition, the storage of carbon in soils prevents its release into the atmosphere, which contributes to climate change.

3.86. Soils in England and Wales are estimated to contain around two billion tonnes of organic carbon, of which 60 per cent is present in the top 30 cm[24]. There are concerns that levels are declining in certain soils and that atmospheric CO_2 levels are increasing as a result. The Environment Agency has estimated that the cost of soil carbon loss, a considerable proportion of which will end up as atmospheric CO_2, stands at around £85 million per annum.[25] As the effects of climate change become more pronounced, losses of soil carbon are expected to increase as changes in temperature and in soil moisture content affect carbon turnover. As such, there is a need for greater understanding of processes behind carbon sequestration and storage in soils and of potential measures to reduce losses.

3.87. There is a growing base of evidence on the cycling of carbon in ecosystems and soils, and on the extent to which soils and vegetation act as a store of organic carbon. Living peat bogs and woodlands are major sequesters of carbon, although all plant materials sequester CO_2 to some extent. Peat and organo-mineral soils act as major carbon sinks, as do estuarine mud and salt mashes. Many blanket bogs in the uplands are now in unfavourable condition following years of management under the Common Agricultural Policy (CAP) which led to overgrazing and burning to support the increasing numbers of sheep being grazed. This has severely damaged the top 'living skin' of the bogs while drainage with grips has caused many to dry out which has had a similar effect, with the exposed dry peat being susceptible to erosion.

Existing and potential indicators of the storage of carbon in soils

3.88. Compared to the other three services, research into the spatial distribution of soil carbon, and the natural and human-driven cycles that release carbon from and store it in soils, is at an early stage.

3.89. Elementary data for the organic carbon content of soils at the 0-15 cm depth across England and Wales was recorded in the National Soil Resources Institute's (NSRI) National Soils Inventory (NSI). The carbon content for soil horizons is available through Horizon Fundamentals, which links to the NATMAP vector data. The NSI sampled soils on a 5-km by 5-km grid across England and Wales during the period 1978 to 1983 (with a proportion of samples being repeated since). Amongst the range of data collected in the NSI is the carbon content in each soil horizon. Summary data from the NSI (consisting of key characteristics of the dominant soil series in each one km^2) was available to this study through the National Soils Map of England and Wales that is held under licence from the NSRI by the Environment Agency.

[23] Defra (2008)d
[24] Dawson and Smith (2006)
[25] Defra (2008)d

This dataset records the percentage of organic carbon in each soil horizon (the depth of which varies between each soil series).

3.90. The Countryside Survey (see paragraph 4.19) measured the carbon content of the top 15 cm of soil in a stratified sample of sites across England and Wales in 1978, 1998 and 2007. Unlike the NSRI, Countryside Survey provides only partial spatial coverage. Comparison of NSRI and Countryside Survey data has revealed significantly different trends in soil carbon.

Environmental limits for storage of carbon in soils

3.91. The concept of carbon flux was developed by Cranfield University, the Macaulay Land Research Institute and Centre for Ecology and Hydrology, amongst others. Carbon flux describes the dynamic processes through which carbon originating in plant material is immobilized and held in soils and through which soil carbon may be mobilized into atmospheric carbon dioxide or leached out dissolved in water. Soil carbon accumulates if the rate of immobilization exceeds mobilization and it is lost if the reverse is true. These rates vary naturally with rainfall and temperature (which determine levels of plant growth and soil chemistry), leading to seasonal and multi-annual cycles.

3.92. There is growing scientific and policy interest in how human activity (such as land use and management, abstraction of water and atmospheric deposition of nitrogen) affects carbon flux in soils. A team from the Centre for Ecology and Hydrology (CEH) is researching the emissions and removals of carbon arising from land use and land use change across the UK[26]. This work includes emissions from the use of fossil fuels in agricultural machinery and fertiliser and other causes of carbon releases that do not relate to soil carbon. The data from this work was not available to this study.

3.93. In due course, when the processes of carbon flux are better understood, it will be possible to define an environmental limit for the point at which net losses or gains of carbon reach an unacceptable level. Given the importance of organic material in soils as a store for atmospheric carbon, any long-term loss of carbon from soils should be considered as exceeding the limit. However, peat soils store much more carbon than mineral soils and, where the semi-natural vegetation on these soils (particularly blanket bog) is growing, these soils are capable of sequestering large amounts of carbon (compared to mineral soils where carbon sequestration is much slower). This suggests that an environmental limit should focus on soils with highest levels of organic carbon and greatest potential to increase these.

3.94. The information needed to spatially map the current levels of carbon emissions or sequestration from soils is not available. Instead, the study can report on the spatial distribution of those soils that contain the greatest volume of carbon within their first horizon (the depth of which will vary) from the National Soils Map of England and Wales. Bellamy *et al.* (2005) mapped and analysed the NSRI data on soil carbon, which might be considered more accurate than the National Soils Map data, but the detailed spatial data from that work was not available to this study.

3.95. Figure 3.23 shows that highest concentrations and largest areas of soil carbon are found in the upland peat soils of the north of England (such as the Pennines, Cumbrian Fells, Forest of Bowland and Peak District), Wales (such as Snowdonia, the Cambrian Mountains and Brecon Beacons) and the south west of England (Dartmoor, Exmoor and Bodmin Moor). In these areas, the deepest peat soils have developed on raised bogs, with shallower peat under

[26] Mobbs *et al.* (2007)

dwarf shrub heath and acid grassland. Significant areas of soils with high concentrations of organic carbon in the first horizon are also present in the lowlands, including the relatively deep peat soils found in the Fens of Cambridgeshire, Somerset Levels, Lancashire Mosses and Norfolk Broads (areas where historically peat developed from sphagnum moss growing in lowland bogs), and the shallower peat deposits on lowland heathland such as the New Forest, Thames Basin Heaths, and Cannock Chase.

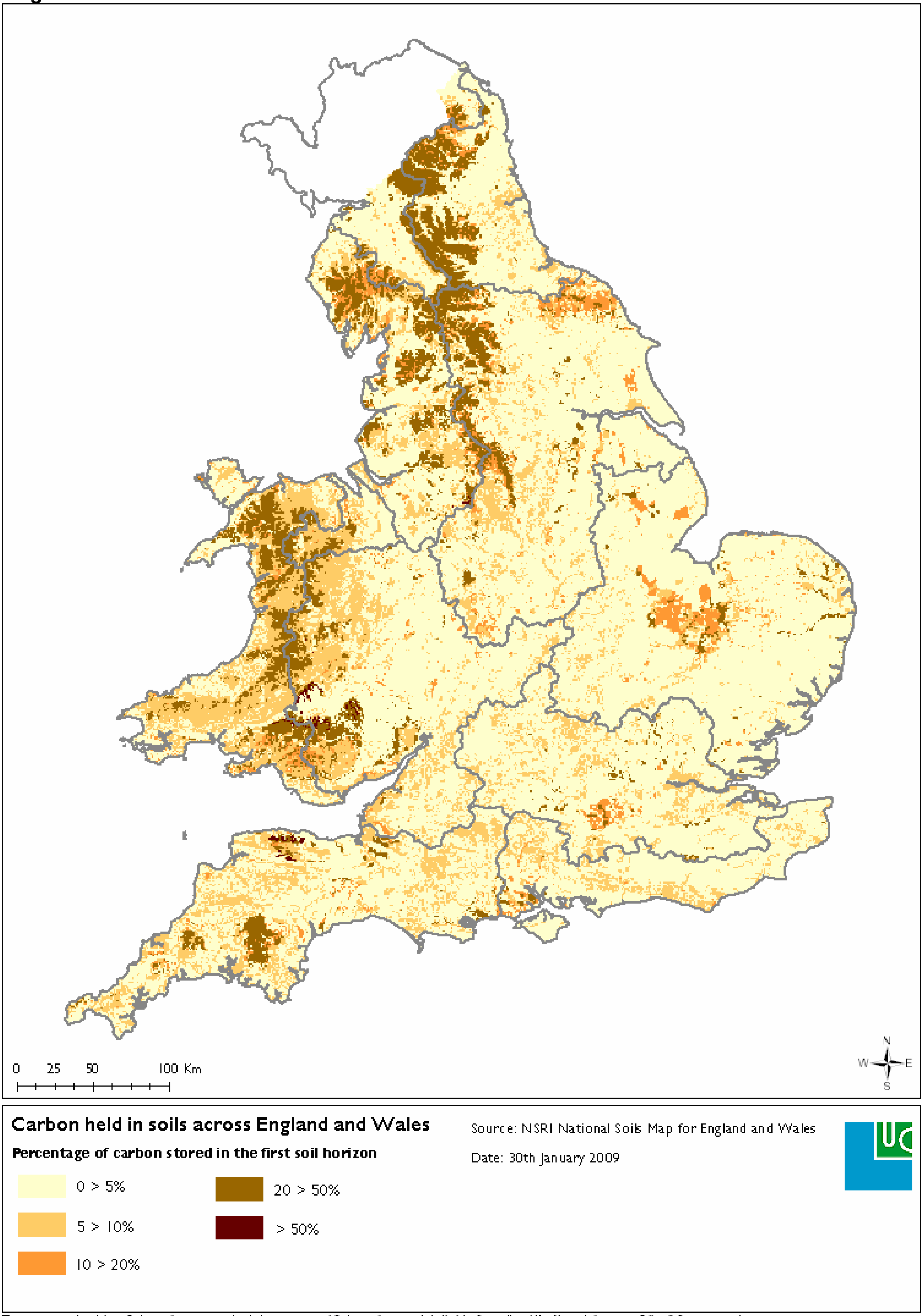
Trends in the storage of carbon in soils

3.96. The recent changes of soil carbon have been the subject of much debate. Two recent studies have come up with quite different conclusions. Bellamy *et al*. (2005)[27] used the National Soils Inventory data for 1978 to 1983 as a baseline and compared this with data collected from a sample of the NSI sample points during 1994 to1996 (for cropland and managed grassland) and 2002-2003 (for forestry, moorland and extensive grazing). These comparisons suggested that carbon was being lost from soils at a mean rate of 0.6 gm of organic carbon per kg of soil per year. For soils with more than 100 gm per kg carbon rate of loss greater than 2 gm per kg per year (soils with higher carbon contents were losing carbon at a faster rate than those with lower carbon content). The research team suggested that these losses were likely due to climate change, with other factors being the extension and intensification of agriculture and forestry on peat lands and atmospheric pollution (increased nitrogen deposition). This analysis has been challenged by others[28] who have suggested that climate change is likely to account for only 10-20 per cent of carbon losses and that overall losses may be less than those reported.

3.97. More recently, the Centre for Ecology and Hydrology (CEH) used the results of soil samples collected as part of the Countryside Surveys of 1978, 1998 and 2007 to monitor changes in soil carbon in the top 15 cm of soil.[29] Overall for Great Britain there was no significant difference between the mean carbon concentration in 1978 and 2007, although changes were noted during this period.

[27] Bellamy *et al.* (2005)
[28] Smith *et al.* (2007)
[29] CEH (2008)

Figure 3.23. Percentage content of organic carbon in the top soil horizon across England and Wales.



Conclusions

3.98. In this chapter, the potential indicators of the delivery of each of the four key services were described and the best sources of data to set suitable environmental thresholds were selected. The data sources and environmental thresholds selected are summarised in Figure 3.24 below.

Figure 3.24. Summary matrix of selected environmental thresholds.

Environmental service	Sub-category	Data source	Environmental threshold or measure of potential impact
Regulation of water quality	Ecological status of rivers	WFD Compliance monitoring. Overall Ecological Classification	Above threshold: classes high, good and moderate. Below threshold: classes poor and bad
	Chemical status of rivers	WFD Compliance monitoring. Overall Chemical Classification	Above threshold: Good condition. Below threshold: Failing to achieve good condition
	Chemical status of groundwater	WFD Compliance monitoring. Overall Chemical Classification	Above threshold: Good condition. Below threshold: Poor condition
Availability of water resources	Surface water bodies	WFD (RBC2) Risks from surface water abstraction and flow pressures	Above threshold: No risk and low risk. Below threshold: High risk and moderate risk
	Groundwater	WFD (RBC2) Risks from groundwater abstraction	Above threshold: No risk and low risk. Below threshold: High risk and moderate risk
Management of flood risk	Flood generation	Research: Environment Agency (2008) Identification of catchments sensitive to land use change	No spatial data to define a threshold for flood generation. But: Low sensitivity and very low sensitivity to surface water run-off likely to indicate low risk of flood generation. High sensitivity and moderate sensitivity to surface water run-off likely to indicate high risk of flood generation.
	Flood propagation	Environment Agency Flood Map	No spatial data to define a threshold for ***acceptable*** levels of flood propagation. But: Flood map Zone 1 defines areas with little risk of flooding. Zone 3 (high risk) and Zone 2 (moderate risk) defines areas at higher risk of flooding.
Storage of soil carbon	Carbon content of soils (percentage)	National Soils Map of England and Wales. Percent carbon in the first horizon	No spatial data available to define threshold. Areas at highest risk: Soils with more than 20 per cent organic carbon in first horizon

4. Land use and capability

4.1. The focus of this study is on the impacts of land use and management on the environmental services explored in the last chapter. Before these impacts can be analysed, it is necessary to provide a brief overview of the different forms of land use that occur in England and Wales. This chapter:

- introduces the different categories of land use in this study;
- briefly examines the distinction between land use and management;
- examines the various sources of data on the distribution of land use;
- reviews the areas and trends in each category of land use;
- reviews evidence on land capability as a measure of the potential productivity of land.

Categories of land use adopted in This study

4.2. Land use describes what land is used for, distinguishing between broad functional categories of land cover. The categories adopted depend on issues under consideration. For instance, the Generalised Land Use Database maintained by the Department for Communities and Local Government (CLG) distinguishes nine categories of land use, seven of which relate to different types of developed land and one of which (greenspace) covers all land used for agriculture and forestry (see paragraph 4.22 and 4.34 below). In contrast, categorisations in relation to biodiversity concentrate on differences in semi-natural habitats but pay little attention to highly modified forms of land use (paragraph 4.21). Previous studies that have examined the relationship between land use and water based services have adopted a relatively simple classification of cultivated, pastoral and forestry land,[30], while others have focussed on differences in land management rather than categories of land use.[31]

4.3. Another important criterion for the choice of land use categories in this study is the availability of spatial data for England and Wales. As explained in more detail below, the classes and sub-classes used in the Land Cover Map data for 2000 were an important consideration in the choice of land use categories for this study.

4.4. Finally, given that this study seeks to influence strategic land use policies, it is important to use categories that reflect public policy paradigms (for instance between developed, agricultural, forestry and semi-natural uses).

4.5. Taking these considerations into account, nine categories of land use were adopted for this study, as follows:

- ***Developed land***: Urban, including residential land, urban open space, industrial uses and other built developments.
- ***Arable and horticultural crops:*** Including combinable crops, field vegetables and intensive horticultural cropping.

[30] See, for example LUPG (2003)
[31] For example Defra and Environment Agency (2004)

- ***Improved grassland***: Agriculturally improved grassland, consisting of temporary grass leys and permanent pasture that is seeded and fertilised for agricultural production.
- ***Semi-natural grassland:*** Grassland receiving little or no inorganic fertiliser and including calcareous, neutral and acid grassland, and other related habitats (such as bracken dominated land).
- ***Dwarf shrub heath, fen, marsh and bog***: Heathland and wetland vegetation found both on upland moorland and lowland heath and fen.
- ***Broadleaved woodland:*** Covering broadleaved woodland whether semi-natural or not, and whether actively managed or not.
- ***Coniferous woodland:*** Consisting mostly, but not exclusively, of plantation forestry.
- ***Coastal habitats:*** Including saltmarsh and intertidal mudflats and rocky shorelines.
- ***Inland water:*** Including ponds, lakes and reservoirs.

Relationship between land use and management

4.6. Land management is concerned with how land is managed rather than with land cover. Examples of land management are land drainage, soil cultivation, irrigation, applications of inputs, harvesting of crops, use of livestock and control of non-crop vegetation.

4.7. Land use categories tend to be mutually exclusive – one can talk about conversions from one use to another (for instance from semi-natural grassland to improved grassland or from arable to developed land). This is not the case for land management activities which can operate in a wide variety of combinations and on a continuum (for instance varying intensities of livestock grazing or inputs of fertiliser).

4.8. Because differences in land management are often not visible and because land management can change over short distances and time periods, it is more difficult to map the spatial distribution of land management than land use.

4.9. Critically for this study, land use and management can act as pressures on the state of environmental services and can provide opportunities for relieving or mitigating other pressures. In terms of policy interventions to address these pressures, it is usually land management that is addressed first before changes in land use are sought.

4.10. This means that, while it is easier to identify spatial relationships between land uses and environmental services, action to address pressures is more likely to focus on land management than on land use. However, these changes in management may be more difficult to quantify in a spatial sense.

4.11. The remainder of this chapter is limited to consideration of land use and the related issue of the capability of land to support different land uses. The relationship between land use and management is returned to again in the following chapters.

Sources of data on land use

4.12. An essential requirement of this study is to be able to describe and map the distribution of land use across England and Wales, since it is against this baseline that the levels of service delivery are compared in the following chapters. As noted above, the baseline of land use needs to differentiate between different forms of agricultural and woodland management, as well as showing areas of semi-natural vegetation and developed land. Key sources of data are identified below.

Land Cover Map

4.13. Land Cover Map 2000 is a digital map prepared by the Centre for Ecology and Hydrology (CEH) created by analysis of data from Earth observation satellites acquired during the summer and winter of 1998 or the nearest alternative year. [32] It updates an early but less detailed map produced in 1990. An updated map, using data derived from Countryside Survey 2007, will be available in 2009 (individual country-level reports will be available in March/April 2009 and access to GIS data later in 2009).

4.14. The map is built up from a grid of approximately 25 m x 25 m cells or 'pixels'. The data portray a landscape structure in which individual land parcels and dissected patterns of semi-natural vegetation can be distinguished.

4.15. The technical process through which the remote-sensing data were converted to digital information on different land use types is outside the scope of this report.[33] However, the process was largely automated with limited use of field surveys to 'ground truth' the data. This led to a limited level of error in the data.

4.16. Land Cover Map 2000 is available from CEH in different formats. For this study, raster data using the standard level of detail, or Level 2 (see below), were used. Two resolutions of these data are available: 25 metre squared and one kilometre squared. It was decided that the one-km^2 version, which takes the dominant target/subclass value from the combined 25 m pixels which lie within it, was more suitable for this study which is reviewing land use at the national level.

4.17. The standard level of detail (Level 2) provided by CEH distinguishes between 26 sub-classes of land use across the UK as a whole. Of these 26 sub-classes, three are not present at the one-km^2 level in England and Wales (montane habitats, littoral rock and supra-littoral rock). Given that this study sought to provide a relatively high level overview of land use (spatially and thematically), the 23 sub-classes present at the one-km^2 level in England and Wales were rationalised to create nine land use types for this study. These are shown in Figure 4.1.

4.18. Some concerns have been voiced about the accuracy of LCM 2000. For instance in Wales, comparison between LCM 2000 and the Phase 1 Habitat Map (described below) highlighted inconsistencies which, when groundtruthed, were shown to be errors in LCM 2000. However, while it is not perfect, LCM 2000 has the advantage of providing complete cover for both England and Wales in a format that is widely recognised and used across government agencies and departments.

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[32] www.ceh.ac.uk/sections/seo/lcm2000_home.html

[33] More information is available from Fuller *et al*. (2002)

Figure 4.1. LCM 2000 Level 2 subclasses and land use types used in this study.

LCM2000 Subclasses	L2 class no.	% 1km tiles	Land Use Type	% 1km tiles
Arable cereals	4.1	14.0	Arable and horticultural crops	34.9
Arable horticulture	4.2	20.8		
Non-rotational horticulture	4.3	0.1		
Improved grassland	5.1	32.8	Improved grassland	33.0
Set-aside grass	5.2	0.2		
Neutral grass	6.1	3.4	Semi-natural grassland	10.5
Calcareous grass	7.1	2.8		
Acid grass	8.1	3.8		
Bracken	9.1	0.4		
Suburban/rural developed	17.1	6.5	Developed land	8.8
Continuous urban	17.2	2.1		
Inland bare ground	16.1	0.2		
Broad-leaved woodland	1.1	4.8	Broad-leaved woodland	4.8
Coniferous woodland	2.1	2.5	Coniferous woodland	2.5
Dwarf shrub heath	10.1	1.2	Dwarf shrub heath, fen, marsh and bog	2.7
Open dwarf shrub heath	10.2	0.8		
Fen, marsh, swamp	11.1	0.0		
Bog	12.1	0.7		
Sea/Estuary	22.1	1.2	Coastal habitats	2.
Littoral sediment	21.1	1.1		
Saltmarsh	21.2	0.2		
Supra-littoral sediment	19.1	0.1		
Water (inland)	13.1	0.3	Inland water	0.3

Countryside Survey

4.19. The Countryside Survey, which has been undertaken at regular intervals since 1978 by the Centre for Ecology and Hydrology and its predecessor the Institute of Terrestrial Ecology, provides an audit of the natural resources of the UK's countryside. The survey is based on a representative sample of survey areas (some are repeated in each survey and some are changed) to provide statistically significant data on the distribution and change in the condition of features, habitats and key species. The last survey was conducted in 2007 and overview reports were produced in 2008. More detailed reports and primary data will be published in 2009. While Countryside Survey does not provide complete spatial coverage of all areas of England and Wales, it provides a unique and valuable record of trends since 1978.

Habitat survey data

4.20. The Phase 1 Habitat Survey of Wales, which was completed in 1997 by the Countryside Council for Wales (CCW), provides coverage of the whole of Wales (80 per cent habitat land cover), based on extensive field survey between 1987-1997.[34] The survey used the established Phase I survey method[35] and distinguished between the UK Biodiversity Action Plan (BAP) broad habitats (such as arable and horticultural land, improved grassland and neutral grassland) as well as some priority habitats. The GIS dataset from this survey was made available to the study team.

[34] Howe *et al.* (2005)
[35] JNCC (2003)

4.21. In England there has been no equivalent Phase 1 Habitat Survey covering the whole country. However, separate surveys have mapped the extent of many of the BAP priority habitats (for instance lowland calcareous grassland, upland heath and upland oakwoods) and Natural England has also drawn together data from county level surveys (particularly for unimproved grassland) into national datasets. These datasets can be accessed from the Magic.gov.uk website.

Generalised Land Use Database (GLUD)

4.22. This database is maintained by the Department for Communities and Local Government (CLG) and covers England. It is sampled data based on the categories of land use recorded by the Ordnance Survey. Its primary focus is on developed land, with a single category ('greenspace') covering the majority of England that is not developed. The latest version of the database, produced in 2005, distinguishes between the following nine categories: domestic buildings; domestic gardens; non-domestic buildings; roads; rail; paths; greenspace; water; and other land uses. Summaries of the areas of each of these categories are available for each ward in England but not at a finer spatial scale.

4.23. The method used by the GLUD to classify different land uses has changed at intervals, making precise comparisons between different periods difficult. Data from 1989 onwards is considered by CLG to be most reliable[36].

National Inventory of Woodland and Trees

4.24. The Forestry Commission's National Inventory of Woodland and Trees (NIWT), which covers England, Wales and Scotland, is based on two separate datasets. The main survey dataset provides complete national coverage of all woodland over two ha in size. The second survey, based on a stratified random sample of one-km squares covering around one per cent of the land area, was used to estimate the area and character of small woodland (0.1 to 2.0 ha in size). The original data collection from aerial photography and sampled field work took place in 1995/1996 but the inventory has been periodically updated, with the latest update taking in data to 2002.

4.25. The main survey records the Interpreted Forest Type of each parcel of woodland. These types are conifer; broadleaved; mixed; coppice and coppice with standards (one type); young trees and shrubs (one type); ground prepared for planting and felled. These parcels of land are available as a GIS dataset, licensed from the Forestry Commission's UK Country Services in Edinburgh.

The June Agricultural Survey

4.26. The June Agricultural Survey is derived from returns provided by a sample of registered agricultural holdings. It provides data on the types of enterprise and tenure of holdings, the area of land under different crops and the numbers of livestock kept and staff employed on 1 June of each year. In England the data are provided at the level of district or unitary authorities and in Wales at the level of 'small agricultural areas'. Both are relatively large units of land and give poor spatial detail. In addition, data are withheld at this level where the number of holdings involved is small and revealing the data might allow individual holdings to be identified. However, the agricultural survey does allow regional

[36] Personal communication. Sarah Brown, DIUS

and national patterns in particular crops and livestock to be identified and, being an annual survey, it allows trends over time to be analysed.

IACS field data

4.27. Since 1994, farmers claiming certain subsidies from the Common Agricultural Policy have been required to complete field datasheets for the 'Integrated Agricultural Control System' or IACS. Until and including 2004, these field datasheets recorded the crops present on 15 March each year in each parcel of land which was being used to claim the subsidies.

4.28. Previous studies have used the 2004 field data provided by the Rural Payments Agency (RPA) in England to identify the cropping of land being used to claim subsidies. The reforms of the CAP that introduced the Single Farm Payment in January 2005 simplified the coding of land use in each field to the extent that the IACS field data is no long useful as an indicator of cropping.

4.29. The data released by the RPA in England for the years to 2004 suffers from a number of drawbacks. Firstly, land use is linked only to a national grid reference locating the centre of each field parcel and the area of the parcel is not given. Secondly, some agricultural sectors such as specialist horticultural and pig keeping businesses and dairy farmers who grew no arable crops and did not claim subsidies for beef or sheep did not need to complete an IACS return.

Conclusion on current land use

4.30. This study needed a consistent approach to describing land use that covered all of England and Wales and distinguished the main types of agriculture and forestry land management as well as areas of semi-natural habitat and developed land. Land Cover Map 2000 provided this and, despite a level of error in classification, was felt to give the best baseline data for this study. However, Countryside Survey 2007, The Generalised Land Use Database and the June Agricultural Survey gave valuable information on recent trends in land use change. The habitat survey data and the National Inventory of Woodland and Trees both provided alternative, and more detailed, sources of information on land use categories.

Distribution and summary data on land use

4.31. The following section takes each of the land use categories used by this study, describing its extent and distribution, and recent trends, based on the data sources covered above.

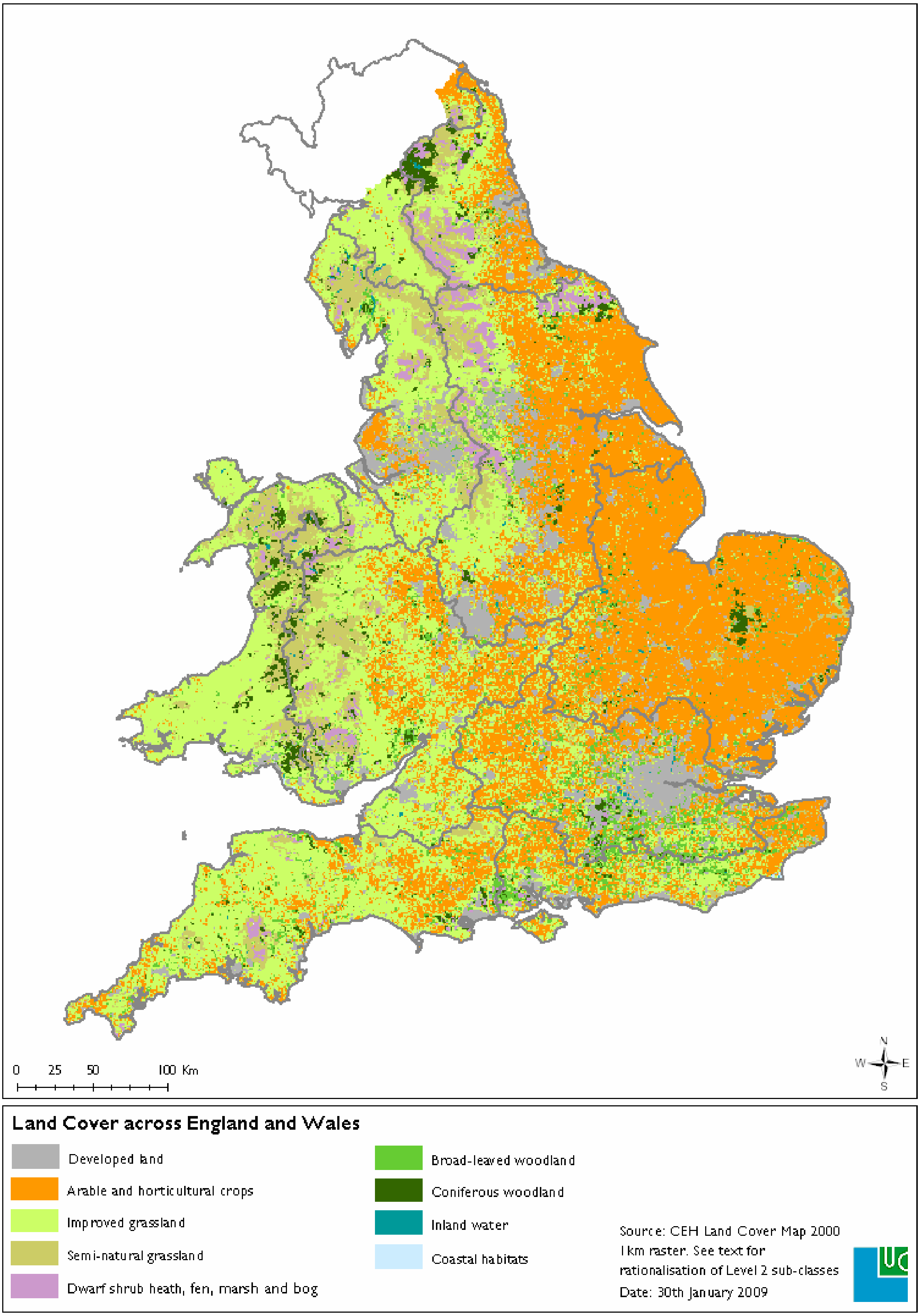
4.32. As context, Figure 4.2 maps the distribution of land use categories, based on the Land Cover Map 2000 data, at a resolution of one-km^2, and also shows the boundaries of the eleven River Basin Districts (RBD) used for the Water Framework Directive in England and Wales, including the Solway Tweed RBD, the majority of which is in Scotland. Two overall impressions emerge from this map.

- Firstly, the two dominant land use categories are: (a) arable and horticultural crops, which occur predominantly on the eastern side of England (particularly the Anglian and eastern parts of the Humber and Northumbrian RBDs); and (b) improved grassland, which predominates in Wales and the western parts of England (particularly in western Wales, the North West and South West RBDs).

- Secondly, the uplands regions (central Wales, the Pennines, Cheviots, Cumbrian Fells, North York Moors and South West Uplands) can be picked out by the high concentrations of semi-natural grassland and dwarf shrub heath land use types.

4.33. Other patterns are described further below.

Figure 4.2. Distribution of land use categories across England and Wales.



Developed land

4.34. In 2001, at the time of the last national population census, 1.2 million ha in England and Wales (eight per cent of the land area) occurred within settlements that had a population greater than 1,500.[37] Nearly 60 per cent of built-up areas occur in the 68 largest towns and cities (those with more than 100,000 population). Wales has significantly fewer built-up areas than England (Figure 4.3).

Figure 4.3. Summary of area and populations in settlements over 1,500 people, 2001.

Geography	No. settlements with pop'n over 1,500	Area (ha)	Percent of land area	Population
England and Wales	1,950	1,197,390	7.9	46,794,939
England	1,768	1,132,653	8.7	44,445,644
Wales	182	64,737	3.1	2,349,295

Source: UK Statistics Authority. 2001 Population Census

4.35. These built-up areas include large areas of green space. The Generalised Land Use Database shows that in England, half of developed land is occupied by domestic gardens, a quarter by roads and a fifth by buildings (the remainder being paths and rail).[38] There is significant variation between urban areas. For instance, the proportion of domestic gardens varies between 27% for the Inner London Authorities and 51% for the non-metropolitan authorities across the whole of England.

4.36. While the twentieth century saw an increase in built-up land, planning policy in the last ten years has been to focus growth on previously developed land ('brownfield' sites) within urban areas.[39] Nevertheless, rural areas face high demand for housing, and analysis of planning applications shows significantly more applications for permission to build or develop dwellings in rural than urban areas.[40] The latest results from the Countryside Survey 2007 show, perhaps surprisingly, no increase in area of built-up land in rural areas since 1998. These findings are contradicted by other work[41] which concludes that the broader countryside has accommodated more newly built dwellings and seen a greater net increase in the dwelling stock than has the urban margin.

4.37. In England, the Generalised Land Use Database shows:

- A net change to developed use of around 7,200 hectares of land a year between 1985 and 1996, falling to 5,000 ha in 2002 (the most recent year for which comparable data is available – See Figure 4.4).
- Most of the land being developed was previously used for agriculture, though a quarter of the land had other rural uses, such as forestry or outdoor recreation, or was undeveloped vacant land in urban areas. No equivalent data is available for Wales.

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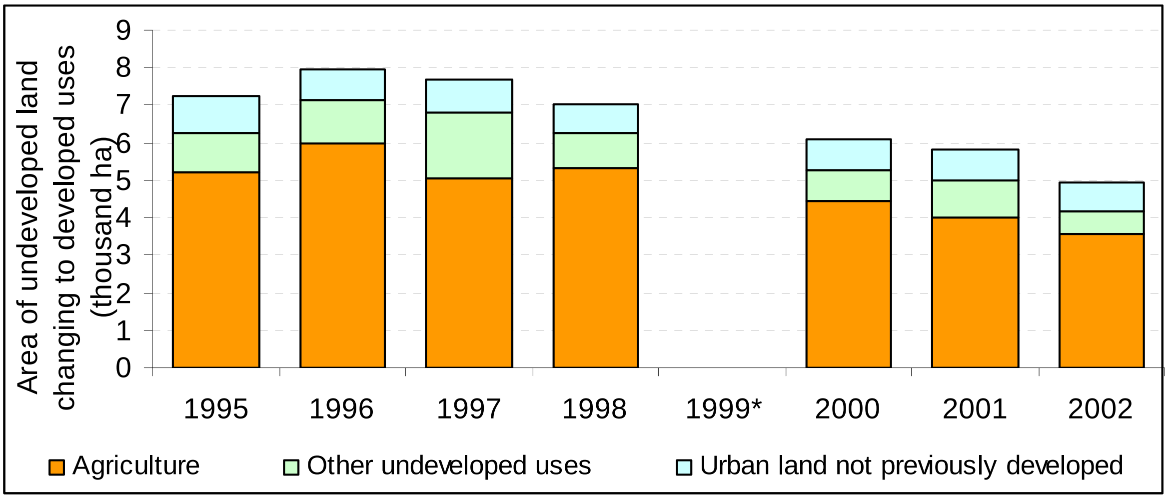
[37] The way these settlements are defined spatially by Ordnance Survey includes industrial and other employment land.
[38] CLG (2006)a
[39] Planning Policy Guidance Note 3 sets a target for planning authorities of at least 60 per cent of new housing to be built on previously developed land.
[40] Commission for Rural Community (2008)
[41] Countryside Quality Counts (CQC) report on Land Use Change at the Urban: Rural Fringe and in the Wider
Countryside (2006) between 1998 and 2003

Figure 4.4. Change of undeveloped to developed land in England 1995 to 2002.



Source: Communities and Local Government Generalised Land Use Database. Note: 1999 data incomplete.

4.38. The development of land at risk of flooding has been of increasing concern. Over the period 1996-2005, around seven per cent each year of newly developed land in England was situated in the floodplain, with significantly higher proportions in regions such as London, the East Midlands and Yorkshire and Humberside.[42]

4.39. Looking to the future, in England the Government wishes to see an increase in the rate of housebuilding to 200,000 homes a year. Most of this growth in housebuilding and the associated infrastructure is planned for the south east of England (including areas in the East and West Midlands, South West and East of England regions), although all regions of England will see significant growth, with growth areas and points identified as priorities for new development.

Arable and horticultural land

4.40. The and WAG Agricultural Surveys for June 2008 show arable and horticultural crops as occupying 37 per cent of land on agricultural holdings in England and Wales but only 27 per cent of the total land area[43] which is the same as the proportion of land occupied by the 'arable and horticultural broad habitats' class used by Countryside Survey 2007.[44]

4.41. The June Agricultural Survey for 2008 states that:

- cereal crops (principally wheat and barley) account for 68 per cent of the cropped area;
- other arable crops account for 29 per cent;
- horticultural crops (including field vegetables, orchards and crops grown under glass) account for only four per cent.

[42] CLG (2006)b
[43] Final results of the June Surveys of Agriculture and Horticulture: Defra (2008)e and WAG (2008)
[44] LCM 2000 data shows that the arable and horticultural land cover type dominates in nearly 35 per cent of the one-km tiles in England and Wales (Figure 4.1). This higher proportion than the Agricultural Survey and Countryside Survey 2007 data is due to rounding of the LCM 2000 data at the one-km resolution.

4.42. Figure 4.2 shows that arable crops are the dominant land use in most of the eastern side of England but are much less frequent in the west and Wales. Horticultural crops tend to be concentrated on land of the highest agricultural quality such as Kent, the Fens, southern Lincolnshire, the Vale of Evesham and southern Lancashire.

4.43. The Countryside Survey shows a significant decline of eight per cent in the area of arable and horticultural crops in England and Wales between 1990 and 2007, although this period saw a small increase in Wales.

Improved grassland

4.44. Countryside Survey 2007 shows ‘improved grassland broad habitats’ as occupying 24 per cent of land area (22 per cent in England and 24 per cent in Wales).[45] The June Agricultural Surveys state that:

- temporary grassland (less than five years old), all of which is likely to be agriculturally improved, covers five per cent of the land area;
- permanent grassland (five years old and over), some of which is likely to be semi-natural in its species composition, covers 29 per cent of land area;
- set-aside and bare fallow land occupies one per cent of the land area;
- the major difference between England and Wales is that permanent grassland covers 49% of Wales but 26% of England.

4.45. Figure 4.2 shows that improved grassland is found principally in Wales and the south west and the western half of the north of England, with a noticeable concentration in the Weald in the south east of England.

4.46. Together, arable and horticultural crops and improved grassland account for the large majority of agriculturally managed land.

4.47. Noticeable trends in improved grassland are a seven per fent fall in the area of improved grassland in England between 1990 and 2007 compared to little change in Wales (Countryside Survey 2007). In contrast, the June Agricultural Surveys show an overall rise between 1996 and 2008 in the area of grassland under agricultural management, but a fall in the area of temporary grassland.

4.48. The area of set-aside land fell by 200 per cent between 1996 and 2008 due to the removal in 2008 of set-aside as a compulsory requirement for farmers claiming agricultural support under the CAP. The January 2009 update of the Defra Agricultural Observatory report *Change in the Area and Distribution of Uncropped Land in England* highlights this recent trend, showing that the area of uncropped land (set-aside and fallow) fell by 62 per cent in England between 2007 and 2008.

Semi-natural grassland

4.49. This land use type includes agriculturally unimproved grassland (covering the semi-natural types of neutral grassland, calcareous grassland and acid grassland) as well as bracken dominated land.

- LCM 2000 shows this land use being the predominant land use in 10.5% of the land area at the one-km^2 resolution

[45] LCM 2000 shows that improved grassland (including a small area of set-aside grassland) dominated the land cover in 33% of the one-km tiles. Again the difference is due to rounding at this resolution.

- Countryside Survey 2007 data shows semi-natural grassland accounting for 16 per cent of the land area (14 per cent in England and 23 per cent in Wales).

4.50. Figure 4.2 shows that the main concentrations of semi-natural grassland (at the resolution of one-km^2) are in the uplands of central Wales, and northern and south west England. Although present in small parcels in the lowlands, these areas are rarely large enough to register as the dominant land use in any one-km^2.

4.51. As noted above, a proportion of the area of permanent grassland reported in the June Agricultural Surveys is likely to fall into this land use type.

4.52. Countryside Survey 2007 shows a substantial (statistically significant) rise of 46 per cent in the area of neutral grassland in England since 1990. This was partly off-set by smaller (and not statistically significant) declines in calcareous grassland in England and acid grassland in England and Wales. The CS 2007 report attributes this increase in neutral grassland to the transfer of land from arable and horticulture to naturally regenerated set-aside recorded as neutral grassland. As noted above, the removal of set-aside as a requirement of CAP payments is likely to reverse this change from 2008.

Dwarf shrub heath, fen, marsh and bog

4.53. The Countryside Survey 2007 states that:

- 5.2% of the land area of England and Wales is covered by these habitats, with a little over half of this being dwarf shrub heath.
- The proportion of land area is higher in Wales (9.7%) than in England (4.5%)[46].

4.54. Figure 4.2 shows that these habitats are limited to upland areas of Wales (Brecon Beacons and Snowdonia), northern England (the Yorkshire Dales, North York Moors, Bowland Fells and Peak District) and Dartmoor in south west England. During this study, the Countryside Council for Wales commented that some of the LCM 2000 data for central Wales had been wrongly classified as woodland and should be shown as dwarf shrub heath and bog. While this is likely to be the case, there was insufficient evidence to do this accurately.

4.55. The Countryside Survey 2007 report suggests that there has been a significant seven per cent increase in the area of dwarf shrub heath in England since 1990 but offers no explanation for this. It is possible that this increase reflects improvements in the condition of upland and lowland heathland under agri-environment schemes and Heritage Lottery funding over this period.

Woodland

4.56. The National Inventories of Woodland and Trees for England and Wales show that:

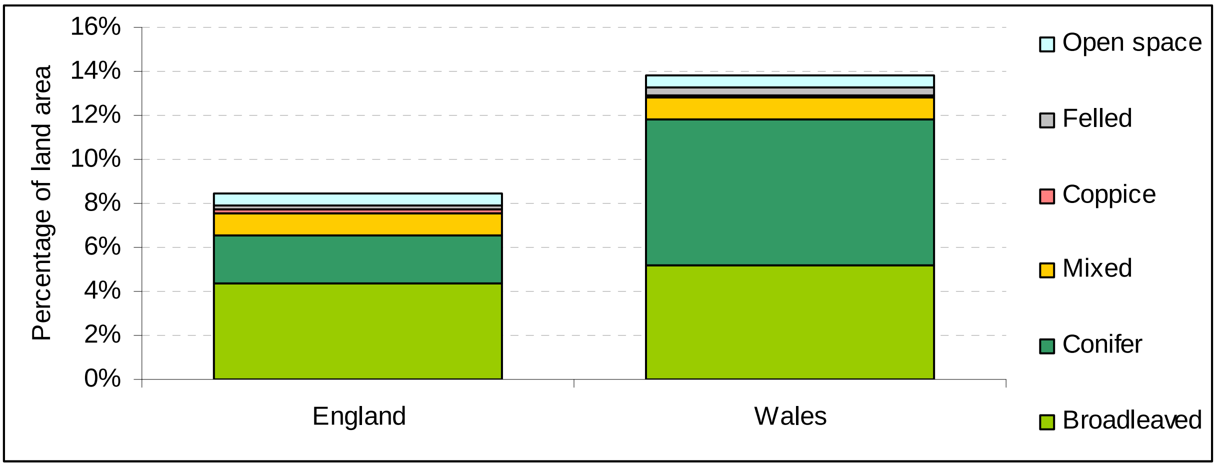
- in 1997/98 woodland in parcels greater than 0.1 ha (including felled areas and open space in woodland) occupied 9.2% per cent of the land area;
- half of the wooded area (4.5 per cent of the land area) is broadleaved woodland, with oak and ash the most common species, and 30 per cent of

[46] LCM 2000, rounded to one-km^2, shows that these habitats dominate in 2.7 per cent of tiles in England and Wales.

- the wooded area (2.8 per cent of the land area) is conifer, with sitka spruce and pines the most common species;
- the remaining woodland is mixed (11 per cent), open space (six per cent), felled or coppiced (two per cent each).

4.57. Figure 4.5 shows that woodland cover is higher in Wales which has a much larger proportion of land (48 per cent of its woodland area) under conifer plantations.

Figure 4.5. Proportion of land area covered by different types of woodland.



Source: Forestry Commission National Inventories of Woodland and Trees for England (1998) and Wales (1997).

4.58. The majority of woodland blocks, particularly broadleaved woodlands, are relatively small.

- In England, the mean size of woodland is 18.5 ha and 17 per cent of woodlands are less than 10 ha in size.
- In Wales, the mean size is larger at 28.2 ha and only 11 per cent of woodlands are smaller than 10 ha in size.

4.59. The dispersed nature of many woodlands means that the spatial distribution of woodland in Figure 4.2 underestimates the extent of woodland cover, particularly broadleaved woodland in the lowlands. Figure 4.2 shows that significant concentrations of broadleaved woodland is found in the south east of England, particularly in the Weald and on the Chilterns, as well as in the New Forest, Forest of Dean and southern edge of the Lake District. Conversely, conifer woodlands tend to be concentrated in forestry plantations in the uplands of Wales and in Northumberland. Large blocks of conifers occur in the English lowlands on the Brecklands in the east of England and on the heathlands of Surrey.

4.60. The National Inventories of Woodland and Trees report a steady growth in the area of woodland since the beginning of the twentieth century in both England and Wales, with parts of Wales (particularly Gwynedd and Glamorgan) seeing increases in excess of 12 per cent of their area, largely as the result of large conifer plantations.

Coastal habitats

4.61. Coastal habitats include sand dunes, salt marshes, mudflats, shingle and maritime cliffs and slopes. These areas are not separately recorded in the Countryside Survey 2007 and the areas of mudflats, maritime cliffs and slopes and vegetated shingle recorded in the priority Biodiversity Action Plan habitats in England present only a partial picture. The LMC 2000 data shows that littoral sediment is the dominant land cover in one per cent of km^2, saltmarsh in 0.2 per cent and supra-littoral sediment in 0.1 per cent. However, this is likely to under-record the narrow areas around coasts where these categories are not the dominant land cover.

LAND USE POTENTIAL

4.62. Information about the capacity of land to support different types of land use in future is useful to the analysis in the following chapters. Agricultural land classification and soil types can potentially provide this information.

Agricultural Land Classification

4.63. The Agricultural Land Classification (ALC) provides a method for assessing the quality of farmland to enable informed choices to be made about its future use within the planning system.[47] The ALC system classifies land into five grades, with Grade 3 subdivided into Sub-grades 3a and 3b. The 'best and most versatile land' is defined as Grades 1, 2 and 3a in Planning Policy Statement 7 (PPS 7) 'Sustainable Development in Rural Areas'. This is the land which is most flexible, productive and efficient in response to inputs, and which can best deliver future crops for food and non-food uses.

4.64. The ALC system is used by Defra and others to give advice to local planning authorities, developers and the public if development is proposed on agricultural land or other 'greenfield' sites that could grow crops.

4.65. The classification is based on the long-term physical limitations of land for agricultural use. Factors affecting the grade are climate, site and soil characteristics, and the important interactions between them.

- Climate: temperature and rainfall; aspect, exposure and frost risk.
- Site: gradient, micro-relief and flood risk.
- Soil: texture, structure, depth and stoniness and chemical properties which cannot be corrected.

4.66. The combination of climate and soil factors determines soil wetness and droughtiness. Wetness and droughtiness influence the choice of crops grown and the level and consistency of yields, as well as the use of land for grazing livestock. The classification is concerned with the inherent potential of land under a range of farming systems (see Figure 4.6). The current agricultural use, or intensity of use, does not affect the ALC grade. Over most of the UK, this information has been derived remotely (without any field survey) and should therefore be regarded as indicative.

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[47] Defra (2003)b

Figure 4.6. Summary land use descriptions of the ALC grades.

Grade 1 - excellent quality agricultural land: Land with no or very minor limitations to agricultural use. A very wide range of agricultural and horticultural crops can be grown and commonly includes top fruit, soft fruit, salad crops and winter harvested vegetables. Yields are high and less variable than on land of lower quality.
Grade 2 - very good quality agricultural land: Land with minor limitations which affect crop yield, cultivations or harvesting. A wide range of agricultural and horticultural crops can usually be grown but on some land in this grade there may be reduced flexibility due to difficulties with the production of the more demanding crops such as winter-harvested vegetables and arable root crops. The level of yield is generally high but may be lower or more variable than Grade 1.
Grade 3 - good to moderate quality agricultural land: Land with moderate limitations which affect the choice of crops, timing and type of cultivation, harvesting or the level of yield. Where more demanding crops are grown yields are generally lower or more variable than on land in Grades 1 and 2.
Grade 4 - poor quality agricultural land: Land with severe limitations which significantly restrict the range of crops and/or level of yields. It is mainly suited to grass with occasional arable crops (e.g. cereals and forage crops) the yields of which are variable. In moist climates, yields of grass may be moderate to high but there may be difficulties in utilisation. The grade also includes very droughty arable land.
Grade 5 - very poor quality agricultural land: Land with very severe limitations which restrict use to permanent pasture or rough grazing, except for occasional pioneer forage crops.
Urban: Built-up or 'hard' uses with relatively little potential for a return to agriculture including: housing, industry, commerce, education, transport, religious buildings, and cemeteries. Also, hard-surfaced sports facilities, permanent caravan sites and vacant land; all types of derelict land, including mineral workings which are only likely to be reclaimed using derelict land grants.
Non-agricultural: 'Soft' uses where most of the land could be returned relatively easily to agriculture, including: golf courses, private parkland, public open spaces, sports fields, allotments and soft-surfaced areas on airports/airfields. Also active mineral workings and refuse tips where restoration conditions to 'soft' after-uses may apply.

Source: MAFF (1988) *Agricultural Land Classification of England and Wales. Revised guidelines and criteria for grading the quality of agricultural land*.

4.67. The ‘provisional’ series of maps covering the whole of England and Wales was prepared from reconnaissance field surveys and published at a scale of one inch to one mile over the period 1967 to 1974. These maps were intended to provide general strategic guidance on land quality for planners and are not sufficiently accurate to assess individual fields. They do not distinguish between Grades 3a and 3b (the subdivision of Grade 3 occurred after 1976). They have not been updated and are being allowed to go out of print. However, the maps have been digitised and a national GIS dataset, intended for use at a scale of 1:250,000, is available from Defra.

4.68. Since 1976, selected areas have been re-surveyed in greater detail and to revised guidelines and criteria. However, these data are selective (tending to focus on potential development land) and are not suitable for this study.

4.69. Figure 4.7 maps the distribution of agricultural land classes across England and Wales, based on the dominant class in each one-km^2. This shows that concentrations of the most productive (Grade 1) land lie in the Fens, the North Kent Plain and the Isles of Thanet and in west Lancashire. Large swathes of Grade 2 land occur in Cambridgeshire, Bedfordshire, Lincolnshire, Herefordshire and Shropshire with a broad distribution in lowland valleys and coastal plains elsewhere (being restricted in Wales to South Glamorgan and the lower Clwyd valley). Grade 3 land is the most frequently occurring land class overall and dominates in the lowlands of England and Wales, in areas not in

Grades 1 and 2. Grade 4 land is found on poor soils in the lowlands (such as the sandy soils of the Thames Valley and the heavy clay soils of the Weald) and on the steep slopes of upland areas. Grade 5 land is found on the highest ground, and in the heathland soils of the New Forest and other areas of extensive lowland heath.

4.70. Figure 4.8 relates the distribution of the main land use types to the Agricultural Land Classification. This figure shows the extent to which each land use is over- or under-represented in each land class. It shows that arable and horticultural land is strongly linked to Grade 1 and 2 land; improved grassland to Grades 3 and 4; semi-natural grassland and dwarf shrub heath to Grade 5 land; and woodland (as would be expected) to non-agricultural land.

Figure 4.7. Agricultural Land Classification across England and Wales.

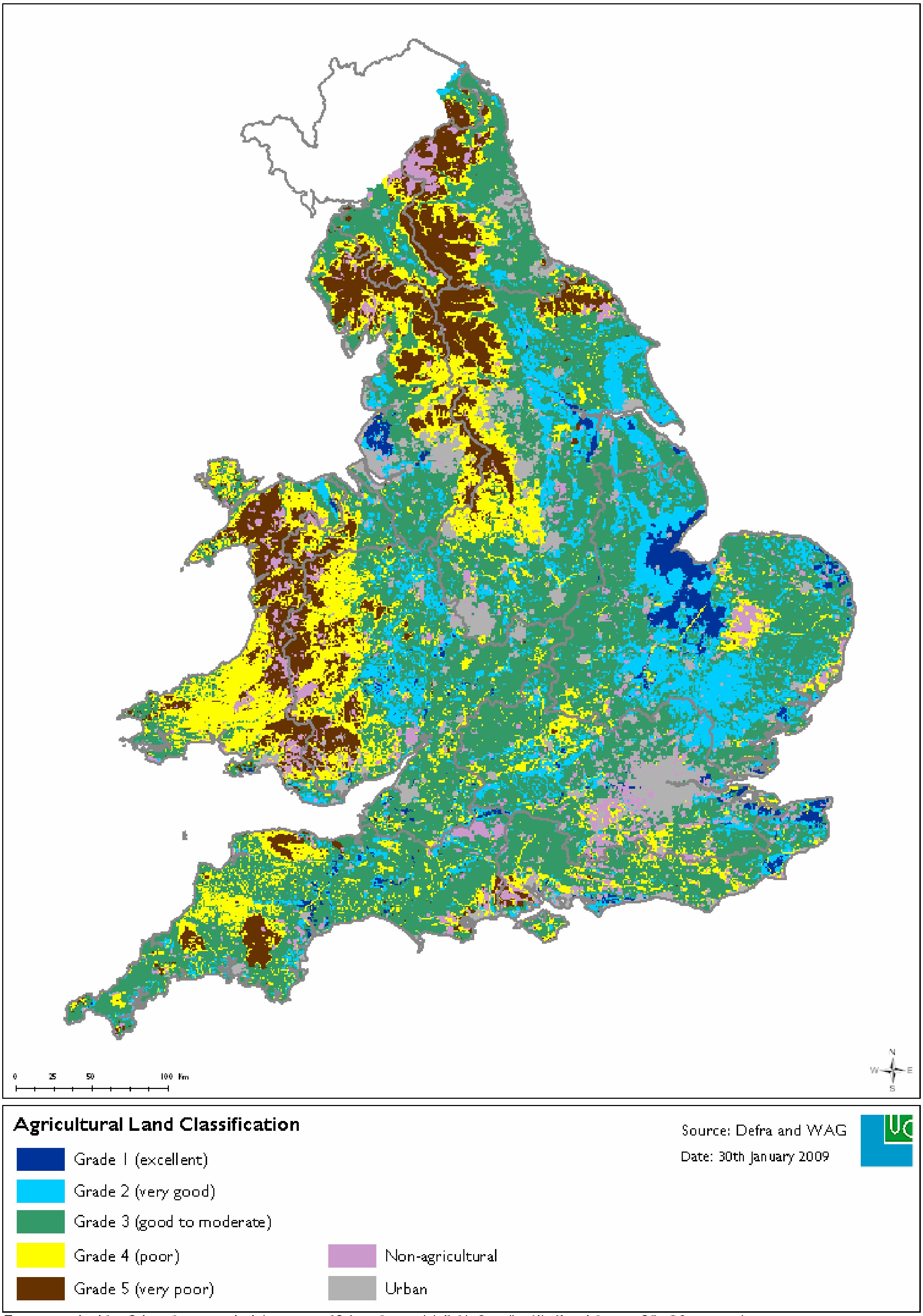
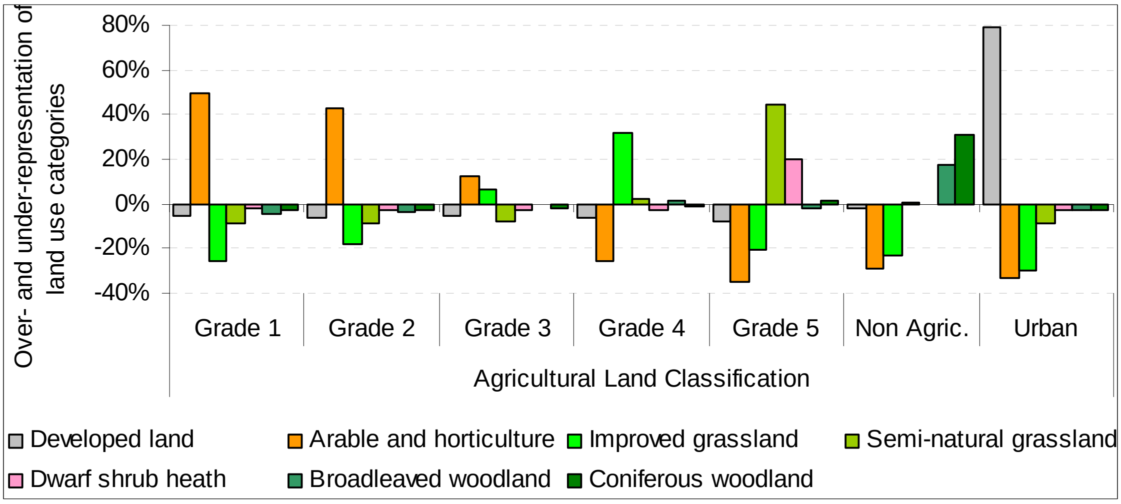


Figure 4.8. Relationship between land use and agricultural land classification.



Soils

4.71. The National Soils Research Institute (NSRI) at Cranfield University publishes datasets on soils at a range of different formats and scales using the Soil Series developed by the Soil Survey of England and Wales. The National Soils Map of England and Wales shows the predominant soil series in each one-km square in England and Wales, together with a simplified description (up to eight words) of each soil series. Whereas there are several hundred different soils series shown in the dataset, there are 91 types of simplified descriptions.

5. Pressures and forces for change

Review of recent literature

5.1. This chapter is based around a report produced for the Environment Agency by Cumulus Consultants (2008) entitled *Taking a Strategic View of Land Use: a Policy Options Paper*. It identifies the main drivers of land use change and describes in detail the pressures that they exert within England and Wales.

5.2. The purpose of the work by Cumulus Consultants was to consider potential land use issues and what they might mean in the context of the future scenarios set out in the 2006 report *Environment Agency Scenarios 2030*. This work identified 19 priority drivers considered to exert the most significant pressure on the UK environment up to 2030. These drivers were used as a starting point for the work by Cumulus, along with those identified in another report, *Baseline Scanning Project* for Defra (2005).

5.3. Reports of this nature become quickly dated in relation to technological developments and the economic climate. The work by Cumulus was published around the time that the current period of recession began. This is anticipated to last into 2010, and although the longer-term predictions made by the Organisation for Economic Cooperation and Development (OECD) on economic growth remain valid, it is important to be mindful of the current slowdown.

5.4. The aim of this chapter is to consider how different land uses are likely to change over time as a result of the pressures exerted by a range of drivers. Although discussion of the drivers and pressures is based on the Cumulus (2008) report, the conclusions drawn on their impacts on land use change are made independently from that work. The nine land use categories considered are those described in the previous chapter.

Drivers of change

5.5. The underlying forces driving land use change are summarised in Figure 5.1 below

Figure 5.1: Drivers of land use change and management.

Environmental	Social	Economic	Political	Science and Technology
▪ Climate change ▪ Environmental legislation, policy and regulation	▪ Rising global and UK population ▪ Changing household size ▪ Continuing consumption culture ▪ Changing social values ▪ Increasing personal mobility	▪ Globalisation ▪ Economic cycles ▪ Peak oil and rising energy demand ▪ Increasingly stressed infrastructure	▪ Uncertainty over international governance ▪ Expanding EU ▪ Pressure on public spending	▪ GRIN technologies ▪ New environmental technologies ▪ Increasing scientific understanding of environmental systems

Future land use pressures

5.6. The pressures on land use, and on the environmental services covered by this study, that arise from the above drivers are summarised below.

Climate Change Impacts

5.7. In response to the clear evidence on climate change, the EU Climate and Energy package, published in January 2008, sets out proposals to achieve a reduction in EU greenhouse gas emissions of 20 per cent by 2020, and 80 per cent by 2050, compared to 1990 levels. For the UK these figures are now reflected in the UK Climate Change Act 2008. The Government will set five-year carbon budgets to enable these targets to be met.

5.8. Climate change will be fundamental in driving changes in land use and management both to mitigate the causes of climate change and meet targets for carbon reductions and to adapt to its effects. The anticipated impacts of climate change include warmer temperatures, wetter winters, more extreme weather events and rising sea levels. There may also be changes to habitat distribution, species composition and migration patterns.

The UK Climate Impacts Programme (UKCIP02) has summarised headline messages from its climate modelling scenarios. Key predictions for the UK's climate, of which UKCIP has assigned a 'high confidence' score, include:

- **UK temperatures will continue to get warmer** – by 2040, average annual temperature for the UK is expected to rise by between 0.5 and 1°C, depending on region. By 2100, average annual temperature for the UK is expected to rise by between 1 and 5°C, depending on region and emissions scenario.
- **Summers will continue to get hotter and drier** – by 2040, average summer temperature for the UK is expected to rise by between 0.5 and 2°C, depending on region. By 2100, this is expected to rise by between 1 and 6°C.
- **Winters will continue to get milder and wetter** – by 2040, average winter temperature for the UK is expected to rise by between 0.5 and 1°C, depending on region. By 2100, the increase is likely to be between 1 and 4°C. By 2100, there is expected to be up to 30 per cent more precipitation in the winter months.

5.9. In terms of regional differences, under both 'high emissions' and 'low emissions' scenarios[48], general patterns have emerged from the climate modelling. For mean temperature change, the South East is likely to experience the greatest annual rise – up to 4.5°C by the 2080s under a 'high emissions' scenario, compared with a 3°C rise for the North West region. In terms of summer precipitation levels, again southern England is likely to be most affected in all

[48] These alternative scenarios result from uncertainty about future trends and behaviour – such as population growth, socio-economic development and technological progress – and how these might influence future global emissions of greenhouse gases. To address this uncertainty, the UKCIP02 scenarios describe future climate change under four alternative futures, ranging from rapid economic growth with intensive use of fossil fuels (high emissions) to increased economic, social and environmental sustainability with cleaner energy technologies (low emissions).

scenarios, with the greatest decrease. An increase in winter precipitation levels is predicted to be most acute in the North, the Midlands, eastern England and the south coast, particularly under the 'medium-high' and 'high' emissions scenarios.

5.10. According to *Part of the Solution*, the report of the joint NFU/CLA/AIC Climate Change Task Force, 2007 warmer temperatures may provide opportunities for diversification into new varieties and types of crops, and an extension of the range and yields of some crops northward. Increasing temperatures, particularly in the summer, may have a detrimental effect on some crops, with timing of maturity, crop uniformity and product quality all affected by temperature changes. Warmer summers may also result in heat stress effects on livestock, increasing ventilation and shade needs. Conversely, warming winters will lead to less frost damage, allowing earlier sowing, a longer growing season, double cropping and prolonged outdoor grazing for livestock.

5.11. Reporting in 2008 the Committee on Climate Change (CCC) highlighted the role of agriculture in delivering a significant proportion (15 per cent) of the UK savings in greenhouse gas emissions. Currently the whole food chain is responsible for around 18 per cent of UK greenhouse gas emissions. This could have a noticeable effect on land use and management with reduced fertiliser inputs (important sources of nitrous oxide); reduced production and consumption of carbon-intensive forms of meat; and changes in feeding and management in the dairy and beef sectors (primary sources of methane). Use of anaerobic digestion using farm waste can provide a renewable energy source as well as disposing of methane-generating waste. The CCC states that associated land use/ management changes may include increased afforestation and increased use of maize as part of changing livestock diets.

5.12. Modelling by the Environment Agency based on the medium high UKCIP02 scenarios shows that there will be a significant impact on average river flows across England and Wales over the next forty years. By 2050, river flows in winter may increase by 10 to 15 percent but with lower flows in most rivers from April to December. River flows in the late summer and early autumn could fall by over 50 percent, and by as much as 80 percent in catchments in central and eastern England. Overall, this could mean a drop in annual river flows of up to 15 percent.

5.13. There will be a higher risk of flooding, particularly in low-lying regions, and areas of low-lying coastal land are expected to be lost through inundation as sea levels rise. In turn, there will be changes in the range and types of pests, diseases and weeds. Woodlands will be at risk of damage from storms and pests including Sudden Oak Death (Phytopthera Ramorum), which also affects beech.

5.14. This fall in rainfall and river flows will reduce the recharge of aquifers and lead to a consequent lowering of groundwater levels. At the same time, higher temperatures and drought could lead to increased demand for water from households and for crop irrigation in parts of the country that are already short of water resources, putting further pressure on river flows and groundwaters. These changes will present a major challenge to ensure that there is enough water for people and for the natural environment.

5.15. Research undertaken by UKCIP under their MONARCH programme[49] has also looked at the potential impacts of climate change on semi-natural habitats. For

[49] The UK Climate Impacts Programme (2001)

example, beech woodlands in southern and eastern England could be major casualties – they are drought-sensitive and therefore will be expected to die back as soils become drier in the summer. The departure of the beech may be hastened by the invasion of more drought-tolerant tree species such as oak and yew. The species composition of calcareous grasslands, found in lowland areas, and upland hay meadows, will also shift as a result of climate change. Heathlands may expand in some northern and western areas of Britain where increased winter rainfall waterlogs former areas of dry heath. Conversely, in south east England, wet heaths could dry out and revert to dry heath or acid grasslands. Peat bogs, already a threatened habitat, are also likely to dry out in southern and central locations as a result of an increase in summer drought. This may, however, be counterbalanced by better conditions for bog growth further north, due to increased rainfall, particularly in winter. This is the subject of ongoing research. Other wetland habitats dependent on rainfall patterns across the seasons will be seriously affected by an increase in drought conditions. This is predicted to lead to widespread desiccation of many wetland habitats, expected to be most severe in South East England.

Urban development

5.16. Pressure for urban development is increasing as a result of population growth, changing household structures and a lack of affordable housing. The UK population is forecast to be 67 million by 2031 and will continue to rise to 2074. In England, the Government had aimed to build 60 per cent of the projected housing requirement on brownfield land by 2008,[50] but in light of the fact that it has also indicated a need to increase the supply of new housing to 200,000 per year, a rate of even 40 per cent greenfield development would have a significant impact in terms of land take.

5.17. In 2002 the Government announced a series of growth areas in the south east and east of England including the Thames Gateway, Ashford and the Milton Keynes area. This was followed in 2005 by launch of the growth points initiative providing government support for local communities who wish to undertake large-scale sustainable growth. In 2006, 29 local authorities were designated as growth points in the first round of the programme in the South East, Eastern and Midlands regions. This was expanded in 2007 with the announcement of 20 second-round growth points spread across all regions of England.

5.18. Further, as part of its strategy for dealing with the increasing housing demand in a sustainable way, the Government has set out plans for a new generation of eco-towns. These will be small towns of between 5,000 and 20,000 homes, creating a complete new settlement using innovative design and architecture that will result in zero-carbon construction. The sustainability objectives will relate to social, as well as environmental outcomes, with developments including a mix of affordable housing and a range of facilities such as schools. Eco-towns will provide valuable experience of eco-developments that can inform development elsewhere, including at growth areas and growth points.

5.19. As a result of these changes, an increase in the area of land under urban use is expected, as a result of both residential and other built development – the Council for the Protection of Rural England has predicted that an area the size of Southampton will be lost to development each year. The effects of this are likely to be compounded by the associated increase in pressure on natural resources such as water. Coastal habitats and upland areas are unlikely to be

[50] Cumulus Consultants (2008)

significantly affected by urban growth; however, large areas of agricultural land are likely to go to development around the urban fringe.

Water supply (see also climate change)

5.20. Although household water consumption in the UK is relatively stable, it remains high despite shortages in certain regions. In addition, agricultural water consumption has doubled since 1979, mainly due to the irrigation of potatoes and vegetable crop.[51] The demand for consistently high quality crops, combined with climate change means that levels of abstraction are likely to continue rising, with a predicted 25 per cent increase in the use of water for irrigation by 2020.

5.21. Continued high levels of water abstraction will affect inland hydrological systems by lowering the water table, affecting the level and flow of lakes and rivers. The issue of water availability will have a significant impact on the future of farming in the UK in terms of cropping patterns and crop types and may dictate where development takes place.

Food production (see also climate change)

5.22. Overall food production in England and Wales has declined in recent years as a result of changes to agricultural policy and the shifting global market. In terms of future changes, the Environment Agency[52] has indicated that by 2015 the area of wheat and oilseed production will increase as a result of land returning to production from set-aside, whilst sugar beet and potato production will decrease. Livestock numbers are expected to decline markedly, particularly in upland areas, affecting the viability of farm businesses and farming systems. There will also be a continued reduction in the number of dairy cows.

5.23. Central to the issue of future food production is the ongoing debate on food security. This is of increasing concern as a result of the declining proportion of UK food which is domestically produced, and the rising uncertainty in terms of global trade, climate change and international relations. The growing flood risk is likely to place further strain on agricultural production, and there is a view that flood defences may become increasingly necessary to protect productive land. More marginal land may be brought into production, supported by increased inputs (although this would counter other pressures to reduce greenhouse gas emissions with an emphasis on more extensive farming). The drive for food production in a changing climate could also lead to deterioration in the soil resource which remains the fundamental asset (along with water) essential for food production.

5.24. In terms of the impacts of these changes on land use, an increase in the area of agricultural improved grassland and of land used for arable cropping is expected. Coastal habitats are considered unlikely to be significantly affected by these changes as the expected inundation of low-lying coastal farmland makes such regions unsuitable for significant agricultural expansion. Where areas of cropping are expanded, the resultant increase in water abstraction may place pressure on the hydrological system (see above).

5.25. Despite increases in some forms of agricultural land use, land will also be taken by urban development and infrastructure (see above); energy crops (see below); and woodland/ afforestation (also see below).

[51] Cumulus Consultants (2008)
[52] University of Cambridge and SAC (2006)

Woodland and forestry

5.26. In terms of woodland cover, the gradual increase occurring in England and Wales is expected to continue. Much of this growth is anticipated near urban areas as part of green infrastructure proposals, providing a local amenity and fuel source. The poor viability of upland farming systems and associated decline in upland heath are likely to further support the trend of increasing woodland cover (although the system of agricultural support may continue to constrain change, particularly until the next major reforms of the Common Agricultural Policy). The expected decline in upland grazing will bring about changes to areas of upland heath, with some potential reversion to woodland cover.

Energy production

5.27. In 2000 the UK set a target for 10 per cent of electricity to come from renewable sources by 2010, with an announcement in 2006 to double that level by 2020. In March 2007 EU leaders, including the UK Government, agreed to adopt a binding target of sourcing 20 per cent of the EU's energy from renewable sources by 2020. The UK's agreed contribution to the EU target is to increase the share of renewables in the UK energy mix from around 1.5 per cent in 2006 to 15 per cent by 2020. In June 2008 the Government launched its consultation draft UK Renewables Strategy, to deliver the UK's share of the EU target.

5.28. The draft strategy puts forward a range of possible measures to deliver what is viewed as a very ambitious target for the UK requiring a step change in a short timeframe to 2020. It has been estimated that it could require investment of at least £100 billion over the next decade. The draft strategy states that, due to the limited growth potential of landfill gas as a renewable energy source, the main growth in biomass energy generation is likely to come from other sources including energy crops. The Royal Commission on Environmental Pollution has suggested that by 2040, 20 per cent of all farmland could be devoted to biomass crops, primarily short rotation coppice (SRC) (with its high evapo-transpiration rates), miscanthus and other crops that will come forward in the following years. In addition, green waste may increasingly be used in anaerobic digestion, potentially providing a new market for conservation arisings.

Minerals and waste

5.29. Demand for minerals is expected to rise with the increasing use of gravel and sand in the construction of houses, roads and other developments, although the development of more sustainable building options may have some effect on controlling this demand. Higher levels of consumption will produce increasing volumes of waste, putting pressure on the landfill system. The UK already produces more waste than the EU average and sends more than 60 per cent to landfill. Over time, this proportion should decrease and the percentage of waste that is recycled or used as a renewable energy source should increase. Agricultural land is likely to receive a growing volume of recycled or composted waste, with biowastes more frequently spread on the land as a result of the Landfill Directive. However, it is equally likely that biowastes will be used in energy production through anaerobic digestion, making a contribution to renewable energy targets.

Leisure and amenity use

5.30. The Government is highlighting the importance of countryside accessibility and links to health, with the Environment Agency launching its 'Blue Gyms' initiative aiming to encourage participation in swimming and watersports as a way of tackling obesity and improving mental health. Advice is given to local authorities to enable them to bring underused public water areas into use.

5.31. While overall numbers of visitors to the countryside are falling, the types of activity and places where people may spend time are shifting or are likely to shift in the future, influenced, for example, by climate change and changing cultural tastes. For example, the Henley Centre states that enhanced urban environments may mean that more recreation time is spent in towns and cities than in rural areas (a pattern that is already seen in the GB leisure day visitor survey data). This may create additional pressure for urban green space. These patterns may be counterbalanced by an increasing growth in the population of rural areas, with such people seeking recreational opportunities in their immediate area. Indeed the timing of visits to the countryside is already changing with use outside the peak summer months.

5.32. With climate change coastal habitats may come under increasing pressure from recreation, as may inland waterways, potentially encouraging the creation of artificial lakes that can be used to meet the demand for recreation space.

Ecosystems services

5.33. As greater emphasis is placed on sustainable land management, agriculture and forestry will be expected to make an increasing contribution to the delivery of a wide range of goods and services (ecosystems services) – the growing emphasis will be on multi-purpose land use. Despite the fact that most of the agricultural land in England and Wales is now subject to cross-compliance, its environmental quality varies, and the decreasing value of the Single Payment raises questions about the future effectiveness of cross-compliance as a means of influencing environmental standards. As a result, an increasing focus on planning land use to support key environmental services is anticipated. This may be delivered by the range of advice and incentive schemes which are offered under the CAP and those of other programmes.

5.34. Choices regarding land use and management are expected to be increasingly influenced by the resulting impacts on ecosystems service delivery, with different types of land use becoming more or less attractive depending on the range of services that they are able to deliver, consistent with local needs such as flood alleviation.

Conclusions

5.35. Taking the pressures outlined above, likely affects on land use and management in the future may be:

Changes in land use

- An increase in the area of urban land especially in the south east, eastern and midland regions of England. Potentially 60 per cent of growth to come from greenfield sites.

- The above matched by increases in mineral extraction and landfill sites (although waste may increasingly be used as a ‘fuel’ for energy production, including anaerobic digestion).
- Potential bringing of marginal land back into production to address issues of food security, leading to the conversion of semi-natural habitats to improved grassland.
- Potential steady increase in woodland area, especially around settlements and in the uplands as natural regeneration where grazing levels fall away.
- Potential increase in biomass planting – up to 20 per cent of farmed area by 2040.
- Widespread desiccation of wetland habitats, especially in the south east of England, with potential conversion to other habitat types or agricultural land.
- Loss of blanket bogs from south west England but potential expansion in the uplands of northern England and Wales.

Changes in land management

- More nutrient additions with double cropping (allowed by climate change) to meet food security. But equal requirements to reduce fertiliser inputs in response to rising energy costs and to meet greenhouse gas emission targets.
- Potential reduction in livestock numbers, especially in the uplands.
- Grazing animals kept out year-round with milder winters, with potential implications for soil erosion and soil structure.
- Farm wastes potentially diverted to anaerobic digestion, reducing the spreading of slurries on land, although other composted wastes may be spread on the land.
- Potential increase in maize as animal fodder to address issues of methane production.
- Increased stress to trees and crops from extreme weather, pests and disease.

Water resources

- Increase in average winter river flows by 10-15 per cent and increased winter flooding of low-lying areas and along the coast, with more frequent extreme flood events, as a consequence of climate change.
- The above matched by low river flows, April to September (with flows down by half by late summer), likely to be further exacerbated by increased abstraction for public water supply (as the population grows) with the greatest pressure felt in areas with the least available water resources such as the south east and eastern regions of England.
- Increases in abstraction for agriculture, with a potential 25 per cent increase in the use of water for irrigation by 2020.
- Reduced aquifer recharge and falling water tables, again most strongly felt in the south east of England.

- To address issues of food security, the potential need to protect the most productive lands from flooding.

6. Regulation of water quality

Introduction

6.1. The next four chapters look in more detail at each of the key environmental services being considered through this study, starting with the regulation of water quality. The chapters examine how the delivery of each service is affected by land use and management and the potential for changes in land use and management to improve delivery of each service to within its defined environmental limits.

6.2. A number of steps are needed for this analysis.

- Firstly, conclusions on current levels of service, described in Chapter 3, are reviewed.
- Secondly, the relationship between delivery of the service and te categories of land use defined in Chapter 4 is described. This draws on a statistical comparison of levels of service delivery with land use type in each of the one-km tiles across England and Wales, using the two case study areas to examine particular issues.
- Thirdly, the nature of the relationship between the different categories of land use and the service is analysed with reference to research evidence. This section explores the extent to which land use and management are the cause of poor service delivery, as well as changes in land use and management that could improve service delivery.
- Fourthly, the chapter reviews measures to address failures in service delivery, distinguishing between changes in land management (within current forms of land use), changes in land use and other measures that do not involve land use or management. This section takes account of the drivers of change that will apply to land use up to 2030, as identified in Chapter 5.
- Finally, the chapter draws overall conclusions about the extent to which changes in land use and management can contribute to improved delivery of this service above environmental thresholds.

Summary of service delivery

6.3. From Chapter 3 it is evident that:

- It is appropriate to measure water quality in three ways, each having a separate environmental limit. These are the ecological status of rivers (as the most widespread measure of surface waters), chemical status of rivers and chemical status of groundwater.
- For the ecological status of rivers, water quality compliance monitoring data prepared for draft River Basin Management Plans by the Environment Agency record that (for rivers that have been assessed, by length) 18 per cent of rivers are in good or better condition, 61 per cent are moderate, 17 per cent are poor and four per cent are bad.

- For the chemical status of rivers, the majority of river stretches by length (66 per cent) have not been assigned a classification. Of those that have, 65 per cent have passed the required standard while the remaining 35 per cent have failed.
- Spatially, there is a complex picture for river water quality (ecological and chemical). The different classifications are widely distributed across England and Wales and rivers of good and poor condition often occur close to each other. Bad or poor quality water in the upper reaches of rivers often improves in quality as it mixes with water from other rivers as it flows downstream.
- For groundwater, the draft compliance monitoring data for chemical status shows that 59 per cent of the 304 groundwater areas are classified as in good status and 41 per cent are classified as in poor status. These groundwater areas are relatively large (having an average size of 490 km^2).

Service delivery and land use

6.4. A decision needs to be made about the robustness of these datasets to enable comparison with the distribution of land use. As noted in Chapter 3 (paragraph 3.30), WFD compliance monitoring is risk-based and samples are taken where the Environment Agency anticipates that damage may occur. The river water quality ecological status data is substantially complete (only 14 per cent of rivers by length have not yet been assessed). For the river quality chemical status, the Environment Agency only takes samples where it has reason to believe that chemicals are discharged into the environment in significant quantities. This means that the majority of river stretches have not been, and are not likely to be, assessed.

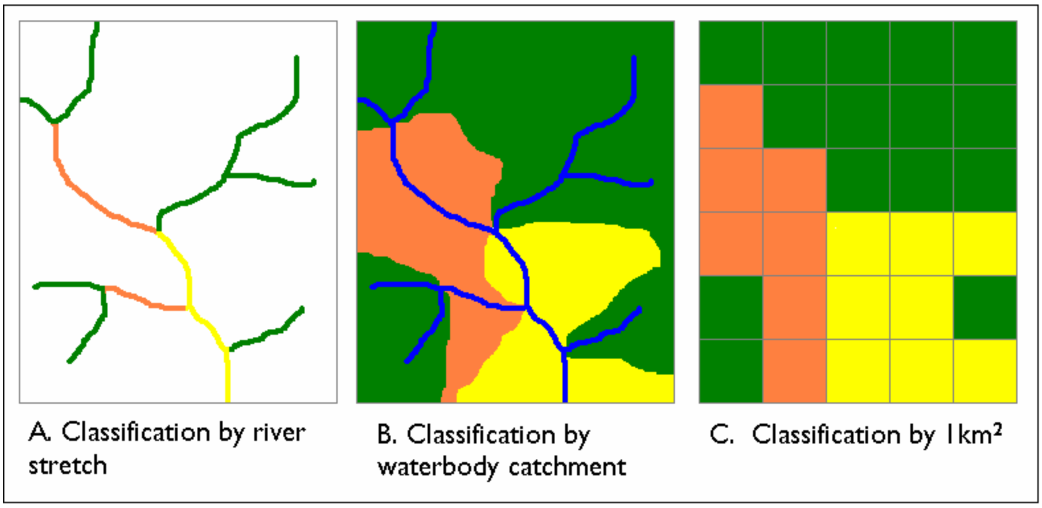
6.5. For groundwater classification data, the link between land use and quality of groundwater needs to be considered. This link depends on a number of hydro-geological factors such as properties of the soil, thickness of the unsaturated subsoil and rock (depth to the water table) and porosity of the strata below the water table. The relationship between groundwater quality and land use operates at a much larger scale than for river water quality (individual point sources being much less likely to produce measurable effects). In addition, the much longer lag times between changes in land use and the quality of water reaching groundwater means that demonstrating a link between particular activities on the land surface and the response of groundwater quality is more difficult.

6.6. Nevertheless, the importance of groundwaters in large parts of England and Wales as aquifers and sources of public water supply, and their role as sources of water for rivers and lakes, together with the pressures that have been shown to apply (such as from nitrates and pesticides) mean that the influence of land use and management must by assessed. However, the data available to this study makes it difficult for these links to be made statistically.

Linking data on river stretches with land use on surrounding catchments

6.7. To make direct comparisons with the dominant land use in each one-km tile, it is necessary to apply the status of individual river stretches to the surrounding catchment geography. This can be done using the water body catchments developed by the Environment Agency based on hydrological models of river flow and terrain.[53] After assigning the status of each stretch of river to its water body catchment, these catchments can be 'clipped' to the same one-km grid used for the land use data, with each one-km tile taking the dominant status that occurs within it. This process is illustrated in **Figure 6.1**.

Figure 6.1. Method for assigning river quality status from river stretches to one-km tiles.



6.8. This method has its limitations. Most importantly, it assumes a hydrological link between the river and the land immediately adjacent to it. In terms of water quality, particularly for point sources of pollution, land use upstream, as much as immediately adjacent to the river, is an important influence. Secondly, by assigning the status of each one-km tile to the dominant status lying within it, the method simplifies spatial differences in status. However, at the broad scale being taken by this study, the method is considered valid.

6.9. Once the predominant river quality status of each one-km tile has been determined, this can be compared to the dominant land use type (from LCM 2000) for that tile. **Figure 6.2** shows the cross-tabulated matrix of ecological status categories against land use types for all 151,033 km^2 tiles in England and Wales.

Figure 6.2. Grid recording number of one-km tiles by land use type and river water ecological status across England and Wales.

Land Use Type	River water quality – Ecological status					
	High	**Good**	**Mod.**	**Poor**	**Bad**	**N/A**
Developed land	1	511	7,669	2,115	434	2,757
Arable and horticultural crops	0	4,812	31,882	6,490	1,164	9,337
Improved grassland	3	9,227	25,265	7,176	1,788	7,387
Semi-natural grassland	79	3,638	7,051	1,908	1,088	2,341
Dwarf shrub heath, fen, marsh and bog	91	1,084	1,870	447	180	478
Broadleaved woodland	2	908	4,035	1,029	258	1,138
Coniferous woodland	1	759	1,685	457	389	598

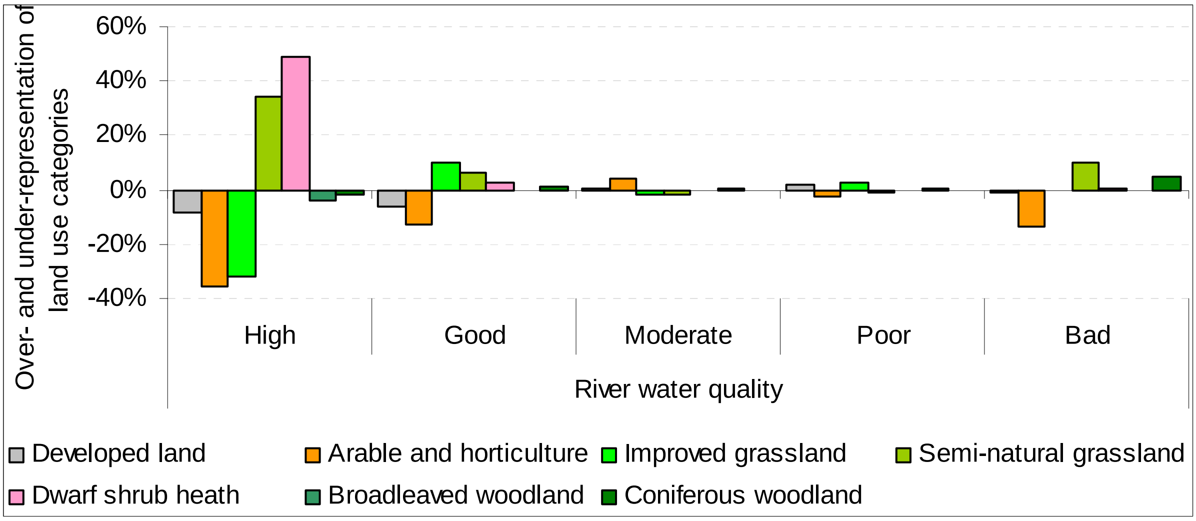
[53] This model is the Centre for Ecology and Hydrology (CEH) Flow Grid Hydrological Model Run with the CEH Integrated Hydrological Digital Terrain Model with upstream catchment size also calculated. The geographies obtained from this model were modified with large amounts of manual editing by Environment Agency staff.

Inland water	0	24	183	56	13	160
Coastal habitats	0	90	324	57	17	577
Total	177	21,05 3	79,96 4	19,73 5	5,331	24,77 3

6.10. Figure 6.3 portrays the data in Figure 6.2 in a more accessible chart that illustrates whether each land use appears proportionally in each ecological status category. For instance, whereas dwarf shrub heath is the predominant land use across only 4,150 of the 151,033 (2.7 per cent) one-km tiles in England and Wales, it is found on 91 of the 177 (51 per cent) one-km tiles with high ecological status – 49 per cent higher than might have been expected. Conversely, improved grassland is found on 33 per cent of the one-km tiles across England and Wales but only 1.7 per cent of tiles with high ecological status.

6.11. It is important not to attribute a cause and effect solely as a result of the patterns seen in Figure 6.3. For instance, rivers may be judged to have poor ecological status as a result of metrics on fish classification which are the result of the physical morphology of the channel, with little or no link to land use. Nevertheless, tentative conclusions can be drawn from the chart about the associations between certain land use types and river ecological status categories. Dwarf shrub heath and semi-natural grassland are associated with river stretches of high and good ecological status (and also improved grassland with good status rivers). Arable and horticultural cropping are associated with moderate status rivers. Urban areas show less differentiation, but have a positive association with rivers of poor ecological quality and a negative association with rivers of high and good quality.

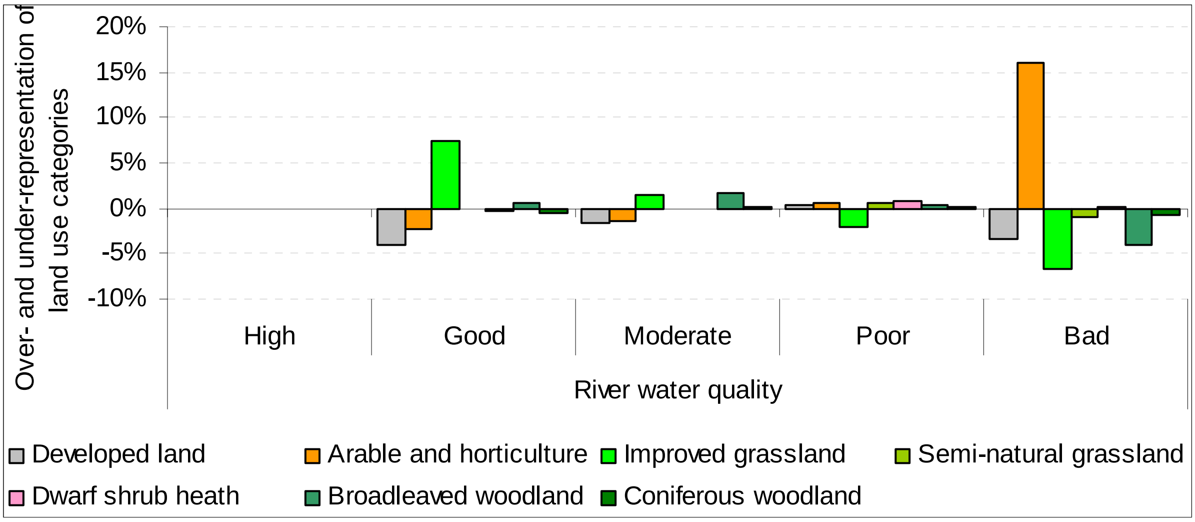
Figure 6.3. Representation of land use categories in relation to different levels of service delivery across England and Wales.



6.12. Notwithstanding the caveats expressed above about cause and effect, the strong association of dwarf shrub heath and semi-natural grassland with high quality river stretches is likely to be strongly influenced by the location of most high quality waters in the headwaters of river systems, which tend to be in upland areas dominated by these land use types. Figure 6.4 repeats the same analysis as Figure 6.3, but for the South East River Basin District only, an area that has no upland areas. This chart suggests a strong association between arable and horticultural cropping and river stretches classified in bad ecological status. Although this observation is drawn from a relatively small sample of areas (only eight per cent of the one-km tiles assessed for river water quality in the RBD are classified as bad quality), there is a corresponding under-representation of this land use in river stretches of good status (based on nine per cent of assessed one-km tiles). It also shows the opposite relationship between improved grassland and, to a lesser extent, broadleaved woodland. In other words, for the South East River Basin District, it appears that areas dominated by arable farming have a greater than average length of rivers classified as bad ecological status, whereas areas dominated by intensive grassland, and to a lesser extent broadleaved woodland, have a greater than average length of rivers classified as good ecological status.

6.13. Again, it should be emphasised that this, on its own, does not infer a causal relationship between land use and river water quality. However, as shown in the following section, there is strong research evidence that the impacts of these land uses, and the management practices they involve, contribute strongly to water quality.

Figure 6.4. Under and over-representation of land use categories in relation to different levels of service delivery in the South East River Basin District.



How land use and management impact on service delivery

6.14. The following section runs through each of the land use types in turn, identifying the way that this use, and the management activities it involves, impacts on water quality. Measures to reduce or mitigate these impacts are described in the following section.

Developed land

6.15. Surface water monitoring in urban areas shows that common pollutants include suspended solids, organic compounds, metals, ammonia and substances exerting a biochemical oxygen demand (BOD), while for groundwaters pollutants include nitrogen (nitrate and ammonia), chlorinated solvents and metals.

6.16. There are a range of potential point and diffuse sources of surface and groundwater water pollution associated with urban land use.[54] Examples of sources of pollution include:

- surface water run-off from contaminated land, as well as discharges of previously contaminated groundwater into surface waters;
- spills and leaks associated with chemical storage and drainage to surface water;
- inadequate urban drainage leading to flushing of petrochemicals and other pollutants (from roads, car parks, buildings) into water bodies during flash floods;
- sewerage systems releasing sewage into water courses and groundwater; disturbance of ground associated with new urban development (such as release of nitrogen from disturbance of soil);
- leaching of pesticides used to control weeds on railways and road verges, and other pesticides used on urban green space (parks and gardens);
- spills and leaks associated with chemical storage and industrial processes;
- authorised discharges to surface water.

6.17. In most cases, the number of potential sources of pollutants that may be present in an urban area means that it is not possible to identify the source of contamination (including whether the pollution has travelled via a surface or groundwater pathway). As a result, for the purpose of WFD monitoring, urban land use is generally considered as a diffuse source of pollution (notwithstanding investigations by the Environment Agency into specific point source incidents).

Box 6.1. Water quality issues and measures in the Adur and Ouse Catchment, South East RBD.

The Adur and Ouse catchments, which are treated as one in the South East RBD Management Plan, include large parts of the South Downs as well as urbanised areas along the coast, covering Brighton and Hove and the port areas of Newhaven and Shoreham, which is an identified development growth point.

Surface water quality in this area is adversely affected by phosphates in effluent from three wastewater treatment works, and by diffuse pollution from urban areas. Sewage effluent becomes more concentrated during periods of low river flow, compounding its effects. Nitrates and phosphates from agriculture and horticulture are a particular problem in the Brighton and Hastings aquifers.

Within the Ouse catchment, there is evidence of declining biodiversity, probably due to chemical pollutants such as agricultural pesticides or oestrogens from sewage effluent.

The Draft River Basin Management Plan proposes a range of actions to bring water quality within good ecological and chemical status. There are limited opportunities for land use change, with an example of this being targeted habitat creation work on priority waters such as the Ridgewood Stream, River Adur at Knepp Castle and Pellingford Stream.

[54] Environment Agency (2007)d

A range of actions that involve land management changes are recommended, including improving sewage works at 20 locations to reduce levels of nutrients such as phosphorous, targeting pollution prevention campaigns around industrial areas, improving road drainage to avoid ground or surface water pollution from road run-off and partnership work to address diffuse pollution from agriculture.

Source: Environment Agency, 2008. South East RBD draft Management Plan

Arable and horticultural cropping

6.18. The two most significant sources of pollution originating from arable and horticultural land are fertilisers (including organic manures) and pesticides and the large majority of the pollution load from these sources is diffuse, occurring from the misapplication of these agricultural inputs, or their leaching from soils once they are applied.

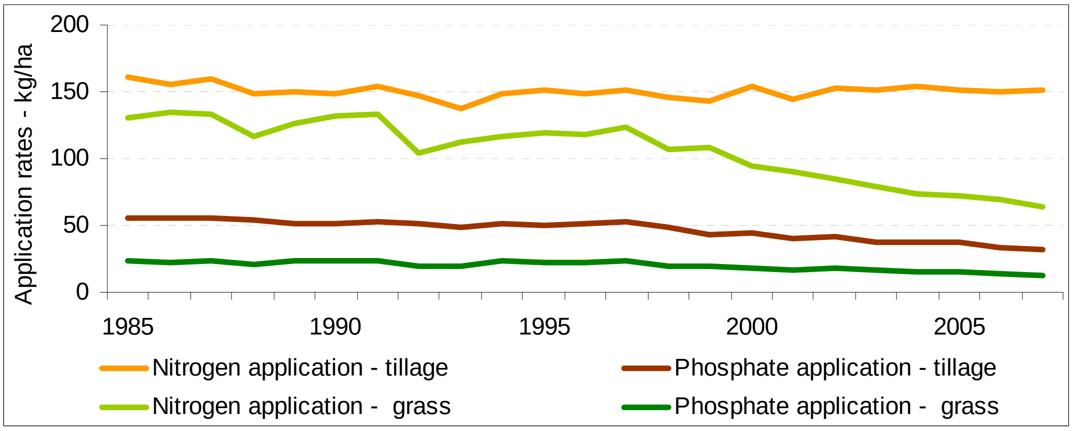
Nitrates and phosphates

6.19. The majority of arable farms operate a nutrient surplus. Diffuse agricultural pollution is thought to account for 60% of the nitrogen load in freshwater systems and arable farming is responsible for a high proportion of this. While much of the focus on diffuse pollution from agriculture has been on nitrogen, concern is also growing about phosphate originating from agricultural fertilisers and animal manures. The most up-to-date research indicates that agricultural phosphorous accounts for 28 per cent of the total phosphorous load,[55] less than was previously thought but still a significant proportion. However, it is not the case that arable and horticultural cropping inevitably leads to poor water quality. The data in Figure 6.2 shows that 23 per cent of the one-km tiles in England and Wales where water quality is regarded as good are dominated by arable and horticultural cropping.

6.20. Figure 6.5 shows that application rates of nitrogen and phosphate fertilisers are generally higher on arable and horticultural crops (shown as tilled land) than on grassland. While application rates of phosphates on grassland and tilled land, and of nitrogen on grassland have fallen in recent years, those of nitrogen on tilled land have stayed the same (this is due to the marginal economic costs and benefits of fertiliser applications and improved knowledge by farmers). It is also the case that leaching of applied nitrogen tends to be higher on arable land than grassland due to higher levels of uptake by grassland[56].

[55] White *et al.* (2006)
[56] Defra (2007)a

Figure 6.5. Trends in application rates of nitrogen and phosphate fertilisers to tillage and grassland in England, 1985-2007.



Source: Defra Sustainable Farming and Food Strategy indicators No. 4.01b. Note: Does not include nitrogen and phosphate applied through manures and slurry.

Box 6.2. Water quality issues and measures in the Test and Itchen Catchments, South East RBD.

The Test and Itchen rivers are both SSSIs supporting a diverse range of species, with the Itchen being of international importance as a Special Area of Conservation (SAC).

The growth of algae, caused by excessive levels of phosphates and nitrates in effluent from sewage works and from industrial and agricultural discharge, causes problems in the rivers and their tributaries. The groundwater supply, which feeds both rivers, is also under pressure from pollution originating in the urbanised area at the south of the catchment. The River Itchen is heavily over-abstracted, which is an additional factor affecting water quality.

The draft RBD Management Plan recommends habitat creation at priority locations on the River Anton, River Itchen, Tanner's Brook and Candover Brook, but no other direct land use changes. Measures which may indirectly lead to land use changes include:

- Work to reduce diffuse pollution from agriculture, partly through Catchment Sensitive Farming.
- Reversing rising trends in nitrate at sources in the Test and Itchen chalk aquifers.

Recommended land management changes include:

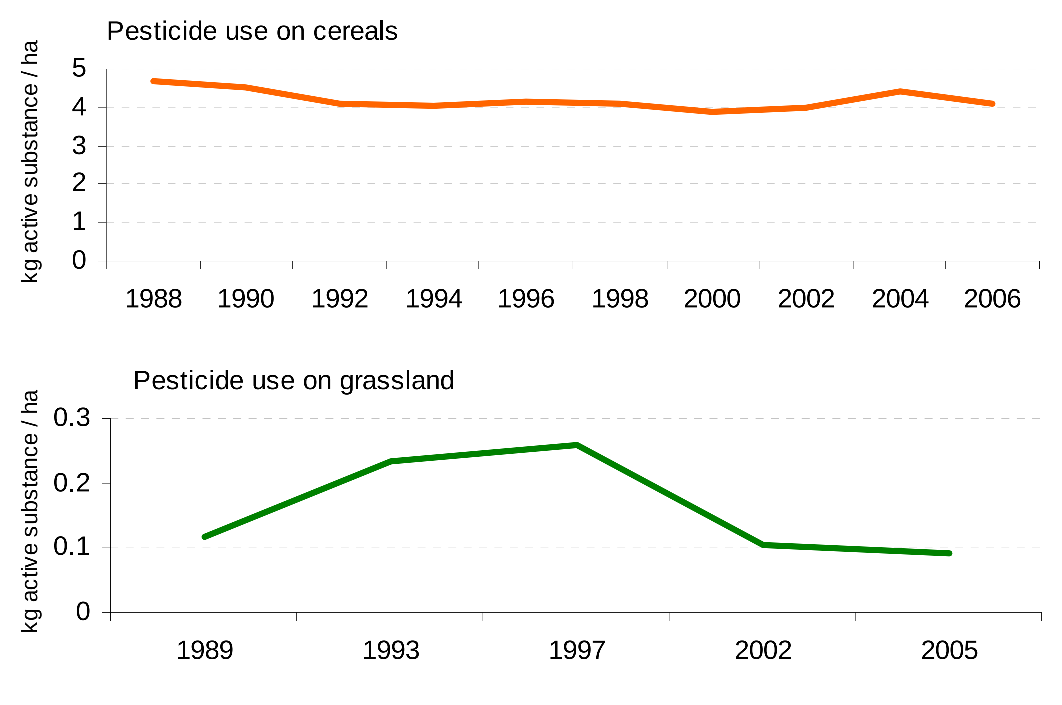
- Improving sewage works at 37 locations including Eastleigh and Andover to reduce levels of phosphorous and organic pollutants.
- Minimising the impact of fish farms and cress farms on water quality.
- Improving road drainage to avoid ground or surface water pollution from road run-off.
- Targeting pollution prevention in urban areas, including domestic oil storage.

Source: Environment Agency, 2008. South East RBD draft Management Plan

Pesticides

6.21. Pesticides are the second major source of poor water quality on arable and horticultural land. Figure 6.6 shows how the amount of pesticides applied to cereals in England has changed little over the period 1988 to 2006 and that pesticide applications on cereals are typically far higher (20 times as much active ingredient) than those on grassland. The trend for the other major arable crops (oilseeds and proteins) is likely to be similar to cereals.

Figure 6.6. Trends in pesticide application rates to cereals and grassland in England.



Source: Defra Sustainable Farming and Food Strategy indicators No. 4.03

6.22. While the total amount of pesticides applied to these crops has not changed significantly, the types of active ingredients have. The EU Pesticides Review, conducted since 2002, has resulted in a significant number of active ingredients, such as the herbicide isoproturon, being withdrawn from sale. For the most part, withdrawn chemicals have been replaced by others considered to be less harmful to the environment. However, it is likely to be several decades before chemicals work their way through to groundwaters.

6.23. Soil erosion from cultivated and unvegetated land has an important link with pollution to surface waters, particularly from pesticides and phosphates which attach to and are transported by soil particles into water. Activities that increase soil erosion, such as leaving bare soil unvegetated during periods of high rainfall, can significantly increase the risk of pollution.

Improved grassland

6.24. Figures 6.4 and 6.5 show that applications of chemical fertilisers and pesticides to agriculturally managed grassland are significantly lower than on arable and horticultural crops, and that application rates have been falling. However, there are two significant sources of pollution that are strongly linked to livestock production, and so to improved grassland as a land use.

6.25. Firstly, manures and slurries from housed livestock need to be collected, stored and then spread to land (to improved grassland and arable land where the latter is on livestock farms). When applied to steep, frozen or waterlogged land or before rainfall, the manure or slurry can be washed into surface waters, exerting high levels of BOD. When applied in concentrations in excess of the crop's ability to make use of the nutrients, they leach into soils and groundwater. The facilities used to collect and store slurry, manure and dirty water from livestock housing can also fail or leak, discharging high levels of nutrients to surface and groundwaters. Failures of slurry stores and extreme cases of surface run-off from fields can amount to point source incidents, but in most cases, the pollution from manure and slurry is considered to be diffuse.

6.26. Secondly, pesticides applied as animal health products can enter surface and groundwaters. The greatest risk comes from sheep dip (to rid sheep of parasites and flies), especially where the dipping takes place close to drains or water courses. Box 6.3 summarises how sheep dip poses risks in the South East RBD.

Box 6.3. Risks to water quality from pesticides in the South East RBD.

The Environment Agency's characterisation of future pressures and risks has estimated that 29 per cent of the total river length and 50 per cent of groundwater areas in the South East RBD are at risk from diffuse pesticides, with risks from sheep dip accounting for eight per cent of the river length.

The chemical cypermethrin (a sheep dip product) has led to failures in Environmental Quality Standards in a number of water bodies including the River Brede (East Sussex between Hastings and Rye) and East Yar (The Isle of Wight).[57] Both of these catchments drain chalk downland where sheep grazing on improved and semi-natural grassland is the dominant land use.

6.27. Pollution from improved grassland may also occur when long-term grassland is ploughed, leading to a flush of nutrients that cannot be taken up by growing vegetation. Stored silage from improved grassland can also be a source of pollution when 'liquor' (excess water containing high levels of dissolved nutrients) are discharged to surface and groundwaters.

6.28. Finally, the density of grazing has a major impact on the risk of surface run-off due to the level of soil compaction. Research shows that surface run-off from overgrazed permanent pasture is typically double that from lightly grazed areas and 12 times that of ungrazed areas[58].

Semi-natural grassland, dwarf shrub heath, fen, marsh and bog

6.29. These habitats receive no direct inputs of chemical fertiliser or pesticides and so have much lower pollution compared to improved grassland. However, the livestock that graze sites are often a source of nutrients (either from their dung when transferring nutrients from improved grassland or supplementary feed, or from manure from housed animals that is spread to the land). Similarly, pesticides can be introduced through animal health treatments to livestock grazing sites. These habitats often occur in upland areas (paragraph 4.49 and 4.53) where high rainfall and steep slopes (and, for fertiliser, the shorter growing season) increase the risk of surface run-off and leaching of nutrients and pesticides into surface and groundwaters.

6.30. Degraded dwarf shrub heath and blanket bog (where vegetation has been damaged by burning or overgrazing or the water table has been lowered by drainage) can pose a risk through increased soil sediment wash or turbidity from eroding peat. These changes change the physical character of surface

[57] Environment Agency (2008)e
[58] Defra (2007)e

waters and can threaten aquatic life. Oxidisation and erosion of peat soils is also a threat to flood risk management and carbon storage (covered in Chapters 8 and 9). Although these risks exist, these habitats nevertheless pose a significantly lower threat to water quality than improved grassland or arable cropping.

Woodland

6.31. Woodland typically receives no fertiliser, except potentially during the establishment of new woodland on impoverished soils (such as in the uplands). Similarly, pesticides are only routinely applied in the establishment phase. Large-scale felling operations can contribute to nutrient leaching, through soil disturbance and erosion, and through the absence of vegetation to take up released nutrients.[59] In general, the greatest risks of water pollution occur during the establishment and harvesting of large-scale commercial woodland.

6.32. Unmanaged woodland, or woodland where management is by selective felling, coppicing and natural regeneration have a lower impact on water quality. Woodland can be effective at slowing or stopping surface run-off, acting as a sink for nutrients from adjoining land. In this way, woodland, especially when planted in strips, can mitigate the impact of pollution on surface waters from other land uses. Heavy shading from riparian woodland can have negative impacts on water quality through low water temperatures (reducing fish growth) and as a result of unvegetated stream sides (leading to soil erosion).[60] To increase the evidence base on the relationship between land use and run-off generation and infiltration, various studies are being carried out, including the Pontbren project in central Wales.[61]

6.33. The influence of large stands of conifers on lowering the pH of waters in sensitive upland catchments has been the subject of much research over the last 25 years.[62] The primary cause of acidification comes from precipitation containing acidifying sulphur and nitrogen pollutants) originating from the burning of coal and oil. It is thought that, by influencing patterns of rainfall (through the greater air turbulence created by their ‘rough’ canopies), trees can increase the amount of pollutants that are deposited by rainfall to forested areas. There is also a coincidence of commercial forestry plantations with areas worst affected by acidification (Cumbria, the Pennines and central Wales) where base-poor, slow-weathering soils and rocks are unable to neutralise the large quantities of acid pollutants that they receive in rainfall. Research is ongoing in the UK and internationally to quantify the amount of pollutants that are captured by forests and identify how the planning, design and management of forests contribute to acidification.

[59] Woodland Trust (2008)
[60] Forest Research (2009)b
[61] Wheater *et al.* (2008)
[62] Forest Research (2009)c

Box 6.4. The relationship between land use and water quality – lessons from the Wye Catchment.

In 2002 it was estimated that around 17 per cent of the Upper Wye and Irfon system was suffering from the effects of acidification[63], mainly caused by the deposition of pollutants from rainfall. The effects were compounded by high rainfall levels in an area with poor base soils. Land use within the catchment is not considered to be the cause of this acidification although it may be exacerbated by widespread conifer planting and commercial forestry activities. The Wye and Usk Foundation have been undertaking liming work in the Upper Wye Catchment since 2003 to reduce the acidity of these waters. Monitoring of water quality and biodiversity has shown major improvements in salmon distribution within the catchment as a result of the improvements in pH levels.

Sheep farming is the main farming activity on the grassland and moorland of the upland catchment, with the majority of arable and dairy farming activities located further downstream. Widespread use of sheep dip in the Upper Wye area has contributed to poor water quality in parts of the catchment, particularly the Irfon above Abergwesyn and the Elan above Rhayader[64].

In the lower part of the catchment, expanding areas of potato farming have led to diffuse pollution problems as a result of increased soil erosion and run-off. Following harvesting of potato crops, the soil structure is heavily disturbed and is vulnerable to erosion, particularly from heavy rainfall. High levels of phosphates enter the Lugg (an important tributary of the Lower Wye) in this way.

In an attempt to tackle these problems, the Environment Agency carries out soil protection work in the English part of the catchment as part of the England Catchment Sensitive Farming Delivery Initiative (ECSFDI), such as conducting soil management training events with farmers.

Coastal habitats

6.34. The coastal habitats of estuarine mudflats, saltmarshes, and cliffs and slopes are rarely a source of pollution in their own right. However, estuaries receive large quantities of sediment, which can carry phosphates, heavy metals, pesticides and other chemicals, from upstream land uses. Estuarine mudflats and salt marshes can act as slow-release sinks of these potential pollutants. In addition, navigational dredging can release large quantities of sediment-bound pollutants into the water, which can have a negative impact.

6.35. Commercial and recreational boating on the coast, particularly in estuaries, can be a source of pollutants from anti-fouling treatments and petrochemicals, but these do not qualify as 'land uses' in the terms of this study.

Box 6.5. The relationship between land use and water quality in Chichester Harbour falling within the South East RBD.

Chichester Harbour forms a small inland sea – the meeting place of four estuaries held back by a single narrow entrance and significant bar. It is covered by three international designations – as a RAMSAR site, SPA and part of the Solent SAC, reflecting that it is the seventh largest area of remaining saltmarsh in Britain and is visited by over 47,000 over-wintering waterfowl. It is also an AONB.

[63] Wye and Usk Foundation (2008)
[64] Environment Agency (2008)c

Water quality can be affected by excessive levels of nutrients (nitrates and phosphates) entering the harbour via drainage or run-off from farmland or discharge of sewage. At certain times of the year, this can lead to eutrophication and cause excessive growth of algal weed which smothers environmentally sensitive saltmarsh and mudflats and results in an unpleasant smell when it is washed up and decomposes on the strandline. Research shows that the highest proportion of nutrients which enter the harbour comes from the wider Solent, rather than within the harbour itself. This makes the management of water quality within the harbour dependent on action taken outside the area.[65]

Summary of land use impacts on water quality

6.36. Figure 6.7 draws out the key conclusions from this section.

Figure 6.7. Summary of land use impact on water quality.

Land Use	Impact	Key sources and land management issues
Urban development	--	Many sources focussing on land drainage and water treatment
Arable/horticulture	--	Chemical fertilisers and pesticides
Improved grassland	--	Chemical fertilisers, animal manure and animal welfare treatments
Semi-natural grassland	-	Animal manures and animal welfare treatments
Dwarf shrub heath	+	Potential to mitigate low water quality from other sources
Broadleaved woodland	+	Potential to mitigate low water quality from other sources
Conifer woodland	?	Possible increase in pollution (acidification) from rainfall
Coastal habitats	O	Concentration of pollution carried in sediments from upstream areas

Key: -- high potential negative impact, - low potential negative impact, O neutral impact, + potential positive impact, ? impact unclear.

Future pressures on Water quality

6.37. The previous chapter identified the following pressures that are likely to influence water quality over the period to 2020 and beyond.

- **Population and industrial growth**. A growing population, more households and greater consumption will involve new land take for developed land and more waste, raising the risk of diffuse water pollution from developed land. However, improved urban design, more efficient use of materials (both in construction and transport), increased recycling and the composting of waste will potentially reduce these risks.
- **Climate change.** Drier and hotter summers will reduce base flows in rivers, increasing concentrations of pollutants in water. The northward movement of climatic zones could introduce new crops and land management practices such as double cropping which could increase the intensity of management and risk of diffuse pollution.
- **Regulation and incentives.** The Water Framework Directive will be an increasingly important driver of land use and management decisions, acting on identified pressures and risks (particularly diffuse pollution) which should

[65] Chichester Harbour Conservancy (2004)

improve water quality. Government policy to reduce greenhouse gas emissions should also have a positive impact, by reducing the use of fertilisers and intensive forms of meat production and diverting farm waste to anaerobic digestion rather than immediate disposal to land.

- **Markets and social change**. There is considerable uncertainty over the economic and social pressures that will influence land use and water quality. Food security issues may increase domestic production of foods leading to more intensive use of cropped land. On the other hand, a decline in livestock numbers is predicted, especially in uplands. The effect of these changes on water quality is likely to be shaped by the regulation and incentives outlined above.

Measures to address failures in service delivery

6.38. This section reviews the actions available to deal with poor water quality. Point source incidents are dealt with through regulation and, where appropriate, prosecution. Measures to prevent such incidents and to treat diffuse sources of pollution are summarised.

Developed land

6.39. Land use change from developed land to any of the other land use types covered by this study is unlikely to occur on anything but a small scale (for instance the restoration of contaminated land to grassland or woodland). At a local scale, there is the potential to use adjacent areas of undeveloped land (land currently used for arable and horticultural crops or improved grassland) to receive dirty water from developed land (particularly run-off from roads and other hard surfaces) that would otherwise be discharged into sewers, soakaways or watercourses. Nevertheless, carefully targeted changes in land use, for example, through Green Infrastructure (GI) proposals, could bring valuable improvements in water quality. This may include the planting of woodlands and tree belts or the creation of reed beds and wetlands as nutrient sinks that also offer a local amenity, a source of fuel, and a local wildlife resource. Improvement of surface and groundwater quality should be a clear objective of GI. However, within existing development there will still need to be a strong focus on changes in land management (for instance the remediation of contaminated land by soil treatment or hydrological isolation from groundwater and investment in public sewerage systems) or on regulation and advice (such as reviewing discharge consents, working with high-use industries to improve practice and reduce risks, and encouraging the use of 'cleaner' technologies).

6.40. It is in the planning of new urban, industrial and transport development that most attention needs to be given to appropriate land uses to improve surface and groundwater quality. This can be achieved through strategic planning and GI to maximise the range of services delivered by a network of soft land uses. The availability of water resources and flood risk are the two most important concerns (covered in the following chapters), but the impact of urban development on water quality, particularly where surface and groundwaters are already facing pressures, is a major concern.

6.41. The strategic planning of new developments needs to take account of likely new sources of pollution (particularly diffuse pollution) and the sensitivity of surface and groundwaters to these pressures. In areas where there is a close hydrological link to sensitive areas such as Groundwater Source Protection Zones and important wildlife sites (SSSIs), especially those of international importance, development may not be appropriate. In other areas, it will be necessary to build in mitigation measures as part of the development planning process to ensure additional risks and pressures can be dealt with adequately. This will involve decisions on retaining and creating certain land uses, particularly semi-natural grassland, wetland, especially reed beds and carr woodland, and other woodland within and adjacent to new developments.

Box 6.6 Groundwater Source Protection Zones.

Source Protection Zones (SPZs) have been identified by the Environment Agency for 2,000 groundwater sources such as wells, boreholes and springs used for public drinking water supply. These zones are used to target pollution prevention measures in areas which are at a higher risk, and to monitor the activities of potential polluters nearby. Groundwater source catchments are divided into four zones: an inner protection zone (Zone 1) where pollution might enter the public water supply within 50 days of discharge; an outer protection zone (Zone 2) where pollution might take up to 400 days to travel to the water supply; the total groundwater catchment area (Zone 3) and a zone of special interest (Zone 4) where local conditions mean that industrial sites and other polluters could affect the groundwater source despite being outside the normal catchment area.

6.42. Sustainable Drainage Systems (SUDS), which seek to integrate drainage with environmental and amenity uses of land, making maximum use of natural systems to treat water and return it clean to groundwater, are becoming more frequently used in new developments. Aspects of SUDS that can improve water quality include:

- permeable paving, allowing ‘clean’ rainwater to drain directly into the soil, reducing the volume of dirty water entering the main sewers and requiring treatment;
- using filter strips between hard surfaces and swales (vegetation drainage channels) to intercept surface run-off and encourage infiltration;
- retention ponds, acting as silt traps;
- biobeds (including reed beds) for the treatment of dirty water.

Arable and horticultural crops and improved grassland

6.43. A number of measures exist to reduce water pollution originating from agriculture, all of which seek changes in the way land is managed as the first recourse, using changes in land use only at a small (within field) scale or, at a larger scale, as a last resort.

6.44. The EU Nitrates Directive aims to reduce water pollution caused by nitrogen from agricultural sources. It requires Member States to designate all land draining to waters that are affected by nitrate pollution as Nitrate Vulnerable Zones (NVZs) and to establish a mandatory Action Programme of measures to tackle nitrate loss from agriculture. In England 70 per cent of land is now designated as NVZ whereas in Wales, the area is much smaller (around three per cent. Within these areas, tighter prescriptions on the use of manures apply to land close to boreholes, springs and streams. The measures that apply to farmland in NVZs in England are summarised in Box 6.7.

Box 6.7. Summary of key NVZ rules in England.

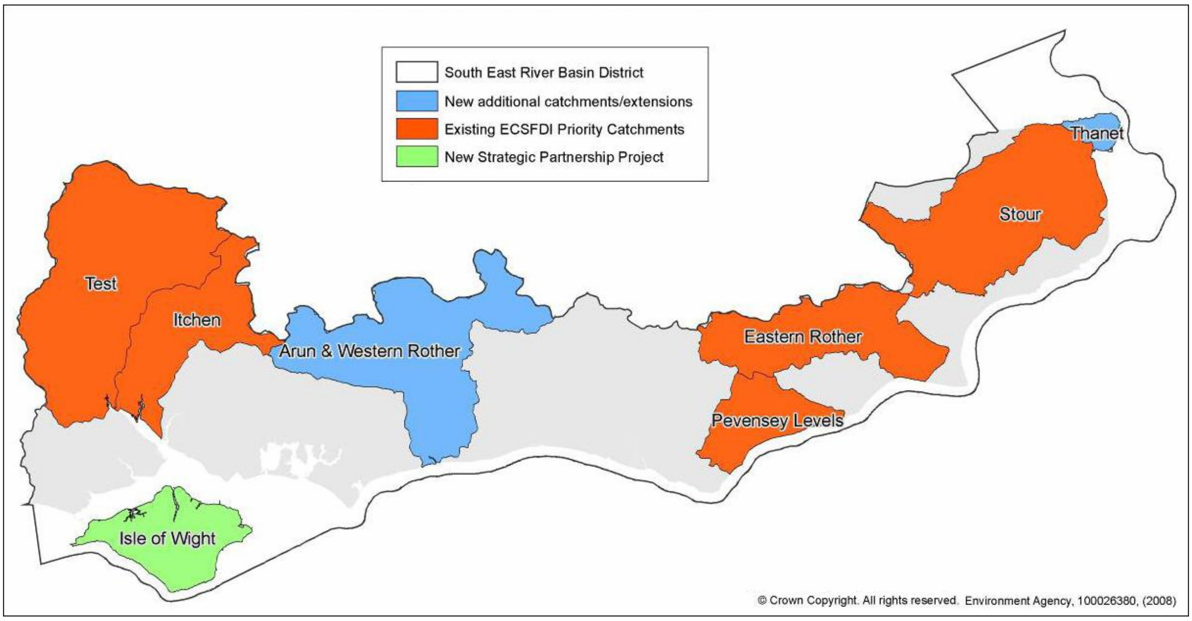
- **Livestock manure limit**: Establishes a loading limit of 170 kg/ha/year of total nitrogen (N) from livestock manures (deposited during grazing and by spreading) averaged across the farmed area.
- **Closed period (organic manures)**: Prohibits the spreading of organic manures with high available nitrogen content during specified periods (three to five months depending on soil type and land use).
- **Manure storage capacity**: Requires farms to provide sufficient storage facilities to store all livestock slurry and manure for a period of five (for pigs and poultry) or six (for cattle) months.
- **Closed period (nitrogen fertilisers)**: Prohibits the spreading of manufactured nitrogen fertiliser during specified periods unless there is a crop nitrogen requirement.
- **Crop requirement**: Requires farmers to plan applications of nitrogen to crops and to comply with an upper cap on nitrogen applications (N maximum limits).
- **Spreading locations**: Requires a written assessment to identify areas of land at risk of run-off and causing water pollution. Prohibits fertiliser and manure applications to areas posing a high risk of run-off.
- **Spreading techniques**: Prohibits the use of high trajectory application techniques for spreading slurry. Requires incorporation of organic manure into bare soil in certain situations.
- **Record-keeping**: Requires records to be kept of all N applications to land and numbers of livestock on the holding.

6.45. Farmers must abide by a set of cross-compliance rules consisting of Statutory Management Requirements (consisting of EU Directives) and Good Agricultural and Environmental Conditions (GAEC which consist of obligations set at the national level to an EU framework). A revision to the EU framework in December 2008 (the 'CAP Health Check') adds requirements for farmers to protect water quality including maintaining buffer zones besides watercourses.

6.46. Agri-environment schemes (Environmental Stewardship in England and Tir Cynnal and Tir Gofal in Wales) offer voluntary agreements to farmers to deliver a range of environmental objectives. In both cases, there are two tiers of agreement available – an entry level tier intended to provide relatively low levels of payment for basic changes in management and a more competitive higher level tier providing higher payments to generate greater public benefits. Natural resource protection, and particularly measures to tackle diffuse pollution, is one of the priority objectives of these schemes. Measures such as the creation and maintenance of buffer zones to protect watercourses and ponds and the use of cover crops to reduce soil erosion are options to meet this objective. Whereas options in the entry level schemes are primarily about changes in land management, the higher level schemes offer payments for farmers to change land use. For options that tackle soil erosion as a source of poor water quality, this includes converting arable and intensively managed grassland to low input grassland.

6.47. The England Catchment Sensitive Farming Delivery Initiative (ECSFDI) is part of Defra's programme to reduce diffuse water pollution from agriculture. It is a voluntary programme to encourage best practice amongst farmers in priority catchments throughout England, jointly delivered by the Environment Agency and Natural England. Figure 6.8 shows the location of priority catchments in the South East River Basin District. Catchment Sensitive Farming Officers arrange demonstration events and visit individual farms, focussing on the risks and pressures in their catchment. Publications such as the Environment Agency's booklet, *Best Farming Practice*, are used to identify suitable land management practices and farmers are advised on the most beneficial aspects of agri-environment scheme options. Capital grants are available to farmers in the priority catchments to improve dirty water handling and storage infrastructure. In Wales, the Welsh Assembly Government has funded pilot Catchment Sensitive Farming initiatives in an intensive dairy lowland catchment in South West Wales and neighbouring upland livestock farming catchments in North Wales. A new Catchment Sensitive Farming scheme for Wales has been developed to follow on from the two pilot areas, targeting specific areas, and will open in 2010.

Figure 6.8. Catchment Sensitive Farming Initiative in the South East RBD.



Source: Environment Agency, 2008. South East River Basin District Draft Management Plan, Annex F, Mechanisms for Action.

6.48. Currently Defra is trying to secure further voluntary action by farmers to address water quality issues (e.g. through agri-environment schemes like the England Catchment Sensitive Farming Delivery Initiative), before deciding whether to bring in further regulation in the form of Water Protection Zones (WPZs, currently being piloted) under Section 93 of the Water Resources Act 1991. The aim of WPZs would be to restrict or prohibit activities that can cause water pollution within a particular area (at any scale - from multiple catchment to sub-catchment). In the longer term WPZs could be merged with NVZs.

6.49. The Voluntary Initiative (VI) was introduced by the private sector as an alternative to pesticide tax, aiming to minimise the environmental impacts of pesticide application. Its best practice guide includes advice on planning strategies and ways to carry out pesticide applications.

6.50. Overall, the primary emphasis for reducing water pollution from arable land, horticulture and improved grassland, will be through changes in land management driven by regulation, agri-environment schemes and guidance. In critical areas this may be supplemented by carefully targeted land use change, primarily to low input grassland or woodland or, indeed, reed beds and other wetlands.

Semi-natural grassland, dwarf shrub heath, fen, marsh and bog

6.51. These land uses benefit from the same measures directed at farmers and landowners as described above. The risks associated with these land uses are generally lower (although issues such as sheep dip may be more important, and preventing the erosion of peat soils has implications for flood risk management and carbon storage as well as water quality). Compared to arable and improved grassland, there are clear multi-purpose benefits from managing these habitats appropriately. These include biodiversity, recreation and cultural heritage, and means that there is a strong case for targeting policy interventions such as agri-environment schemes at these areas. This is evident in the high proportion of dwarf shrub heath that is now under environmental stewardship agreements in England.

Box 6.8 The Sustainable Catchment Management Programme (SCaMP).

The SCaMP programme, a partnership between United Utilities and Royal Society for Protection of Birds (RSPB), is a groundbreaking project focusing on 20,000 hectares of land in the Forest of Bowland and Peak District. As the main source of water for 6.7 million people in the North West, the project aims to manage the water catchment for the benefit of water quality, wildlife and biodiversity. Work includes:

- Restoring blanket bogs by blocking drainage ditches.
- Restoring areas of eroded and exposed peat (aim for the restoration of 5,500 hectares).
- Restoring hay meadows.
- Establishing clough woodland (aim for the planting of 450 hectares of upland oak woodland).
- Restoring heather moorland.
- Providing new farm buildings for indoor wintering of livestock and for lambing.
- Providing new waste management facilities to reduce run-off pollution of water courses.
- Fencing (200 km) to keep livestock away from areas such as rivers, streams and special habitats.
- Improved habitat for breeding waders, including through the creation of 100 scrapes.

The programme is funded through Ofwat with additional capital grants from agri-environment schemes, giving a total fund of around £12 million up to 2010. The vision for 2010 is for:

- Sites of Special Scientific Interest (SSSIs) to be in prime condition.
- A halt to the alarming declines of birds such as twites and hen harriers.
- Return of stunning and vitally important landscapes and habitats such as blanket bog and heather moorland.
- Improvements to water quality.
- Economically-viable farming to maintain special habitats and wildlife, as well as water quality.
- Opportunities to support farming at a time of change and uncertainty.

6.52. As explained above, it is the lower, or zero, inputs of chemical fertiliser and pesticides and the lower livestock densities (reducing soil compaction and therefore soil erosion), that benefit water quality. These benefits mean that low input grassland is often the preferred land use in areas surrounding boreholes (Zone 1 of groundwater SPZs). Wetland habitats have the potential to absorb and process sediments and nutrients, helping to reduce diffuse pollution loading in water courses. Constructed farm wetlands (such as reed beds) can be used to treat lightly contaminated water from point sources before it is released into watercourses or groundwater or can provide a linear buffer filtering run-off before it enters the main watercourse.

6.53. One of the conclusions in Chapter 5 on the drivers for change of future land use was that the need to secure food supplies and more renewable energy from biomass will result in marginal land that is capable of higher agricultural productivity (such as remaining areas of semi-natural grassland in the lowlands) being brought into more intensive uses. This suggests that there will be increased competition for this land to deliver environmental services such as water quality as well as the provision of food and energy.

Woodland

6.54. Woodland establishment has the potential to mitigate poor quality water, mainly by preserving soil structure and reducing soil erosion (by providing shelter from wind, reducing water run-off, increasing infiltration and improving the strength and stability of soils).[66] The stabilising effects of deeper rooted species such as alder are particularly beneficial.[67] Carr woodland (particularly alder and willow) can also be effective at drawing out nutrients from lightly contaminated water, in the same way as reed beds.

6.55. Incentives for managing existing woodland and for establishing new woodland are available through the English Woodland Grant Scheme and the Better Woodlands for Wales scheme, both run by the Forestry Commission. Like the agri-environment schemes, both have multiple objectives of which natural resource protection is one.

Summary of the scope for land use to improve service delivery

6.56. The following points emerge from this chapter.

- The ecological status of rivers, as reported by the Environment Agency for WFD compliance monitoring purposes, provides the most complete measure of water quality that is likely to have the closest link to land use and management. These data show that across England and Wales:
    - Eight per cent of rivers by length are in good or better condition.
    - Sixty-one per cent are moderate.
    - Seventeen per cent are poor.
    - Four per cent are in bad condition.

  There is a geographically complex picture with stretches of rivers often changing from one classification to another over relatively short distances.

- Analysis of the spatial relationship between land use and river water quality suggests there is a relatively strong association of rivers of good and better quality with dwarf shrub heath and semi-natural grassland habitats, concentrated in the upland headwaters of rivers. Analysis of data from the

[66] Nisbet *et al.* (2004)
[67] Woodland Trust (2008)

South East RBD suggests a link between poor water quality and areas dominated by arable and horticultural and a link between good water quality and areas dominated by grasslands, including improved grasslands.

- Research shows that developed land and arable and horticultural cropping typically produce the greatest risks to water quality (the former from a range of domestic, industrial and transport sources and the latter from fertilisers and pesticides, with soil erosion as a contributory issue). In both cases, it is the diffuse nature of the pollution which means that it is difficult to identify and address.

- The lower levels of chemical fertiliser and pesticide inputs to improved and semi-natural grassland (compared to arable and horticulture) means that the risks to water quality from these land uses tend to be lower. However, livestock slurries and manures (their collection, storage and disposal to land) can pose a significant threat, as can animal health products such as sheep dip. The intensity of livestock grazing has an impact on water quality, not only through the volume of manure and slurry produced, but also on the level of soil compaction which is strongly linked with increased risks of surface run-off and soil erosion.

- In contrast, dwarf shrub heath and its associated semi-natural habitats, and woodland have few risks of poor water quality associated with them. For managed woodland, the risks tend to be higher during the establishment and harvesting phase. Large conifer plantations often occur in areas which discharge acid waters (caused by atmospheric emission from burning oil and coal, and received as acid rain) and the forestry may have a contributory impact through increased interception of moisture. But in general, dwarf shrub heath and broadleaved woodland can be considered to have positive impacts on water quality, and can potentially be used to mitigate negative impacts of other land uses.

- It is clear from measures currently used to address poor water quality that changes in the way that land is managed are often appropriate, before changing from one type of land use to another. In many cases, water quality can be raised to acceptable levels by changes in management without requiring changes in land use (nearly a quarter of the areas with good water quality are dominated by arable and horticultural cropping). Some of the negative management activities apply across land use types (for instance nitrate and phosphate leaching from livestock manures occurs on both intensively management grassland and semi-natural grassland) and changing the land use on its own, without considering how it is managed, may not fully address the problem.

- Nevertheless, there are opportunities for changing land uses at a targeted and localised scale to improve water quality. These changes in land use are likely to receive higher policy priority where they deliver a range of other environmental services (such as biodiversity, landscape quality, energy production, flood risk management and public recreation). Examples of beneficial changes in land use include:
  - the creation of SUDS within or adjacent to developed land;
  - the creation of grassland or woodland buffers beside watercourses and ponds on arable and horticultural land;

- the creation of wetlands, reedbeds, willow and alder carr as natural methods of filtering and purifying water before it enters ground or surface water;
- the conversion of cultivated land and improved grassland to semi-natural grassland around boreholes.

- These changes are localised and need to be highly targeted spatially to deliver the required benefit. Land use change of a scale sufficient to change the dominant land use type at a landscape scale (for instance within one-km tiles) is unlikely to be justified solely on the basis of improving water quality so long as a regulatory floor is in place.

6.57. Overall, the priority changes in land use and management to address failures in water quality are as follows:

Land use change

- There are no landscape-scale changes in land use that are justified purely on the basis of improvements to water quality. However, changes from arable and horticultural cropping and improved grassland to less intensive uses of land (for instance semi-natural grassland, woodland and coastal habitats) that are adopted to deliver other environmental services will help to improve water quality.

- Localised small-scale changes in land use to improve water quality include the adoption of sustainable drainage systems as part of green infrastructure on developed land and the use of buffer zones of semi-natural grassland or woodland in river corridors and around boreholes and the creation of wetlands, reedbeds and carr woodland to filter surface run-off that is likely to be carrying polluted water.

Land management change

- There are a range of best practice measures that should be adopted on all arable and grassland farms to reduce diffuse pollution of nitrates and phosphates and soil erosion. These include reducing fertiliser and pesticide applications, ensuring that these inputs are applied at times and in ways that reduce drift and leaching and reducing soil compaction and an increase in infiltration capacity to lessen soil erosion.

7. Availability of water resources

7.1. This chapter follows the same sequence of headings as the previous chapter, as described at paragraph 6.1. The examples from the case studies in this chapter are drawn from the South East RBD rather than the Wye catchment because of the greater significance of water resources as a policy issue in South East England.

Summary of service delivery

7.2. Environmental limits for the availability of water resources were measured in this study using the Environment Agency's modelled data on the pressures and risks arising from water abstraction in surface and groundwaters. These data show that around 15 per cent of surface water catchments and 21 per cent of groundwaters are considered to be at high or moderate risk of over-abstraction, leading to low river flows.

7.3. Spatially, there is a high concentration of surface water catchments at high and moderate risk in the south east and east of England, particularly in chalk catchments. Wales, the south west, and northern regions of England have relatively few such areas.

7.4. The spatial pattern is much simpler for groundwater since the areas are much larger, but it is the primary aquifers closest to major centres of population (for instance the Kent Downs south of London and Chilterns north of London, the Stour and Worfe catchments west of Birmingham, and the Wirral south of Merseyside) that are most at risk.

7.5. In Chapter 5, the future impact of climate change and increased development on river flows and wetland habitats, particularly in the south east of England and around major settlements in other parts of England and Wales, was highlighted. These future pressures will exacerbate the current situation.

Service delivery and land use

7.6. The same method for comparing levels of service delivery against dominant land use was applied to water resources as for water quality (the previous chapter), with the exception that all the water resource data was already available for catchments (and therefore did not need converting from river lengths, as was the case for river water quality). The dominant classification of risk in terms of the availability of water resources in each one-km^2 can therefore be compared to the dominant land use in the same one-km^2.

7.7. The results of this comparison are shown in Figures 7.1 (for surface catchments) and 7.2 (groundwater) and the over- or under-representation of each land use in each risk category are shown graphically in Figures 7.3 and 7.4.

7.8. The data in Figures 7.1 and 7.2 shows that arable and horticultural cropping is the dominant land use on half (49 per cent) of the surface water catchments and over half (57 per cent) of groundwater areas considered at high and moderate risk, compared to the third of all areas where this land use dominates. Grassland (improved and semi-natural) is the dominant land use on 29 per cent of high and moderate risk surface water catchments and 33 per cent of high and moderate risk groundwater areas, compared to a coverage for the whole of England and Wales of 44 per cent.

Figure 7.1. Grid recording number of one-km tiles by land use type and surface water resource pressure across England and Wales.

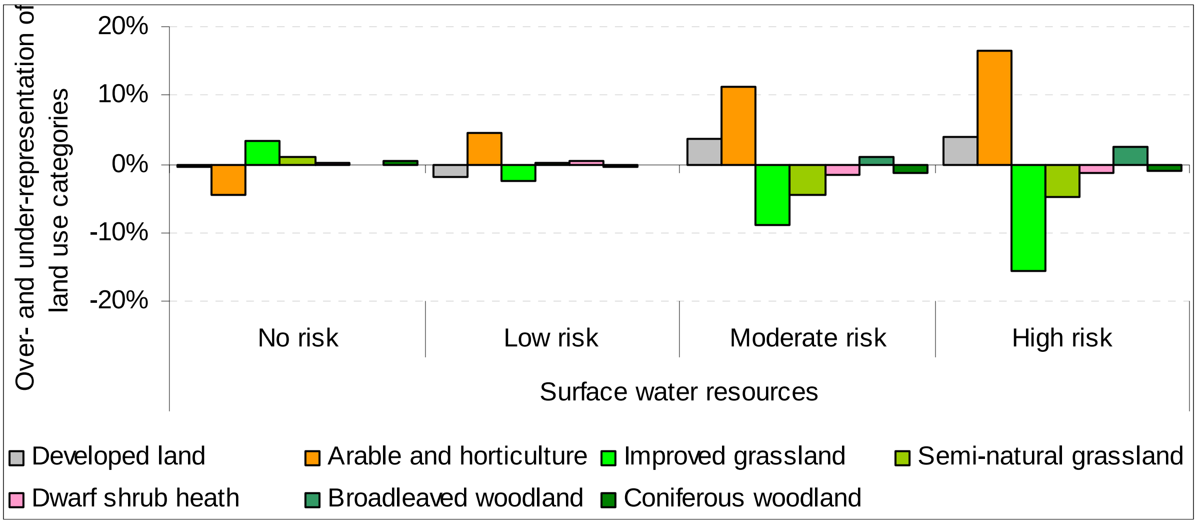
Land Use Type	No risk	Low risk	Mod. risk	High risk	N/A
Developed land	8,575	1,930	1,798	1,006	178
Arable and horticultural crops	30,969	11,137	6,650	4,088	841
Improved grassland	36,874	8,703	3,519	1,419	331
Semi-natural grassland	11,639	3,023	881	459	103
Dwarf shrub heath, fen, marsh and bog	2,950	902	172	117	9
Broadleaved woodland	4,682	1,243	846	568	31
Coniferous woodland	2,899	662	184	122	22
Inland water	237	130	44	12	13
Coastal habitats	704	133	77	65	86
Total Area	**99,529**	**27,863**	**14,171**	**7,856**	**1,614**

Figure 7.2. Grid recording number of one-km tiles by land use type and groundwater resource pressure across England and Wales.

Land Use Type	No risk	Low risk	Mod. risk	High risk	N/A
Developed land	2,095	7,579	2,642	1,114	57
Arable and horticultural crops	11,059	24,341	15,516	2,693	76
Improved grassland	4,072	40,428	5,418	744	184
Semi-natural grassland	657	14,123	1,107	195	23
Dwarf shrub heath, fen, marsh and bog	38	4,033	60	19	0
Broadleaved woodland	1,239	4,207	1,470	418	36
Coniferous woodland	114	3,230	472	71	2
Inland water	56	308	41	31	0
Coastal habitats	84	738	179	22	42
Total Area	**19,414**	**98,987**	**26,905**	**5,307**	**420**

7.9. The over- or under-representation of each of the land use categories for each level of water resource risk is shown in Figures 7.3 and 7.4. For surface water catchments, there are clear trends between the level of risk and over- or under-representation of arable and horticultural cropping and grassland. As risk increases, arable and horticultural cropping and developed land become more significant as the dominant land use. The reverse is true for both grassland types.

Figure 7.3. Under- and over-representation of land use categories in relation to different levels of surface water resource pressures across England and Wales.



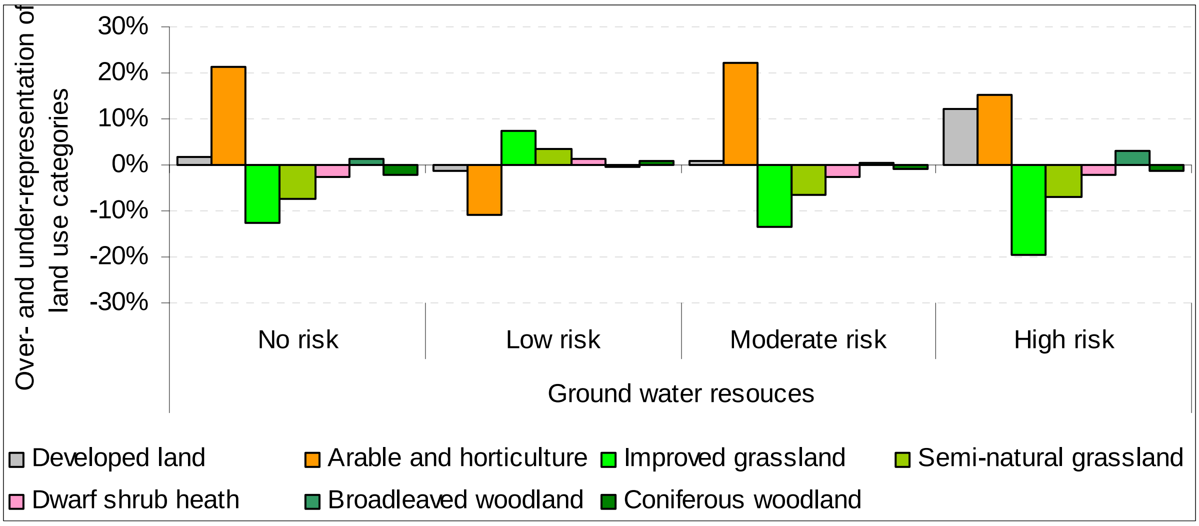
7.10. Care must be taken in attributing a cause and effect relationship to these associations. While it is likely that risks of over-abstraction and low river flows are strongly linked to the levels of demand for water from urban areas, and crop irrigation, most of the main centres of population in England and Wales, and most of the irrigated arable and horticultural crops, occur in the eastern and central parts of the country which receive less rainfall. The following section explores the links between land use and availability of water resources.

7.11. The association between land use and groundwater risks appears to be more complex. Arable and horticultural cropping are over-represented in areas of no risk, as well as those of moderate and high risk, while the opposite is true of grassland. Reference to the map showing the distribution of groundwater resource classifications (Figure 3.16) suggests that it is geology and regional differences in climate that are the determining factors. Most areas of no risk are the clay-dominated areas in south east and central England and are the major aquifers of the chalk, limestone and sandstone strata[68]. These areas have high concentrations of arable and horticultural cropping. Low-risk areas occupy large swathes of the west and north of England and most of Wales where grassland is the dominant land use. This suggests that land use is not a prime cause of groundwater resource availability although, as noted later in this chapter, it can be a contributory factor.

7.12. Figure 7.4 shows that developed land is over-represented over groundwaters at high risk. This is linked to the high demand for water for public supply from aquifers close to the main urban areas such as London (the Chilterns, North Essex Chalk and North Downs – chalk aquifers), West Midlands (Worcestershire Middle Severn groundwater area – sandstone aquifers) and Merseyside (the Wirral – sandstone aquifers).

[68] UK Groundwater Forum (undated)

Figure 7.4. Under- and over-representation of land use categories in relation to different levels of groundwater resource pressures across England and Wales.



How land use and management impact on service delivery

7.13. At its simplest, the availability of water resources is dependent on:

- the amount of precipitation;
- the capacity for storage of water in rivers, reservoirs, groundwaters (affected by underlying geology) and soils;
- the amount of water being taken out by evaporation, transpiration, river and groundwater flows and for human and industrial consumption.[69]

7.14. Land use has an influence (albeit a small one in the case of precipitation) on each of these factors and this influence is examined for each of the land use categories below. In particular, land use affects:

- the amount of water stored in the soil (also potentially helping to regulate river flows (Chapter 8);
- the extent to which underlying aquifers are recharged (as considered below).

Aquifer recharge

7.15. Aquifer recharge is the process through which water moves from the land surface or the unsaturated zone into the saturated zone (groundwater) so that it becomes available for abstraction from boreholes. This process is particularly important in the most heavily used aquifers, to maximise the amount of rainfall that is available for abstraction. Sources of water for recharge include precipitation that infiltrates through soils and unsaturated strata, and water flowing along surface and underground rivers (which may connect directly with the water table or may percolate down to it).

[69] Abstraction for human and industrial consumption is best considered as a net withdrawal since much of the water abstracted, particularly for industrial use such as electricity generation, is quickly returned after use.

7.16. Recharge varies considerably with time and location. Variation over time, which occurs with seasonal or short-term variations in precipitation and evapotranspiration, is greatest in thin unsaturated zones (where recharge may occur within a short time of infiltration) and least in deep unsaturated zones (where recharge is evened out over many years). Spatial variation occurs with climate, topography, soils, geology, and vegetation. In some parts of the UK, groundwater accounts for 70 per cent of water supply into the public grid.[70] so the level of recharge is important, both to ensure continued availability of groundwater, but also to ensure that diminishing groundwater does not damage natural systems (such as river and wetland ecology).

7.17. The proportion of rainfall that is recharged (reaches the groundwater) varies with the amount of rainfall, and also with soil conditions and vegetation type.

- At low levels of rainfall, particularly during the summer, most or all of the rainfall is often intercepted by vegetation and used up through evapotranspiration in the root zone. Where the soil is dry, compacted and/or panned, there may be little infiltration and high levels of surface run-off to watercourses.
- At moderate levels of rainfall, the amount percolating through the soil exceeds the evapotranspiration capacity of plants and a high proportion of rainfall is recharged. Once dry soil is wetted it is able to receive more water (until it becomes saturated) although this can be reduced by soil compaction and panning.
- At high levels of rainfall or conditions of snowmelt, soils become saturated (exacerbated where it is compacted or panned) and excess water runs off.

7.18. Land use therefore has a major impact on aquifer recharge through the type of vegetation and the condition of the soil. A research review examined the evidence on the optimal conditions of vegetation and soils for aquifer recharge[71] and concluded that, while changes in land use can increase infiltration, the scale of change needed to significantly increase aquifer recharge would need to be widespread. This research review, which took place in 2004, found a lack of evidence on the connections between land use and groundwater recharge. Further work has been taking place for the Environment Agency[72] to inform its Water Resources Strategy[73] but there is still a lack of evidence on how future changes in land use are likely to influence groundwater levels.

7.19. How different land uses and land management practices can influence the availability of water resources through storage of water in soils and aquifer recharge is discussed below.

Developed land

7.20. Across England and Wales as a whole, public water supply is responsible for half of water abstraction from non-tidal waters, and industry is responsible for a further 40 per cent.[74] These demands are located predominantly on developed land – particularly the eight per cent of the land area that contains two-thirds of the population (Figure 4.3).

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[70] Environment Agency (2004)
[71] Defra and Environment Agency (2004)
[72] See for instance Environment Agency (2008)h
[73] Environment Agency (2009)
[74] Environment Agency (2008)d. Two-thirds of the water used for industry is abstracted for use in electricity generation and most of this is returned to rivers close to the point of abstraction.

7.21. As noted earlier (Figures 3.17 and 3.18), the amount of water abstracted for public consumption has stayed relatively constant in recent years, with rising per capita consumption but lower amounts lost to leakage. Government targets for growth in house building, particularly in the identified growth areas and growth points are set to increase demand. These areas are concentrated in the south east and midlands of England where groundwater resources are already stretched. As noted in Box 7.1, the adequate provision of water resources (for public supply and the environment) in areas such as the South East will only be secured through efficiency savings (particularly metering of households and reductions in leakages) and investment by the water companies in the sharing and development of water resources.

Box 7.1 Planning for additional housing and water use in the South East RBD.

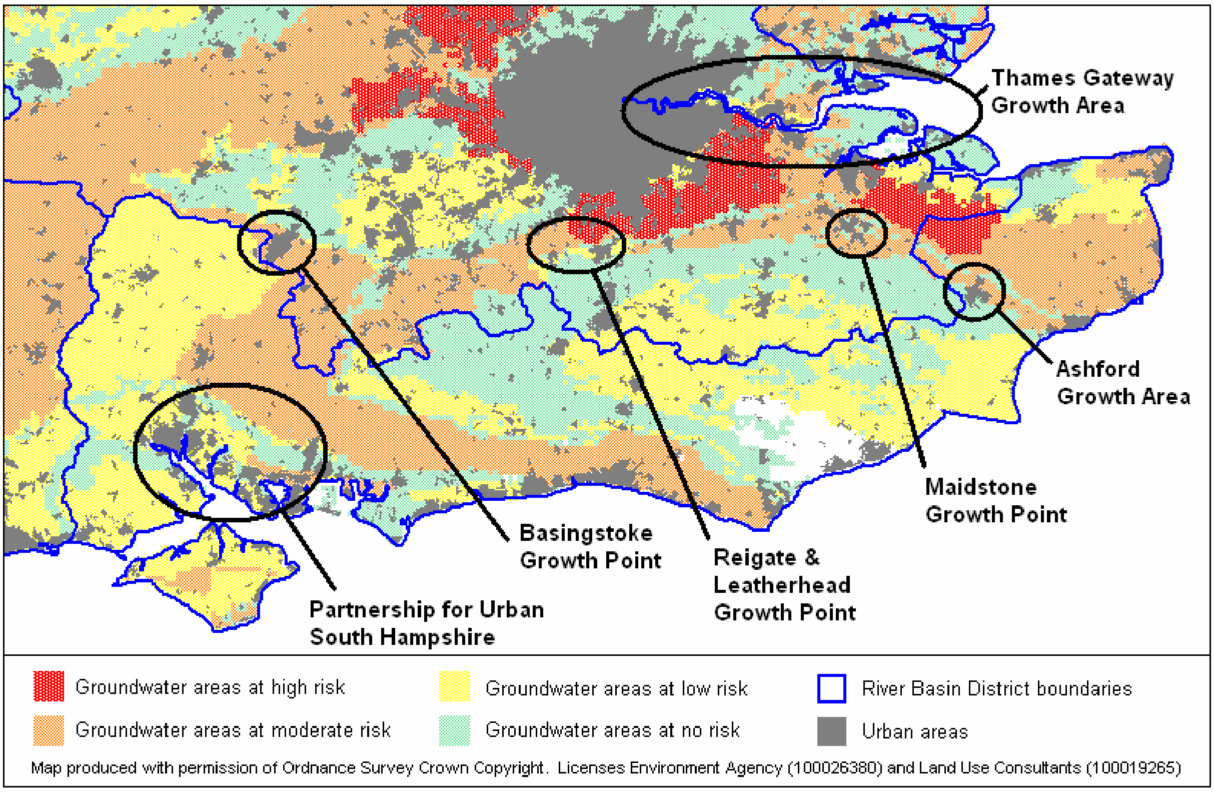
Figure 7.5 shows the location of the growth areas, growth points and partnership growth areas that lie in or close to the South East RBD, also showing the classification of risk to groundwater resources from the Environment Agency's river basin characterisation work.

The Partnership for Urban South Hampshire (PUSH) area is projected in the South East Plan to receive an extra 80,000 houses up to 2026 and the Ashford Growth Area is projected to receive an extra 22,400 houses. Both draw water from chalk aquifers that have been characterised as at moderate risk (the River Itchen and East Hants groundwater areas and the East Kent Chalk groundwater area, respectively). The Basingstoke and Maidstone Growth Points both lie close to the South East RBD and additional housing is likely to draw water from the RBDs groundwater. Housing growth is also forecast on the coast between Brighton and Chichester, but at a lower rate.

The Environment Agency has commented on the proposed housing allocations in the South East Plan.[75] Based on a series of scenarios on the levels of housing growth, water efficiency savings and investment in infrastructure by water companies, the report concludes that without significant water efficiency savings and infrastructure investment, large parts of the region will go into water deficit, with South Hampshire facing the greatest deficit in excess of 40 per cent. However, with efficiency savings and investment, the levels of growth projected in the South East Plan can be accommodated so that water resources are in surplus.

[75] Environment Agency (2006)

Figure 7.5. Location of growth areas and points in and around the South East RBD mapped in relation to risks to groundwater resources.



7.22. Finally, within the high proportion of developed land covered by impermeable surfaces (roads, buildings, and so on), levels of infiltration and recharge are lower than they are for any other land use. As a consequence, although the overall area of developed land is significantly less than the combined area of 'soft land uses' (but growing fast) it 'punches well above its weight' in terms of its adverse effects on water infiltration.

Arable and horticultural cropping

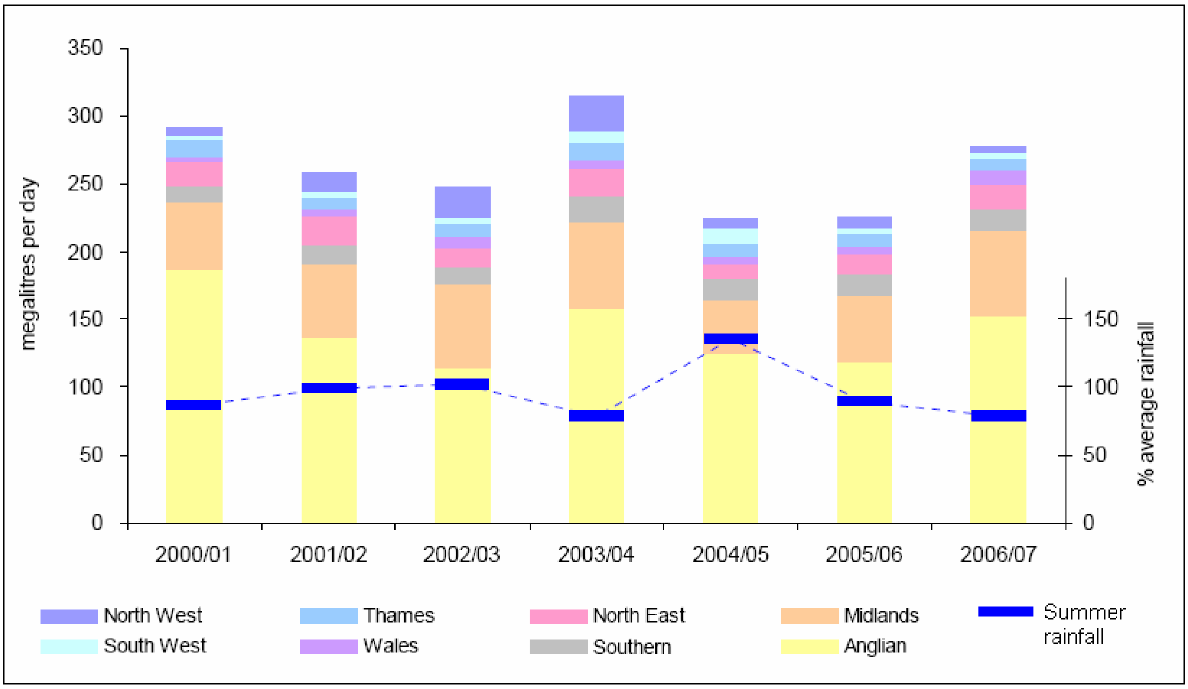
7.23. Arable and horticultural cropping has an impact on the availability of water resources in three ways. Firstly, the irrigation of crops draws water from rivers and groundwater, usually at locations and times when resources are least available. Secondly, the type of crop, its size of canopy and rate of growth uses water through interception and evapotranspiration. Thirdly, the state of the soil influences what proportion of rainfall is held for slow release into rivers or percolation to the groundwater, and what proportion runs off for quick discharge into rivers.

7.24. On the first issue of crop irrigation, farmers use less than one per cent of the total amount of water abstracted in England and Wales for spray irrigation. However, those areas where there is most irrigation tend to be those with lowest rainfall, and irrigation occurs more in dry years than wet ones (Figure 7.6). In East Anglia, abstraction for irrigation can average 20 per cent of all abstractions at a local level over a typical summer and on hot dry days more water may be used for spray irrigation than for public water supply.[76] In addition, nearly all the water used for spray irrigation is taken up by evaporation, compared to most other uses where much of the water is returned to rivers or the groundwater. There is likely to be an increase in the demand for irrigation

[76] Environment Agency (2008)d

(potential for a 25 per cent increase by 2020 – paragraph 5.20), felt most in those areas already under greatest water stress.

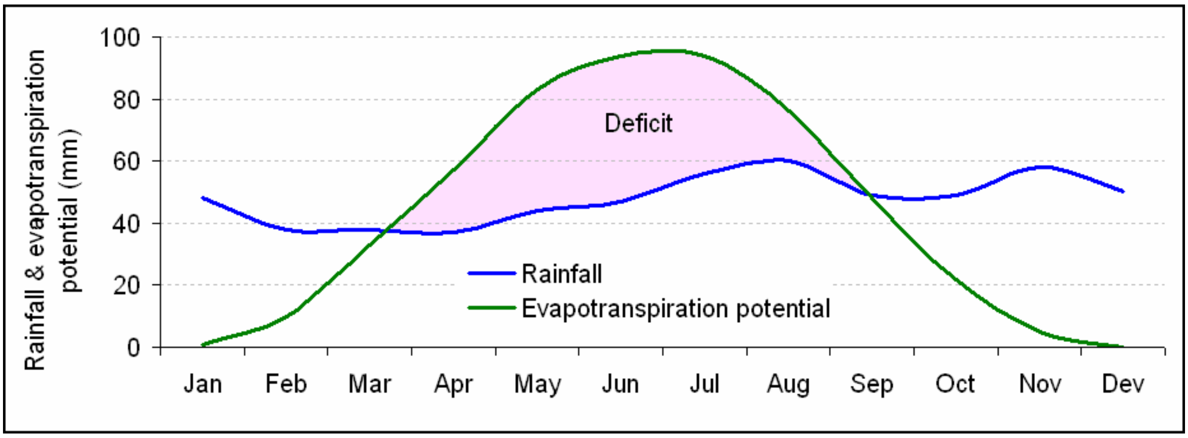
Figure 7.6. Use of water for spray irrigation in England and Wales.



Source: Environment Agency, 2008. *Water resources in England and Wales – current state and future pressures*.

7.25. On the second issue of the way in which different crops use water, it is helpful to distinguish between the interception of rainfall by foliage (from which it can evaporate directly back to the atmosphere) and the evapotranspiration of soil moisture by the plant's respiration (where water is drawn up from the roots to the leaves and then returns to the atmosphere). Tall plants with a large surface area of foliage (such as maize crops) produce highest levels of interception while dense and actively growing crops have the highest levels of evapotranspiration. These uses of water by crops can produce a soil moisture deficit during the summer when crops are growing most actively and rainfall is low (Figure 7.7).

Figure 7.7. Theoretical annual variation in rainfall and evapotranspiration in Cambridgeshire.



Source: Data quoted in Smith LP (1976). The agricultural climate of England and Wales: Arial averages 1941-70. HMSO, London, quoted in Stephens *et al*. (2001).

7.26. A detailed review of the different levels of interception and evapotranspiration between crops is outside the scope of this study. In general terms, crops such as winter wheat have similar average levels of evapotranspiration as permanent grassland while taller and denser crops such as maize and especially biomass crops have higher levels (and therefore give rise to lower levels of infiltration into soils)[77]. However, a great deal depends on the levels of growth of crops and the intensity and seasonality of rainfall.

7.27. On the third issue of the influence of soil cultivation on the infiltration of water into soil, best practice advice[78] shows that soil that has a good structure (is not compacted or panned and has good levels of soil organic matter) achieves a high level of infiltration. Soils and vegetation that present a 'rough' profile also slow the overland passage of water, allowing more time for infiltration to take place.

7.28. On all these issues, the characteristics that improve infiltration and reduce run-off are well-known but there is insufficient evidence on the extent to which these contribute, at a catchment level, to aquifer recharge. Thus, while it is possible to say with confidence the forms of land management that will improve infiltration and recharge, it is much more difficult to say what the impact of changing from one land use to another will have at a catchment scale. This conclusion also applies to the other land use types covered below. Nevertheless, the Environment Agency has expressed concern over the growing of water-demanding energy crops in water resource-sensitive areas, based on the evidence of previous studies[79]. Short rotation coppice of willow and poplar varieties have particularly high levels of evapotranspiration during summer periods and, were these crops to be grown over large areas in water-stressed catchments, they could significantly reduce water infiltration in periods of low rainfall to rivers (exacerbating low flows) and groundwater.

Grassland

7.29. Grassland is rarely irrigated (although on dairy farms it can receive dirty water from yards and slurry) and it is thus the structure and rate of growth of the grass, and the state of the soil, that have the greatest influence on infiltration. Agriculturally improved grassland receiving fertiliser and high levels of grazing or cutting of grass has much higher levels of growth compared to semi-natural grassland, and evapotranspiration levels will be higher.

7.30. The structure of soils under grassland tends to be better than that under arable crops and infiltration levels can be up to six times higher on long-established permanent pasture than on arable soils.[80] As noted in the previous chapter, grazing animals compact soils under grass and this can have a major impact on the levels of infiltration into soils. Defra (2007) quotes results from a range of studies suggesting that surface run-off can be 12 times greater on overgrazed than ungrazed grassland.

Dwarf shrub heath, fen, marsh and bog

7.31. The key impact of this vegetation type is through the effect of soils with high levels of organic matter (particularly peat soils) and wetlands in holding back water from periods of high rainfall and releasing it slowly, helping to balance

[77] Environment Agency (2008)h
[78] Environment Agency (2008)a
[79] Stephens *et al.* (2001)
[80] Defra (2007)f

flows in rivers.[81] The level of land drainage (for instance the use of ‘grips’ cut into deep peat soils) obviously greatly accelerates the speed at which water is released.

7.32. Since peat soils and wetlands often occur in areas of high rainfall (and most peat soils do not occur over permeable aquifers), the beneficial effect at a catchment level is less than it might be in areas with low or highly seasonal rainfall. Nevertheless, the regulating effects of peat and organo-mineral soils on water flows is vital and is felt well beyond the uplands, with many of Britain’s most important reservoirs and rivers used extensively for water supply, fed by upland headwaters, that are regulated by the condition of these upland peats.

Woodland

7.33. Trees have relatively high levels of water use compared to grassland and unirrigated arable crops and while they have been extensively planted in reservoir and upper water catchments, research undertaken by Forest Research and others[82] concludes that:

- Conifers lose 25 to 45 per cent of annual rainfall by interception compared to 10 to 25 per cent for broadleaves (and virtually zero for grass and low growing arable crops).
- Conifers lose an additional 300 mm to 350 mm per year due to transpiration, on top of the 300 mm to 390 mm lost by broadleaves.
- Interception and transpiration losses vary between species, with some species such as willow and poplar able to sustain high transpiration losses (above 500 mm/year, for example) when well supplied with water. This underlines the importance of avoiding the planting of short rotation coppice (SRC) in catchments where water resource availability is a concern.
- On a catchment basis in the wetter uplands, the additional water use by a complete cover of mature conifer forest can result in a 15 to 20 per cent reduction in the annual volume of streamflow.
- The impact on water supplies can be even greater in the lowlands, where a conifer forest can reduce the annual volume of water recharging a groundwater aquifer by 70 per cent or more compared to grass.
- The impact of broadleaved woodland is much less than conifers and some species on certain soils and geologies can increase the annual volume of groundwater recharge.[83]

7.34. The generally higher levels of water use by woodlands needs to be balanced against other benefits, including the potential to protect water quality, enhance freshwater habitats and reduce flood generation and propagation (considered in Chapter 8).

[81] Environment Agency (2008)a
[82] Forest Research (2009)a
[83] Forest Research (2009)a

Figure 7.8. Summary of land use impact on water resources.

Land Use	Impact	Issues of land management
Urban development	--	Demand for water. Impermeable surfaces reduce recharge
Arable/horticulture	-	Evapotranspiration and poor soil condition
Improved grassland	-	Evapotranspiration and soil compaction by livestock
Semi-natural grassland	0	
Dwarf shrub heath	+	Slow release by peat soils and wetlands, where undrained
Broadleaved woodland	0	Impacts depend on species and soils
Conifer woodland	-	High levels of interception and evapotranspiration

Key: -- high potential negative impact, - low potential negative impact, O neutral impact, + potential positive impact, ? impact unclear.

Future pressures on Water resources

7.35. Chapter 5 identified the following key pressures that are likely to influence water resources over the period to 2020 and beyond.

- **Population and industrial growth**. There is likely to be greater demand for water in areas already facing considerable water stress (particularly the south east of England). This increased demand may be partly mitigated by more efficient distribution of water (for example, fewer losses to leakage), better urban design (eco-developments and SUDS) and lower levels of per capita consumption (encourage by water metering).
- **Climate change**. An overall drop in river flows, particularly in Wales and the west of England where the underlying geology means that the flows are not supported by groundwater, will reduce the recharge of aquifers. At the same time, higher temperatures, particularly in the south east of England, could lead to increased demand for water from households and for crop irrigation.
- **Regulation and incentives**. As noted above, improved urban design and measures to reduce water demand and losses should reduce per capita consumption but this may not be enough to counter increased population and reduced supply. A major increase in the area of biomass energy crops would increase uptake through evapotranspiration and, depending on where these crops were grown, increase water stress.

Actions to address failures in service delivery

7.36. The protection and management of water resources is vital for many reasons. Clearly water resources are essential for public water supply, industry and agriculture. River and groundwaters are also essential for wetland ecology (much of it of international importance) and for public amenity. Over-abstraction can lead to low flows in rivers or whole river sections drying up; to the loss of water-dependent habitats as water tables fall; to the drying of springs and spring-fed streams and, where groundwaters are over-abstracted, to the significant migration downstream of the perennial river head.

7.37. The review of impacts of different land use types and their management on water resources shows major differences between the amounts of water that are typically withdrawn by these land uses, and the extent to which they enable infiltration of water into the soil for slow release to rivers and aquifer recharge.

Changing land use between types could therefore contribute to the balance of water resources in an area. For instance, restoring upland conifer plantations to moorland vegetation, especially where this involves blocking drainage channels, can produce more even flows in rivers, reducing low flows during periods of low rainfall. Converting downland arable crops or heavily grazed grassland with high levels of evapotranspiration and low levels of soil infiltration to extensively managed semi-natural chalk grassland could increase aquifer recharge.

7.38. However, there is no firm evidence of catchment-scale benefits from these land use changes, relative to the scale of abstractions from rivers and aquifers. Water Resource Management Plans being prepared by water companies in England and Wales (drafts were consulted on during 2008 and the final plans published in 2009) contain little if any reference to the scope for large-scale changes in land use to improve water resource availability. This is likely to be due to the current lack of firm evidence of the benefits, and lack of policy instruments to achieve these changes. As a consequence, emphasis is being placed on investment in demand management measures and resource development. For example, Box 7.2 describes how South East Water is proposing to increase its storage capacity over the next 25 years. These are proposals from South East Water as contained in their plan, and are not necessarily supported by the Environment Agency.

7.39. Currently the primary tool available to the Environment Agency to address the adverse effects of over-abstraction is to amend abstraction licences. The Restoring Sustainable Abstraction (RSA) Programme was set up by the Environment Agency in 1999 to identify and catalogue those sites which may be at risk from abstraction, and to develop solutions where abstraction is confirmed as the cause of damage. The RSA programme is a way of prioritising and progressively examining and resolving these concerns. As part of this programme, the Environment Agency has been investigating sites that are affected by the EC Habitats Directive, Sites of Specific Scientific Interest (SSSIs) and more local sites.

7.40. Small-scale land use change such as the introduction of SUDS to urban areas and beside roads, and buffer strips, swales or banks to agricultural land, can improve infiltration of water at a local scale. But the chief benefit of these will be in reducing flood run-off and soil erosion rather than improving the availability of water resources.

7.41. On farmland, such small-scale land use changes can be achieved through agri-environment schemes. However, compared to the focus in these schemes on diffuse water pollution (covered in the previous chapter), water resource management is not an overt objective of Environmental Stewardship. While many of the land use options in the higher level schemes could benefit water resource management whilst fulfilling the primary objectives of the scheme, this is not necessarily the case. For instance, establishment of woodland for biodiversity, landscape or to buffer watercourses from pollution is likely to increase interception and evapotranspiration levels and reduce recharge. In Wales, the current review of Axis 2 of the Rural Development Plan is considering resource management options. A number of resource protection/management options are possible and the practical impacts of these options on other objectives have to be considered.

Box 7.2. Proposed work by South East Water to secure water supply in parts of the South East RBD over the next 25 years.

South East Water's Water Resource Management Plan is split into eight resource zones, five of which are substantially in the South East RBD. Examples are given from two of these zones.

Resource Zone 2 covers the Ouse and Cuckmere catchments in East Sussex and part of the Rother catchment in Kent. It is currently in deficit and relies on transfers of water from other zones. It is proposed that these transfers continue in the early years of the plan with small improvement works to increase the efficiency of abstraction from existing groundwater sources at Balcombe, Cowbeech, Eridge and Crowhurst Bridge. In 2017 a new winter storage reservoir is proposed at Clay Hill near Lewes to deliver 16.8 million litres per day on average, increasing to 21.8 Ml/d during summer peak periods.

Resource Zone 3 covers most of the Rother catchment in Kent. It remains in surplus until 2016 and then starts to receive water from the proposed reservoir at Clay Hill. Forecast growth in demand after 2026 indicates that additional action will be required. Consideration has been given to effluent processing and reuse and desalination schemes but the high cost of these means that the transfer of surpluses from another new winter storage reservoir at Broad Oak near Canterbury (delivering average supply of 27.59Ml/d) in Zone 8 is preferred. This will require the construction of a new water main from the new Broad Oak reservoir.

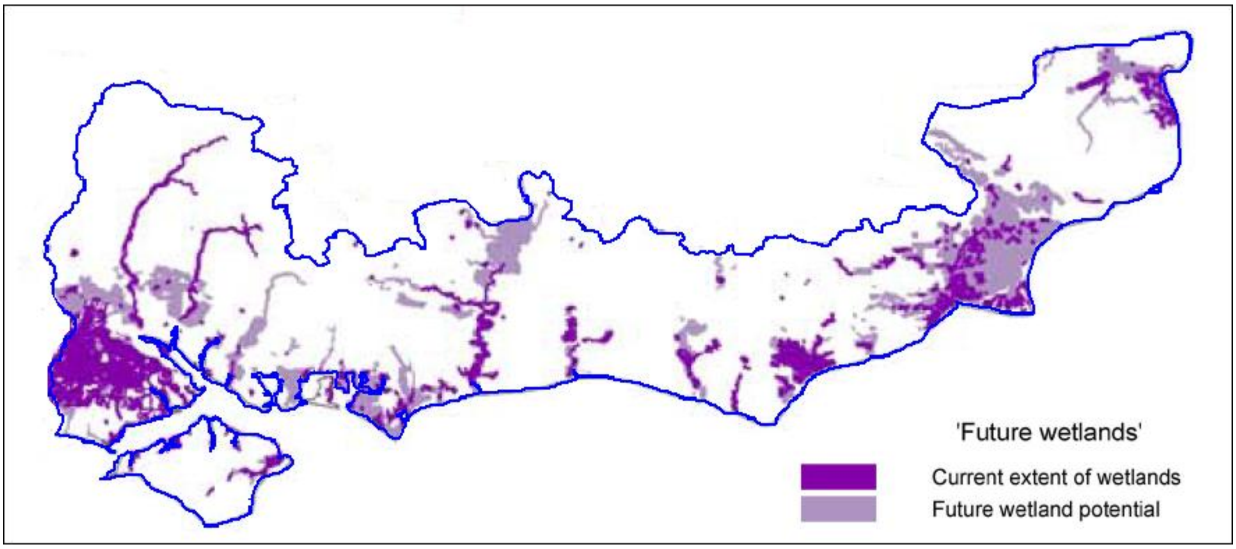
Source: South East Water (2008). *Draft Water Resource Management Plan*, May 2008.

7.42. An example of how water resource management might be considered in the future is provided by the Wetland Vision in England, which will be used by its partner bodies to target future land use and management change (Box 7.3). The Vision will be implemented through current mechanisms and partnerships, such as agri-environment schemes, remedial work to SSSIs, the Environment Agency's Regional Habitat Creation Programme and nature reserve acquisition. It is a multi-objective initiative where groundwater recharge sits alongside a wide range of other environmental objectives.

Box 7.3. The Wetland Vision – potential land use changes in the South East.

The Wetland Vision has been developed in partnership between the Environment Agency, English Heritage, Natural England, Royal Society for the Protection of Birds and the Wildlife Trusts. Launched in July 2008, it sets out the need for strategic action to restore the wetland environment, mainly for nature conservation and preservation of the historic environment, but with significant benefits for society through flood mitigation, groundwater recharge and storage of carbon. Figure 7.9 shows, at an indicative level, areas where new wetlands could be created in the South East RBD to deliver these multiple benefits. This shows major potential for new wetlands in areas likely to face water stress, such as South Hampshire, Romney Marsh and the headwaters of the River Adur.

Figure 7.9. Potential 'future wetlands' areas in relation the South East RBD.



Source: Wetland Vision.
www.wetlandvision.org.uk/userfiles/File/Future%20potential%20for%20wetlands%20(indicative%20map).pdf

7.43. There are plenty of land management changes that can be adopted to improve aquifer recharge and river water supply. Contour ploughing, for example, can be used as a way to slow rates of run-off by altering the angle of compacted channels that provide a ready route for run-off. Zero or trickle irrigation is considered preferable to spray irrigation, as the smaller drop size causes less erosion and is more efficient at delivering water to the plant. Reducing livestock densities can significantly reduce soil compaction. These measures can be adopted within land use types, allowing the original land use to continue but with significant reductions in the impact on water resources.

7.44. **Land management** changes to improve water resources are also good for other environmental services, particularly for flood risk management. However, this is not necessarily the case. For instance, cultivation of arable soils in winter to create a rough surface can, depending on the soil type and level of land drainage, increase soil infiltration and reduce surface run-off. However, this is likely increase release of nitrous oxide (a potent greenhouse gas), increase oxidation of soil carbon, reduce biodiversity and detract from landscape character.

7.45. In general terms, changes in land use or land management need to take place over large areas to have a beneficial impact on water availability (with the exception of winter storage reservoirs). This is in contrast to many of the changes for improving water quality where correctly targeted land use and management change can bring benefits so long as regulatory measures, covering all or the majority of land, restrict the excessive use of fertilisers and pesticides. Run-off rates can also be positively affected by relatively small-scale interventions, as has been shown by work carried out under the Pontbren Project[84],

[84] Wheater, et al. (2008)

Summary of the scope for land use to improve service delivery

7.46. The following points emerge from this chapter.

- Around 15 per cent of surface water catchments in England and Wales and 21 per cent of groundwater areas are considered to be at high or moderate risk of over-abstraction and low river flows, according to the Environment Agency's characterisation of water resource pressures.

- The south east and east of England have a relatively high proportion of surface and groundwaters at risk, particularly on the chalk aquifers that supply London. A lower proportion of Wales and the south west and north of England are considered at risk.

- Comparing the levels of risk for water resources against the dominant land use at the scale of one-km^2 shows a strong association between developed land and high risk, particularly for groundwater areas. This is because of the high levels of abstraction from aquifers for public water supply.

- There is a strong association between arable cropping and moderate and high risk (and a reverse relationship for grassland). However, it is unlikely to be a causal relationship (arable farming creating the pressure). Rather it is likely to be explained by the predominance of arable crops in the drier eastern side of England and on the chalk, limestone and sandstone strata used as aquifers to supply major urban areas in England.

- Public water supply is responsible for half of water abstraction from non-tidal waters and industry is responsible for a further 40 per cent. There is a long-term trend of rising demand for household use, driven by population growth. Levels of per capita consumption, though, have been reasonably stable. Over the past decade, there has been little change in the average amount of water each person uses. This has been supplemented in recent years by reductions in leakage from the distribution network. Future growth in house building, especially in southern and central England by Government and Regional Assemblies, will add to demand. Meeting this demand will require further efficiency savings and investment by water companies in the sharing and development of water resources if environmental limits are not to be further eroded.

- Agricultural use of water for irrigation makes up a small proportion of total water abstraction but is much more significant in dry regions such as East Anglia and during dry weather when it can make up 20 per cent of all abstraction.

- There is good evidence on how the characteristics of different land uses (through their vegetation and soils) influence water infiltration and aquifer recharge. Woodland (particularly conifer woodland) has the highest level of inception and evapotranspiration while soil compaction on arable and horticultural crops and intensively grazed grassland can reduce infiltration leading to high levels of surface run-off. Dwarf shrub heath, blanket bog and other wetland habitats over peat and organo-mineral soils have the capacity, provided the soils have not been drained, to absorb water slowly and release it to rivers and groundwater during dryer periods.

- Despite this knowledge of the characteristics of land use types, research is not available to demonstrate the benefits to water resources that can be achieved at the catchment scale. It is likely that changes to land use or management would have to take place at a large scale (as in the major programmes in the uplands to block grips draining the peatlands) to have any appreciable impact on river flows or aquifer recharge.

- Where justified in the context of a twin track approach with demand management measures, local land use change to winter storage reservoirs is a tried and trusted means of water resource management and over the coming 25 years will be used by a number of water companies. However, with climate change likely to lead to fewer but more intense storms, storage reservoirs may become more vulnerable to drought.

- There are no regulatory controls for water resource protection and enhancement other that the Environment Agency's monitoring of abstraction licences. For example, there are no regulatory controls over the recharge of aquifers (although the use of Water Protection Zones is currently being piloted). This may need to be addressed as water resources become increasingly constrained under climate change. Many of the beneficial changes in land use and management for water resource management are capable of delivering benefits to other environmental services, not least flood risk management, water quality (by reducing soil erosion), climate change mitigation (by rewetting peat soils), biodiversity (by restoring and safeguarding habitats) and landscape quality (by recreating characteristic land uses).

7.47. Overall, the priority changes in land use and management to address pressures on water resource availability are as follows:

Land use change

- On aquifers that are facing greatest water stress (those around the major metropolitan areas) and in the immediate vicinity of boreholes, a large-scale change of land use to semi-natural grassland from arable and horticultural cropping and improved grassland would increase levels of interception of rainfall and aquifer recharge. However, the relative impact of this change compared to other measures (such as reducing water consumption, greater reliance on surface water-fed winter storage reservoirs and the transfer of water from other catchments) means that it is difficult to advocate this land use change as a policy option without further research. These changes of land use are more justifiable where they deliver other environmental services such as water quality, flood risk management and biodiversity (a range of environmental services).

- Small-scale changes in land use to improve water resource availability include the creation of winter storage reservoirs for public and private water supply (in the context of a twin track approach with demand management), and use of sustainable drainage systems as part of green infrastructure on developed land.

Land management change

- Actions to increase the rate at which rainfall infiltrates into soils includes adopting favourable land cultivation techniques (such as contour ploughing), reducing levels of soil compaction (from machinery and high densities of livestock) and increasing soil organic matter levels. Tree planting can increase water infiltration and can be targeted at parts of a field, for example across the contours, for the greatest infiltration effect.

- The potential role of land use and management is of fundamental importance because of existing and future (induced by climate change) water stress, particularly in those regions which will be subject to the greatest growth.

8. Management of flood risk

8.1. This chapter follows the same sequence of analysis as the previous two chapters. It reviews the evidence from Chapter 3 on the levels of delivery in relation to current levels of flood risk, describes how the different land uses impact on flood risk and identifies actions that can be taken to reduce flood risk.

8.2. As noted in Chapter 3, flooding develops from a combination of three separate processes.

- Firstly, flood water is generated throughout catchments as rainfall (and all forms of precipitation) and flows off saturated ground into rivers. In chalk and limestone catchments, flooding will also be caused by rising groundwater levels and associated spring flows. In very wet winters with prolonged periods of precipitation, long dormant springs may be reactivated and the head of rivers may move upstream. Factors influencing flood generation include the amount, duration and intensity of rainfall, soil type, slope and land use.

- Secondly, as large amounts of water flowing down rivers exceed the capacity of the river channel, flooding occurs as water extends over the floodplain. Factors influencing flood propagation include the size and shape of the floodplain and the presence of structures and vegetation that change the movement of water (all of which are heavily influenced by human management). Flooding of the river floodplain is a natural process as indicated in the name. Flood generation only becomes a problem where flooding adversely affects property and farmed land in the floodplain.

- Finally, the height of sea level affects the ability of rivers to discharge water to the sea and can directly flood low-lying coastal land. The height of the sea relative to the land is influenced by natural tidal cycles, atmospheric pressure and wind (low pressure and high winds can combine to create ‘storm surges’). It will also be affected by long-term movements in the land surface and global changes in sea levels.

Summary of service delivery

8.3. The concept of an acceptable environmental limit for flooding is more complex (but no less important in policy terms) than for other services considered here. Notwithstanding the influence of human activity on weather patterns and sea level at a global scale, flooding is an inevitable consequence of our climate and topography over which we have limited control. The concept of acceptable levels of flooding has, until very recently, been concerned with protecting some areas, such as urban areas, though flood alleviation schemes, at the expense of other areas that continue to flood. Thus in the past the focus has been on coping with flood propagation, with little or no thought given to flood generation.

8.4. The two issues that need to be considered in this study are:

- **Flood generation:** Can changes in land use or changes in the way we manage land in the wider catchment help reduce the generation of flooding by delaying or reducing peaks in flood events? It is still not clear whether this potential is sufficient to change the risk of flooding within floodplains affected by the wider catchment.

- **Flood propagation:** Can changes in land use and management affecting river channels and river floodplains help alleviate river and estuarine flooding where it poses a threat to settlements and/or valued agricultural resources?

Flood propagation

8.5. At this point, it is worth reflecting briefly on past and current approaches to land management in river floodplains. Throughout history floodplains and washlands, containing some of the most fertile soils in Britain, have been subject to land drainage, as evident in the history of the Fens and the Somerset Levels to name but two areas. In the post-war drive for food production, this drainage continued apace. In 1977 the Ministry of Agriculture, Fisheries and Food (MAFF) estimated that 2.6 million hectares of agricultural land in England and Wales needed drainage – approximately one-fifth of the nation's farmland. Under grants for land drainage, large areas of river floodplain were drained by water authorities and removed as functional floodplains storing flood waters. Rivers were deepened and straightened to convey water fast off the land. Levees were often constructed to protect the floodplain from flood water and in many areas, such as the Severn Vernwy Confluence, pump drainage schemes were installed lifting water out of the floodplain into adjacent canalised water courses that were now not infrequently raised well above the height of the surrounding land[85].

8.6. By the mid-1980s the emphasis had shifted towards urban flood protection, although money continued to be spent on agricultural drainage. The effects of this drainage are evident in the fact that some 44 per cent of the most productive land (Agricultural Land Classification Grade 1) is located within areas at most risk of flooding (Flood Zone 3 in the EA Flood Map)[86]. As a consequence many rivers, for much of their length, are not connected to floodplains.

8.7. More recently there has been a clear shift in policy, most evident through the cross-departmental programme in England, *Making Space for Water*. This programme is developing a more integrated strategic approach to flood and coastal erosion risk management and is being led by Defra with the Environment Agency taking a key role in adoption of new approaches. The principles behind this new approach are that flood and coastal risk management should:

- Take a holistic approach, both spatially across whole catchments and sections of coast, and sectorally across communities and industry.
- Be based on a rigorous and evidenced-based assessment of risk that assesses environmental and social as well as economic impacts.
- Have strong connections to land use policy, particularly development in floodplains and on low-lying coasts.[87]

Risks of flooding

8.8. **Flood generation:** In Chapter 3, spatial variation in the way that land use and other factors increases the likelihood of surface water run-off, that may lead to flood generation, was measured using the results of the Sensitive Catchments

[85] Purseglove (1988)
[86] LUPG (2009)
[87] Defra (2005)d

Study[88]. That research developed an index of 'combined sensitivity' to surface water run-off based on rainfall, soil type, slope and land use. This showed that areas of highest sensitivity for generation of surface water run-off occur in Wales and the western parts of England where rainfall levels are highest and, at a more local scale, on valley and scarp slopes. Areas of peat soils such as occur on the Cambrian plateau in central Wales, the South West uplands and along the Pennines tend to give rise to moderate to low levels of sensitivity to run-off. Low-lying areas such as the Fens, Humberhead Levels and Somerset Levels are shown as having very low levels of sensitivity for run-off but are clearly at greatest risk for flood propagation.

8.9. **Flood propagation:** Similarly, in Chapter 3, the Environment Agency's Flood Map was used to show the spatial distribution of flood propagation (from both rivers and the sea), based on three probabilities of flooding occurring. This showed that significant areas of the east coast of England, particularly south of the Humber, are at risk of coastal flooding, as well the Somerset and Gwent Levels and the Lancashire Coast around Morecombe Bay. Several major centres of population such as London and Hull are at risk of coastal flooding. Almost all the major rivers in England and Wales have substantial floodplains in their middle and lower reaches with significant examples being the Trent, Great Ouse, Thames and Severn (parts of these will have been removed from the floodplain for reasons explained above). Large settlements that have faced river flooding in recent years include York, Lewes, Tewkesbury and Carlisle.

[88] Environment Agency (2008)f

Box 8.1: Influences on flood generation and propagation in the Lower Wye.

This area of the River Wye catchment is generally rural, covering extensive areas of high quality agricultural land, but also includes the towns of Hay-on-Wye, Leominster, Monmouth, Tintern and Chepstow. The flood risk in the region is associated with river flooding from the Wye and its tributaries, including the Rivers Llynfi, Lugg and Monnow, as well as tidally-influenced fluvial flooding, surface water flooding and sewer flooding. The number of properties at risk from a one per cent AEP (annual exceedence probability) flood event stands at 10,561, which is considerably higher than in most other parts of the Wye catchment. The Lower Wye also suffers the greatest agricultural damages from flooding. Future intensification of agriculture in the catchment is predicted to enhance the flood risk as a result of increased run-off and more frequent river flooding. The Wye and Usk Catchment Flood Risk Management Plan (CFMP) proposes a range of measures to mitigate this increased flood risk through alterations in land use and land management. Letton Lakes, between Hay-on-Wye and Hereford, provide natural water storage within the catchment and ease river flows during flood events, reducing the peak flow downstream towards Hereford. The CFMP highlights the opportunity to improve their management and increase their storage capacity as a way of lowering the flood peak further downstream. The Letton Lakes area includes wetlands of high biodiversity value. Opportunities are also identified in rural parts of the Lower Wye to create wetland areas for water storage and run-off reduction. Integrated Urban Drainage Plans for Ross-on-Wye, Hay-on-Wye, Monmouth, Leominster and Pembridge will be developed to manage the flood risk from urban development in the catchment. The CFMP also sets out the need to further research land use changes to manage the flood risk, with tree planting having particular potential in this area. Agri-environment schemes are encouraged to bring improvements in land management that will reduce run-off rates.

Source: Wye and Usk Catchment Flood Management Plan

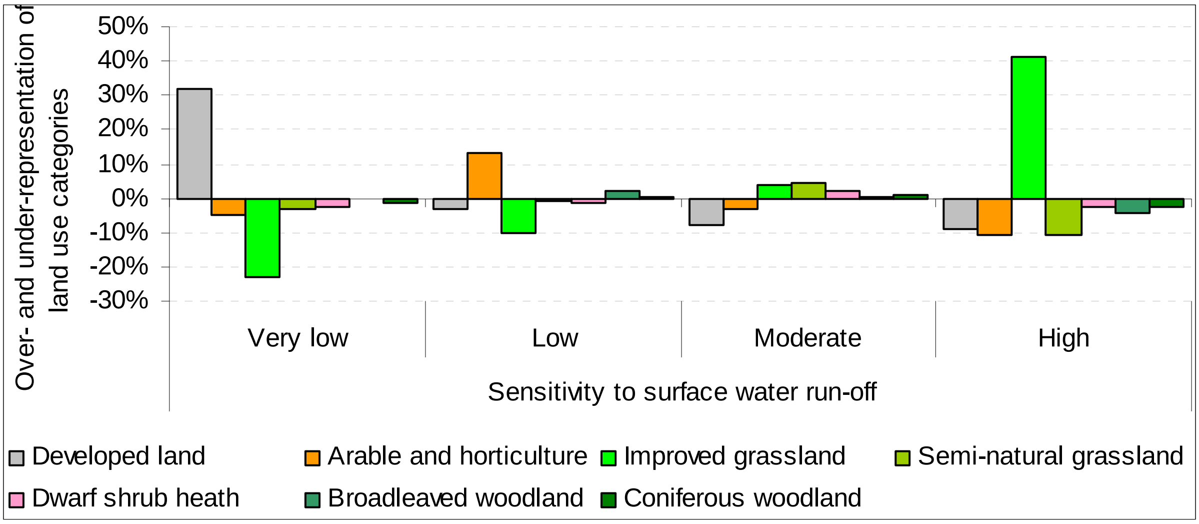
Service delivery and land use

8.10. The sensitivity to surface water run-off and risk of flood propagation in each one-km^2 can be compared to the dominant land use in the same one-km^2 in the same way as was done for water quality and resources in previous chapters. The results of these comparisons are shown in Figures 8.1 and 8.2 (for flood generation) and 8.3 and 8.4 (flood propagation).

Figure 8.1. Grid recording number of one-km tiles by land use type and sensitivity to surface water run-off across England and Wales.

Land Use Type	Very low sensitivity	Low sensitivity	Moderate sensitivity	High sensitivity	Not Assessed
Developed land	10,298	2,232	952	5	0
Arable and horticultural crops	7,737	19,424	22,298	4,225	1
Improved grassland	2,732	9,343	25,946	12,823	2
Semi-natural grassland	1,961	3,869	10,246	21	8
Dwarf shrub heath, fen, marsh and bog	82	601	3,446	21	0
Broadleaved woodland	1,106	2,778	3,413	73	0
Coniferous woodland	373	1,276	2,235	4	1
Inland water	256	122	58	0	0
Coastal habitats	737	200	123	2	3
Total Area	**25,282**	**39,845**	**68,717**	**17,174**	**15**

Figure 8.2. Under- and over-representation of land use categories in relation to different levels of sensitivity to surface water run-off across England and Wales.



8.11. **Flood generation:** The measure of sensitivity to surface water run-off modelled in the Sensitive Catchments Study took account of land use (together with rainfall, soil type and slope) so it is not surprising to find close associations between these data and land use.

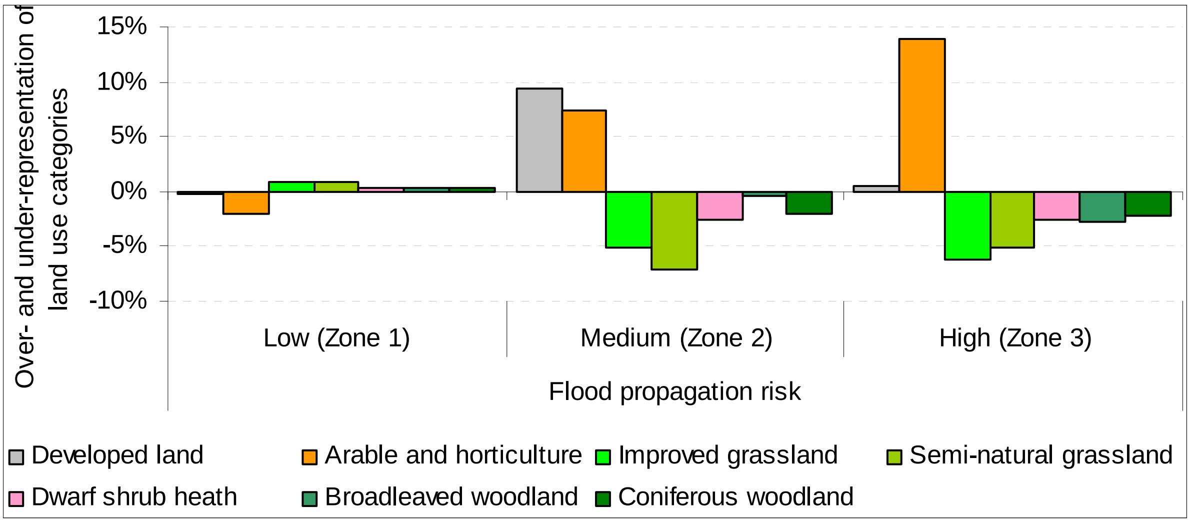
8.12. Figures 8.1 and 8.2 show that intensive grassland dominates strongly on land that has the highest potential to generate flooding from run-off (45 per cent of the one-km tiles judged to be at moderate and high sensitivity are dominated by intensive grassland and this land use is strongly over-represented in tiles with high sensitivity). Arable and horticultural crops also make up a high proportion of land of moderate and high sensitivity (31 per cent of one-km tiles in these classifications) but, relative to their distribution across the country as a whole, are actually under-represented in these classifications. There is a strong association between land dominated by dwarf shrub heath type and semi-natural grassland (84 and 65 per cent respectively), and tiles with moderate or high sensitivity to run-off. This is not surprising as these land use types are associated with the higher rainfall of the uplands and the west side of England and much of Wales.

8.13. **Flood propagation:** Turning to the relationship between land use and flood propagation, Figure 8.3 shows that the large majority of all land use types, with the exception of inland water and coastal habitats, occur on land with low flood risk. Almost half (48 per cent) of land with medium and high flood risk is dominated by arable and horticultural cropping. As Figure 8.4 shows, this land use type is strongly over-represented in these flood risk areas. Eighteen percent of land with medium flood risk is predominantly developed land which again, as shown in Figure 8.4, is a large over-representation of this land use type. This distribution reflects the concentration of arable and horticultural land on the most productive rich soils and flat lands of floodplains largely as a result of past land drainage, and the historical location of urban settlements at river crossing points. As noted earlier, the Flood Map on which these figures are based does not identify areas that have been removed from the floodplain as a result of past land drainage or flood alleviation measures. Conversely, as would be expected, land use types, such as grassland, woodland and dwarf shrub heath, which are typically found on less agriculturally productive land on slopes and at higher altitudes, are under-represented on land at higher flood risk.

Figure 8.3. Grid recording the number of one-km tiles by land use type and flood propagation risk across England and Wales.

Land Use Type	**Low (Zone 1)**	**Medium (Zone 2)**	**High (Zone 3)**
Developed land	11,286	578	1,623
Arable and horticultural crops	43,790	1,355	8,540
Improved grassland	45,185	903	4,758
Semi-natural grassland	15,045	110	950
Dwarf shrub heath, fen, marsh and bog	4,111	3	36
Broadleaved woodland	6,849	141	380
Coniferous woodland	3,811	16	62
Inland water	76	17	343
Coastal habitats	435	33	597
Total Area	**130,588**	**3,156**	**17,289**

Figure 8.4. Under- and over-representation of land use categories in relation to different levels of flood propagation risk across England and Wales.



How land use and management impact on service delivery

Evidence of impacts on flood generation

8.14. The impacts of different land uses on the generation of flood run-off are closely related to those described in the previous chapter in relation to the recharge of groundwater supplies, but with one critical difference. Whereas the infiltration of water into soils to sustain groundwater is a slow process that needs to take place over long periods, its corollary, surface run-off is most significant in short bursts during and after heavy rainfall or snowmelt. In these cases saturated soils and the vegetation are unable to cope with the volume of water generated and as a consequence water flows across land.

8.15. This difference is important when it comes to assessing the impacts of land use and management since gradual low level processes such as soil infiltration and evapotranspiration have little influence when faced with the large volumes of surface water that occur during extreme weather events.

8.16. Several large research studies have reviewed evidence on the extent to which land use and management have a measurable effect on flood generation.[89] These acknowledge that the research base from which to draw conclusions is limited. Not only have few large-scale studies examined changes in land use on river levels, but developing accurate models that allow the impact of land use from the other factors (rainfall patterns, soil types and saturation levels) is extremely complex. Nevertheless, conclusions from these studies are as follows:

- There is substantial evidence that changes in land use and management practices, particularly the intensification of agricultural land use, affect run-off generation at the local scale, but that the effects are complex. There are a range of measures to mitigate local flooding by delaying or diverting run-off and many of these measures can generate other environmental benefits.

[89] Defra and Environment Agency (2004)

- The benefits delivered at a local scale by land use and management changes become less significant as the severity of flooding increases.

- There is only limited evidence that local changes in run-off are transferred to the surface water network and flood propagation downstream. Analysis of peak run-off records has so far produced little firm evidence of catchment-scale reductions on flood generation as a result of changes in land use or land management practices.

- The primary benefit of changing land use and management is likely to be in contributing to the de-synchronisation of peak river flows (changing the speed of run-off in one part of a catchment relative to another), rather than any reduction in the amount of run-off during the overall timescale of the flood event.[90]

- It is theoretically likely that flood generation in the middle and higher levels of catchments is more responsive to changes in land use and management, due to their steeper slopes, higher rainfall levels and moderate to high soil sensitivity.[91]

8.17. Progress is being made in researching the impacts of different land uses on run-off generation at various scales, and evidence is emerging from land management projects in areas such as the Pontbren Project in central Wales[92] and the Parrett Catchment Project in Somerset. [93] However, more evidence will be required before recommendations emerge on the way in which changes in land use and management can produce measurable impacts on flood generation.

8.18. The following sections consider to how land use and management in the wider catchment has the potential to influence flood generation.

Developed land

8.19. The sealing of surfaces in urban areas that results from development reduces infiltration and increases levels of run-off. Historically, efforts to reduce flooding in developed areas have focussed on drainage schemes to evacuate water faster. The replacement of permeable surfaces that retained water with hard surfaces that did not, together with concrete culvert and drains to remove water to rivers, were successful in achieving this. However, the impact of this change in land use is simply to accentuate flood peaks and exacerbate flooding downstream. The overall level of river channel modification work taking place in and close to urban areas has declined since 1990 due to a shifting emphasis on protecting the natural river environment. [94]

Arable and horticultural cropping

8.20. The conversion of grassland to arable cropping, facilitated by land drainage and other land improvement techniques, and the intensity of soil management under arable and horticultural cropping, has increased in the last fifty years, leading to a reduction in the structural integrity of soils (a decline in soil organic matter and increase in soil compaction). These post-war changes in agricultural land use

[90] Environment Agency (2008)b
[91] Environment Agency (2008)b
[92] Wheater, H (2008)
[93] CEM *et al.* (ongoing)
[94] Defra and Environment Agency (2004)

and management are widely assumed to have generated increased volumes of overland flow and led to more rapid discharge of water from farmland.[95] But the impacts of this at the catchment-scale have been difficult to quantify.[96]

8.21. Crops that are most likely to give rise to high levels of run-off are those that leave fine seedbeds exposed to winter rain (such as winter cereals), those with dense canopies but relatively bare soil (such as fully-grown maize) and row crops (such as potatoes), especially where the rows run down slopes. [97]

8.22. As identified in the previous chapter, soil compaction from heavy machinery and frequent machinery passes on land increases surface run-off. Arable machinery tends to run in the same 'tramlines' in fields to minimise damage to crops but this creates wheel ruts which act as drainage channels and can lead to increased levels of run-off and erosion. However, concentrating traffic to narrow tramlines reduces the overall level of soil compaction across the field.[98]

8.23. The efficiency of field drainage on arable (and intensively managed grassland) also has an impact on the speed with which land 'sheds' rainfall. The relationship between soil types, field drainage and run-off is complex (sandy soils can retain more water when drained).

Grassland

8.24. As noted in the previous chapter, grazing animals increase soil compaction in grassland. The recent trend towards 'New Zealand grazing systems' on intensively managed grassland for dairy cattle, where the cattle are kept outside all year round and strip-grazed on grassland to maximise pasture use, is likely to increase run-off during the critical high rainfall winter period. In addition, the short-term and intensively managed grass leys used by dairy farmers produce high levels of run-off than long-term permanent pasture that is more suitable for sheep and beef cattle. Semi-natural grassland can be expected to have the lowest level of soil compaction.[99]

8.25. Although not strictly involving grassland, outdoor pigs can be particularly damaging to soil structures when kept on unsuitable soils in poor conditions.[100]

Dwarf shrub heath, fen, marsh and bog

8.26. Upland peat soils have the potential to store large amounts of water for slow release and when rainfall or snowmelt occurs on unsaturated peat soils (provided they have not been drained) they can delay run-off. However, during winter periods these soils may already be saturated, in which case further rainfall or snowmelt will run straight off. In terms of pressure-state-response relationships this is a case of a key threshold having been reached, leading to the 'flashy' floods responses seen in many upland catchments during the winter.

8.27. The level of land drainage (for instance the use of 'grips' cut into deep peat soils) has a large impact on the speed with which water is released from within peat soils. Trials on the blocking of grips on Whitendale Farm in the Forest of

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[95] Atkins (2007)
[96] Environment Agency (2008)b
[97] Environment Agency (2004)
[98] Environment Agency (2008)a
[99] Defra (2007)f
[100] Environment Agency (2008)a

Bowland reduced run-off in the grip by up to 90 per cent with a 70 per cent average decrease in flow.[101]

8.28. Wetlands can play an important role in reducing the speed of run-off and storing water, although as noted above, not when they are already 'full'.

Woodland

8.29. A summary of the impact of woodland cover on flood risk management is provided by Forest Research on their website.[102] Key conclusions from this are set out below.

8.30. Deforestation has often been seen as a cause of flooding, particularly in tropical countries. However, the emerging view amongst forest hydrologists is that overall woodland cover probably has a limited role in reducing the generation of floods at a catchment scale.

8.31. Most large stands of forestry occur in upland catchments. As noted in the previous chapter, woodland, particularly conifers, use more water through interception and evapotranspiration. Interception by trees can reduce the amount of rainfall reaching the ground by as much as 45 per cent. However, interception declines with the size and intensity of precipitation, reaching a maximum of 5-7 mm in a day which means that interception rates during major rainfall may be less than 10 per cent of rainfall.

8.32. Forest soils tend to have a more open structure resulting from greater amounts of organic matter and the action of tree roots and soil fauna. These conditions enhance the ability of the soil to receive and store water – commonly referred to as a 'sponge effect'. However, as noted above for dwarf shrub heath, once soils are saturated, further rainfall runs off so the 'sponge effect' is likely to be most significant in low and modest rainfall events.

8.33. Forestry practices in plantation sites, such as soil cultivation and drainage, road construction and timber harvesting, increase the speed of water run-off. Forest clear felling in particular can result in rapid surface run-off due to the removal of the vegetation cover and harvesting machinery having the potential to cause soil compaction and rutting. This provides an endorsement for the use of continuous cover forestry where appropriate (which avoids clear felling), reducing these negative impacts.

8.34. These issues apply to woodland cover at a generic level across catchments. At a more local scale, work in the Pontbren Project in central Wales[103] and earlier work in Upper Wharfedale in the Yorkshire Dales[104] has suggested that strategically sited woodland belts can slow surface water run-off at specific sites. The targeted establishment of relatively small areas of woodland in areas of greatest risk of overland flow might therefore combine to have a beneficial impact at a sub-catchment level. As noted below, floodplain woodland also has the potential to reduce flood propagation.

Summary of impacts on flood generation

8.35. **Impact of land uses**: Figure 8.5 shows the ranking of different land uses in relation to run-off that is quoted in the recent review for Defra and the

[101] McGrath and Smith (2006)
[102] Forest Research (2009)d
[103] Wheater H (2008)
[104] www.therrc.co.uk/rrc_river_projects1.php?csid=41

Environment Agency. This shows that forestry and woodland are the least likely, and horticultural crops and arable root crops are the most likely, to generate run-off. Short-term grassland is identified as more likely to generate run-off compared to cereal crops. Although not included on this list, it is likely that upland and heathland habitats will be near the top of the list (least likely to generate run-off), and developed land at the bottom (most likely to generate run-off).

Figure 8.5. Summary of land use impact on run-off.

Run-off risks of different land uses

1. Forestry/woodland
2. Permanent pasture
3. Spring cereals
4. Autumn cereals
5. Short-term grass ley
6. Sugar beet/potatoes/horticultural crops

Source: Armstrong *et al.* (1990) in Defra & Environment Agency (2004)

8.36. **Impacts of land management**: In general terms, the more intensive the land management, the greater the negative impacts on flood generation. High densities of livestock, highly efficient land drainage and the creation of fine seed beds to maximise seed germination produce fast flood responses from land. Nevertheless, there are management activities that are compatible with high levels of productivity of land. These include the use of soil aerators and sub-soilers to reduce soil compaction and break up soil pans, and practices such as direct drilling and low tillage techniques to improve soil quality, increasing levels of soil infiltration.

Evidence of impacts on flood propagation

8.37. Compared to flood generation, there is greater agreement that using land use to change the morphology of flood and coastal plains, particularly by using land to store water or realigning river channels or coastal profiles, can have appreciable impacts on attenuating flood peaks and protecting sensitive areas from flooding. This is reflected in new emphasis in flood risk and coastal erosion planning (such as through Catchment Flood Management Plans and Shoreline Management Plans in England) on the benefits of holding flood waters back in areas where it will not cause major damage, thus enabling the protection of property and other assets, rather than conveying it away as quickly as possible so adversely affecting downstream areas in the path of flood waters.

8.38. In pre-historic times, floodplains were dominated by wet woodland and braided river channels occupied large parts of floodplains. The fertility of floodplain soils meant that the clearance of woodland and restriction and straightening of river channels to claim floodplains for agriculture (mainly livestock grazing) occurred early in the human landscape.

8.39. Historically, periodic inundation of flood and coastal plains was accommodated by the use of washlands (with flood meadows in some areas of southern England managed to maximise the agricultural benefits of winter and spring flooding to soil fertility and early grass growth) and there was little built development in areas at risk of flooding. During this period, land use and management had a relatively benign impact on flood propagation.

8.40. Many large settlements were originally sited at the cross points of major rivers and during the major urban expansions of the 19th and 20th centuries, there was growing pressure for development onto the floodplain. As noted earlier, agricultural land drainage and protection resulted in large areas of highly productive farmland being removed from the functional floodplain and converted from grassland to arable and horticultural farming. The result of these changes is that the reduced size of the floodplain, and narrowing at particular points with flood defence structures, now means that flooding, where it occurs, tends to be deeper.

Arable and horticultural cropping

8.41. Land drainage and flood defence schemes have meant that much of the best quality land used for arable and horticultural cropping has been removed from the floodplain and, where land is flooded, water is quickly removed through land drainage. Where flooding occurs, particularly in winter where vegetation cover is sparser, this land use offers little hydraulic resistance and does little to slow the flow of water. An exception to this might be provided by multiannual biomass crops, particularly short rotation coppice, which can reduce the speed with which water moves across the land compared to shorter crops.[105]

Grassland

8.42. Many areas of improved grassland in floodplains have also been subject to land drainage and flood protection. Like arable crops, grassland offers little hydraulic resistance to flood water (with grazed grassland offering less resistance than most arable crops in summer).

8.43. Conversely, most of the few remaining areas of semi-natural grassland in floodplains are likely to be located in areas that still flood (for instance the extensive areas of wet grassland in the Somerset Levels and Moors and the coastal plain of the North Kent Marshes). These areas rely on networks of field ditches, rather than subsoil drains and tend to shed flood water more slowly.

8.44. One impact of grassland management beside watercourses and rivers, which may have local impacts, can arise where livestock are given access to large stretches of the river bank or drainage ditches. These livestock can remove (by grazing and trampling) the fringe of riparian vegetation and increase the speed of water in the channel in the process.

Woodland

8.45. Most woodland cover in floodplains has been cleared to give way to agriculture and developed land. However, research to model the impact of floodplain woodland has suggested that its hydraulic resistance can hold back the movement of flood water and reduce the risk of downstream flooding (increasing the risk upstream of the woodland).[106] Forest Research also note[107] that floodplain woodland could impose constraints on flood defence such as restricted access to river banks for flood defence works, loss of engineered flood control, and increased downstream flooding caused by large woody debris

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[105] Reviews of the hydrological impacts of short rotation coppice, such as that by Stephens *et al.* (2001) have focussed on the impact of the high evapotranspiration rates rather than the issue of hydraulic resistance to surface flood water. However, the hydraulic resistant of woodland is also likely to apply – to a lesser extent – to short rotation coppice.
[106] Thomas and Nisbet (2006)
[107] Forest Research (2009)d

blocking bridges and other structures. Work is ongoing through Forest Research's Forest Hydrology Programme to test these assumptions.

Coastal habitats

8.46. At a local scale (such as in estuaries), mudflats, salt marsh and coastal grazing marshes have a major impact on attenuating the tidal prism (slowing the speed, and reducing the peak height) of incoming tides and tidal surges, allowing flood water to spread through creek systems and over mudflat and marsh. This impact will be significant compared with smooth flood defence banks which narrow estuaries and channels, helping to funnel tides upriver.

Box 8.2. Priorities for flood risk management in Chichester District.

Chichester District covers an area of approximately 811 km^2 on the south coast, running from Pagham Harbour in the east to Thorney Island in the west. The town lies in the River Lavant catchment, and is classed by the Arun and Western Streams Catchment Flood Management Plan as having high social vulnerability to flooding.

The length of the Chichester District coastline is approximately 66 km and extends from Pagham Harbour in the east to Emsworth in the west. The latest government guidance indicates that climate change will increase mean sea levels in the area by around one metre by 2106, increasing the area at risk of flooding from the sea in the future. Due to the large chalk bands across the district, a significant proportion of land is likely to be affected by groundwater flooding.

Responses to surface water flooding, as recommended in the Strategic Flood Risk Assessment, include the management of development run-off, such as the use of SUDS. There has also been considerable investment in river defences, including the River Lavant flood alleviation scheme for Chichester.

The CFMP states that opportunities exist to integrate flood risk management within the land use planning system, and says run-off levels may be reduced within the region through more sustainable land management. Wetlands could be used for this purpose, as the CFMP endorses working with landowners such as the RSPB to create and maintain wetlands to aid flood water storage.

The CFMP also identifies a long-term strategy to open up culverts, creating a more natural drainage system and enhancing green spaces along the river corridor through Chichester.

Source: Chichester District Strategic Flood Risk Assessment

Future pressures on flood risk management

8.47. Chapter 5 identified the following key pressures that are likely to influence flood risk management over the period to 2020 and beyond.

- ***Climate change***. More winter rainfall and extreme rainfall events in summer are forecast to increase the frequency and severity of flooding in areas already at risk. Rising sea levels will increase the risk of flooding on low-lying coastal areas.
- ***Urban development***. Impacts will depend on how and where the demand for new housing is met (whether taking land from floodplains and increasing the speed of run-off, or not). Better spatial planning and urban design should reduce the impact of new development, although all land take for

development is likely to increase rather than decrease the flood response from this land.

- ***Other land use change***. Concerns about food and energy security could see greater emphasis on the most productive land, most of which occurs in floodplains, requiring flood protection of this land. Conversely, more planting of woodland and biomass crops could reduce flood generation but much will depend on where these are located.

Actions to address failures in service delivery

8.48. It is important to bear in mind here the caveats mentioned at the start of the previous section on the limited evidence on the link between changes in land use or management and catchment-scale impacts on flood generation and propagation.

Urban development

8.49. Local planning authorities in England are required by Planning Policy Statement 25 (PPS 25: Development and Flood Risk) to prepare Strategic Flood Risk Management Plans (SFRAs) to inform their planning policies. These involve spatially defining the functional floodplain, based on the Environment Agency's Flood Map, and assessing the impact of increased surface water run-off on receiving watercourses. Local authorities are expected to develop their SFRAs iteratively in stages, to inform the sequential test on flood risk set out in PPS 25. Many local authorities have yet to prepare SFRAs.

8.50. Local authorities in England will also prepare Surface Water Management Plans (recommended in PPS 25) as a tool to manage surface water flood risk on a local basis by improving and optimising coordination between relevant stakeholders. Defra is currently funding a pilot round of these plans in six authorities (Gloucestershire, Hull, Leeds, Richmond, Warrington and Thatcham).

8.51. The role of SUDS in increasing infiltration into permeable barrier strips and vegetated drainage channels has already been described in the previous chapter. SUDS create detention basins or flood storage areas (which may hold water for a matter of hours only) which are likely to benefit flood propagation at a local scale by increasing the area over which flood water can spread.

Arable and horticultural cropping and grassland

8.52. The practical guidance booklet *Best Farming Practice* recently updated by the Environment Agency[108] contains a range of suggestions for changes to soil and crop management to reduce surface run-off (flood generation), such as:

- Avoiding using land that is most at risk of flooding and surface run-off for land uses that carry higher risks of erosion or flood damage.
- Maintaining good soil structure and avoiding soil compaction from machinery, for example by using minimum tillage and machinery pass techniques. Incorporating organic manures into arable soils and using specialist machinery to aerate compacted grassland soils can help to improve the structure and water-holding capacity of land.

[108] Environment Agency (2008)a

- Where run-off is likely to occur, use cross-contour grass buffers, hedgerows and other breaks in cropping, and establish cover crops on bare soils to reduce soil erosion.
- Loosening soil and creating a rough surface after harvesting to allow water to infiltrate more easily. Spring cereals are considered to be better than winter cereals since the soil is uncultivated or roughly cultivated, whereas winter cereals require a fine seedbed. However, this may not be appropriate, as it is likely to increase soil erosion with impacts on water quality and channel capacity.

8.53. Interventions to reduce the impact of flood generation need to be carefully planned to take account of the characteristics of each catchment. Reducing the efficiency of land and field drainage in one part of a catchment could bring the delayed flood run-off from this area into synchronisation with other parts of the catchment, increased the risk of flooding downstream. This requires good knowledge of the run-off responses, under different hydrological (levels of soil saturation) and vegetation conditions (seasonal and multi-annual variation in crop cover) of each catchment. This information is not available, or not to a sufficient level of detail, for most catchments in England and Wales.

8.54. The role of biomass crops in increasing the ‘hydraulic resistance’ of arable land in floodplains has already been noted. Biomass crops are seen as an important element in the mix of renewable energy sources and, while their high evapotranspiration levels could make large areas of these crops unsuitable to catchments facing water stress[109], it is possible that selectively located areas of these crops could have an impact on flood propagation at a local scale. This is currently unproven and would need to be tested through research.

8.55. Cross-compliance requirements of the Common Agricultural Policy (basic mandatory rules that apply to all farmers receiving support from the Single Payment Scheme and agri-environment and other land-based schemes) have the potential to improve soil and crop management practices on arable and grassland farms. These require farmers to prepare simple soil risk assessments (Soil Protection Review in England and Soil Assessment Record in Wales) to identify risks, including soil run-off and erosion. In December 2008, the European Commission completed a ‘CAP Health Check’ which included a review of the operation of cross-compliance. As a result of this, Member States have agreed to extend the coverage of cross-compliance measures to include two new headings for the “*Protection and management of water*” and “*Protect water against pollution and run-off, and manage the use of water*”. The first topic requires farmers to maintain buffer zones beside all watercourses. It is up to national administrations to implement these measures and it remains to be seen how Defra and the Welsh Assembly Government will do so during 2009.

Grassland

8.56. Agri-environment schemes support a range of measures to meet multiple environmental goals. In England, flood risk management is a secondary goal of environmental stewardship, where spin-off benefits are sought from management designed to achieve the five primary objectives. In Wales, flood risk management is a primary aim of the higher tier scheme Tir Gofal, although few schemes were adopted by farmers where this was a major output[110].

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[109] Stephens *et al*. (2001)
[110] Personal communication Chris Uttley, Water Policy Officer, Countryside Council for Wales

8.57. Nevertheless, agri-environment schemes have targeted these remaining areas of semi-natural grassland for their biodiversity value and the schemes encourage farmers to create new areas of semi-natural grassland from improved grassland and arable. Management for biodiversity, involving reduced grazing densities and less land drainage, is likely to produce lower levels of flood generation (although the comment above about the need to ensure that action is co-ordinated at a catchment level, applies here). As noted in Chapter 5, it is predicted that the number of livestock kept in England and Wales, particularly in the uplands, will continue to fall for economic reasons, which could reduce flood generation in these areas. However, there is likely to be a threshold beyond which further falls in livestock numbers will not make a major difference to flood generation.

8.58. Where flood propagation is concerned, management to conserve and enhance biodiversity usually involves raised water level regimes (for instance the creation of 'summer pen levels' to keep water levels higher that in surrounding areas) which reduce their potential capacity to store additional flood water at these times. The deeper levels of inundation that would maximise the potential for flood storage can be damaging to biodiversity. Where prolonged inundation for flood storage occurs in summer, this can be extremely damaging to the grassland sward and water quality as the combination of lush grass and high temperatures leads to high biological oxygen demand (BOD) and anoxic water conditions.

Dwarf shrub heath, fen, marsh and bog

8.59. In a large number of upland areas in England and Wales, projects have been run to rewet areas of blanket bog and upland heath growing on peat where land drainage has lowered the water table. These projects have focussed on the practice of blocking the moorland grips (drainage channels cut through the peat). Examples of where this has been carried out include the Yorkshire Dales (Upper Wharfedale and Tees Water Colour Projects), the Peak District and Forest of Bowland (Sustainable Catchment Management Programme or SCaMP), Berwyn Mountains (on the Vyrnwy Estate) and Exmoor (Exmoor Mire Restoration Project). Most of these projects involve a combination of public bodies (such as National Park Authorities), water companies and voluntary sector (such as the RSPB).

8.60. These moorland rewetting projects have a range of objectives, including protecting and enhancing biodiversity, improving water quality (reducing the discolouration of water from eroding peat deposits) and reducing loss of carbon, but a reduction in the speed with which water is released after rainfall and snowmelt is a further beneficial outcome.

8.61. Although peat soils that are already saturated cannot hold any additional water, dry peat soils do not readily absorb water. The optimal situation for flood risk management is where peat soils are maintained in a 'wetted' condition but where there is space within the soil to hold more water.

8.62. There is an emerging view that upland peatlands in England and Wales could shrink as a result of climate change, but it is too early to make confident predictions on this. Efforts to rewet upland peat soils in the south west of England may be hampered by drier summers but may be assisted in northern England and Wales by milder wetter winters.

Woodland

8.63. Woodland schemes in England and Wales (the English Woodland Grant Scheme and Better Woodlands for Wales) also bring multiple benefits and applicants are able to put forward flood risk management as an objective for new woodland creation or the management of existing woodland.

8.64. The conclusions on woodlands' impacts on flood generation and propagation is that it is in floodplains, where woodland cover is usually low, that large-scale new planting of woodland offers the greatest opportunities for reducing flood risk. Elsewhere, greatest benefit may be gained from careful positioning of new woodland belts, reducing overland run-off and encouraging greater infiltration.

8.65. Although small-scale additions of woodland on farms (for instance in shelterbelts) often have agronomic benefits, large-scale woodland planting on floodplains will compete with agricultural production. A return to the policy of reserving the best quality land for food production (and a new emphasis on biomass energy) to address food and energy security issues could be a major driver in the future. Woodland planted for the multiple purposes of flood risk management, biomass production and biodiversity would deliver these multiple benefits, although compromises in species choice and woodland design would be needed.

Coastal habitats

8.66. Managed realignment is one of the four policy options addressed through Shoreline Management Plans in England and in some estuaries, the conversion of land currently benefiting from coastal flood protection (often used for arable or horticultural cropping) to intertidal salt marsh may be important in managing coastal flood risk.

8.67. In England, Natural England is able to make payments to landowners of £700/ha a year for 20 years for the creation and management of coastal salt marsh on farmland using the Higher Level of Environmental Stewardship. The level and long period of payments recognise the high loss of income (including Single Payment Scheme payments) and future agricultural productivity of the land.

8.68. A small number of schemes have already employed this, such as at Alkborough Flats on the Humber Estuary and Abbots Hall Marshes on the Blackwater Estuary. Not only do such schemes normally required major investment in flood defence structures (breaching existing defences and strengthening those behind the area destined for new salt marsh creation), but the loss of value of the land is significant (both in loss of capital land value and the profit foregone). On the other hand, schemes of this nature have the potential to deliver a range of other benefits, particularly for biodiversity, but also for landscape enhancement and public recreation.

Summary of the scope for land use to improve service delivery

8.69. The following points emerge from this chapter.

- Trends in land use and management, supported by public policy towards flood protection, have increased the rate at which flood water is generated from catchments and has constrained the ability of river channels and floodplains to accommodate flood water. The Government's new approach to flood and coastal erosion risk management, under *Making Space for Water*, is developing more holistic and rigorous evidence- and risk-based policy, in which land use and management has an important role to play.

- Areas of highest sensitivity for land use to contribute to flood generation occur in Wales and the western parts of England where rainfall levels are highest and, at a more local scale, on valley and scarp slopes. Areas of peat soils such as those on the Cambrian plateau in central Wales, the south west uplands of England and along the Pennines tend to have moderate to low sensitivity to flood generation. Low-lying areas such as the Fens, Humberhead Levels and Somerset Levels have very low sensitivity for flood generation but are clearly at greatest risk for flood propagation.

- Large areas of the east coast of England, particularly south of the Humber, are at risk of coastal flooding, as well the Somerset and Gwent Levels and the Lancashire Coast around Morecombe Bay. Several major centres of population such as London and Hull are at risk of coastal flooding, as are many other coastal settlements around the UK.

- Almost all the major rivers in England and Wales have substantial floodplains in their middle and lower reaches with notable examples being the Trent, Great Ouse, Thames and Severn. Large settlements that have faced river flooding in recent years include York, Lewes, Tewkesbury and Carlisle.

- Intensively managed grassland is the land use most likely to give rise to high levels of flood generation because of its location in areas with high rainfall and steep topography and because the high density of livestock produces more compacted soils liable to surface run-off (compared to other habitats common in these areas such as dwarf shrub heath and woodland). Arable and horticultural crops are prone to high levels of surface run-off and flood generation but tend to dominate in the drier east of England.

- Conversely, dwarf shrub heath, woodland and semi-natural grassland can produce low levels of flood generation, provided that land drainage systems are not well developed.

- Almost half of land with medium and high flood risk is dominated by arable and horticultural cropping and this land use type is strongly over-represented in these flood risk areas. Eighteen percent of land with medium flood risk is predominantly developed land which is also an over-representation of this land type. This distribution reflects the concentration of arable and horticultural land on the most productive rich soils and flat lands of floodplains, and the historical location of urban settlements at river crossing points. Conversely, land use types, such as grassland, woodland and dwarf shrub heath, which are typically found on less agriculturally productive land on slopes and at higher altitudes, are under-represented on land at high and medium flood risk.

- There is substantial evidence that changes in land use and management practices, particularly the intensification of farming, affect run-off generation at the local scale. A range of measures can be taken to mitigate local flooding but the benefits delivered by these diminish as the severity of flooding increases.

- There is limited evidence that local changes in run-off are transferred to the surface water network at the larger catchment scale. Analysis of peak run-off records has so far produced little firm evidence of catchment-scale impacts of land use management.

- The primary benefit of changing land use and management is likely to be in contributing to the de-synchronisation of peak river flows (changing the speed of run-off in one part of a catchment relative to another), rather than any major reduction in the amount of run-off during the overall timescale of the flood event.

- The same caveats about land use and management impacts diminishing with geographical scale and the severity of flood event apply to flood propagation. But there is agreement that using land use to change the morphology of flood and coastal plains, particularly by using land to store water or realigning river channels or coastal profiles, can have appreciable impacts on attenuating flood peaks at a local scale.

- In simple terms, developed land produces the fastest run-off responses and has the greatest impact on flood generation. This is followed by root crops such as potatoes and sugar beet and field-scale horticultural crops (which have high proportions of bare soil and where the creation of fine seed beds contribute to poor soil quality), then intensively grazed ley grassland and cereal crops. Land uses that produce the slowest run-off responses are permanent grassland, particularly that with low grazing densities, woodland, wetlands and dwarf shrub heath.

8.70. Overall, the priority changes in land use/management to address flood risk are as follows:

Land use change

- Localised and small-scale changes in land use from arable and horticultural cropping and improved grassland to semi-natural grassland and woodland, in areas where land use contributes most to flood generation, can delay and reduce peak river flows within parts of larger catchments. However, careful planning based on knowledge of catchment hydrology and responses is needed to ensure that the impact of this delayed run-off is positive at a whole-catchment scale.

- Land uses that can help reduce flood propagation beside river channels and on floodplains are wet woodland and the use of land for temporary flood storage (a land use change, if only for short periods). Salt marshes can reduce the propagation of flooding in estuaries and coastal plains.

Land management change

- Land management practices that contribute to downstream flood generation (and where impacts may be measurable at a local scale) include creation of impermeable surfaces, land drainage, ditch and river channel straightening, removal of riparian vegetation by cutting or grazing, and soil compaction by machinery or livestock.

- Land management practices that reduce flood generation (and where impacts are measurable at least at a local scale) include the use of SUDS, techniques to improve the quality of arable soils (such as minimum tillage and use of organic matter) and Continuous Cover Forestry practices.

9. Storage of carbon in soils

9.1. This chapter largely follows the same structure as those covering the other three services. It reviews the evidence from Chapter 3 on the current level of service delivery, describes how the different land uses impact upon carbon storage in soils, and identifies actions that can be taken to increase levels of carbon sequestration and storage.

Summary of service delivery

9.2. It is not currently possible to map the spatial delivery of this service across England and Wales as an environmental limit. Research is ongoing to identify the circumstances, and collect data on the rate of carbon flux in soils, and particularly the loss of carbon that can be attributed to long-term patterns of climate change and to land use. In the absence of this information, this study reports on the spatial distribution of soils that contain the greatest volume of carbon within their first horizon (the depth of which will vary), as held in the National Soils Map of England and Wales held by the Environment Agency under licence from the National Soils Research Institute at Cranfield University.

9.3. The map at Figure 3.23 (Chapter 3) shows that there are two main regions where soils have particularly high carbon content. These are central Wales and the Pennines area of northern England, reaching westwards into Cumbria. Other notable areas of high carbon storage can be identified on Dartmoor in Devon, the fens of East Anglia, the Somerset Levels and the eastern part of North Yorkshire (the North York Moors and Yorkshire Dales). Across southern England, levels of carbon storage are generally slightly higher in the west than in the east, although small pockets of higher levels can be identified on the lowland heathland in parts of Hampshire and Surrey.

Carbon storage and land use

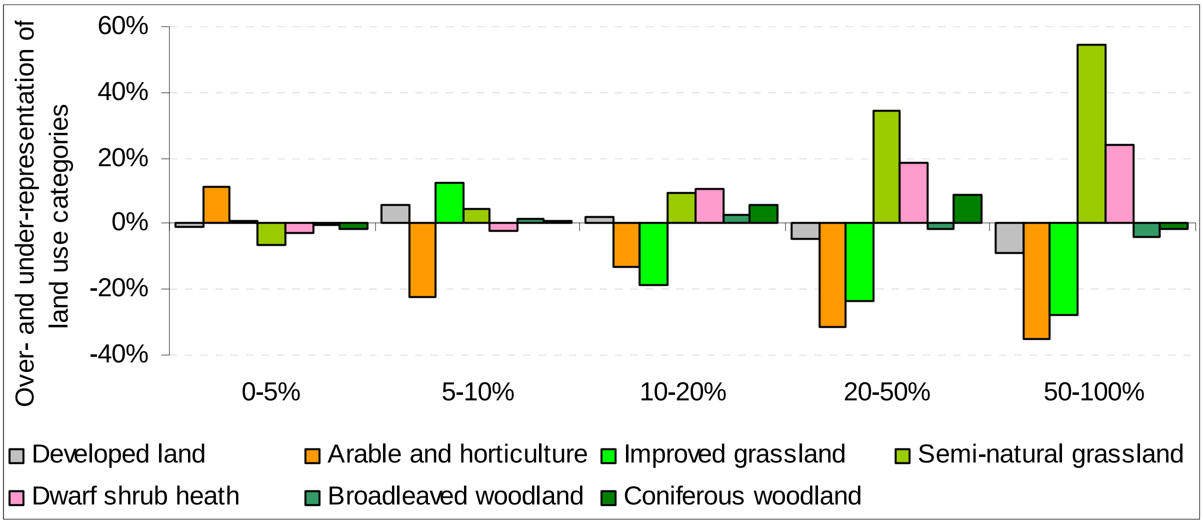
9.4. The same method for comparing levels of service against dominant land use was applied to carbon storage as for the previous services, so that the dominant classification of carbon storage in each one-km^2 could be compared to the dominant land use in the same one-km^2.

9.5. The results of this comparison are shown in Figures 9.1 and 9.2.

Figure 9.1. Grid recording number of one-km tiles by land use type and percentage content of carbon in the first soil horizon across England and Wales.

Land Use Type	**0-5%**	**5-10%**	**10-20%**	**20-50%**	**50-100%**
Developed land	8,081	4,249	588	569	0
Arable and horticultural crops	48,059	3,830	1,200	595	1
Improved grassland	35,147	13,431	806	1,446	16
Semi-natural grassland	4,257	4,327	1,080	6,272	169
Dwarf shrub heath, fen, marsh and bog	167	188	719	3,007	69
Broadleaved woodland	4,558	1,933	407	469	3
Coniferous woodland	793	1,038	463	1,593	2
Inland water	354	52	19	11	0
Coastal habitats	901	49	107	8	0
Total Area	102,317	29,097	5,389	13,970	260

Figure 9.2. Under- and over-representation of land use categories in relation to the content of carbon in the first soil horizon across England and Wales.



9.6. The over- or under-representation of each of the land uses within each category of soil carbon storage is shown in Figure 9.2. Land uses with major variations outside of the expected level of representation are arable and horticulture, improved grassland, semi-natural grassland and dwarf shrub heath. In general, as the percentage of carbon stored in soils increases, areas of semi-natural grassland and dwarf shrub heath become progressively higher as a proportion of the total within that category. Conversely, areas of arable and horticultural cropping and of improved grassland decrease, becoming under-represented in the higher categories of carbon storage. Urban areas are not characteristically associated with peat soils, which is reflected in the under-representation of developed land in the higher percentage categories.

9.7. The data in Figure 9.1 show that arable and horticultural cropping is the dominant land use on 47 per cent of the soils with a carbon content of zero to five per cent, which is an over-representation of 12 per cent. Within all of the other (higher) carbon storage categories however, arable and horticultural cropping covers a smaller proportion of the land area than would be expected given that it covers approximately one-third of the total land area. Ninety-six percent of the total area of arable and horticulture falls within grid squares with a dominant carbon storage level of 10 per cent or less, indicating a link between this type of land use and less carbon storage in soils. Similarly, 95 per cent of improved grassland lies within grid squares with a carbon storage level of 10 per cent or less.

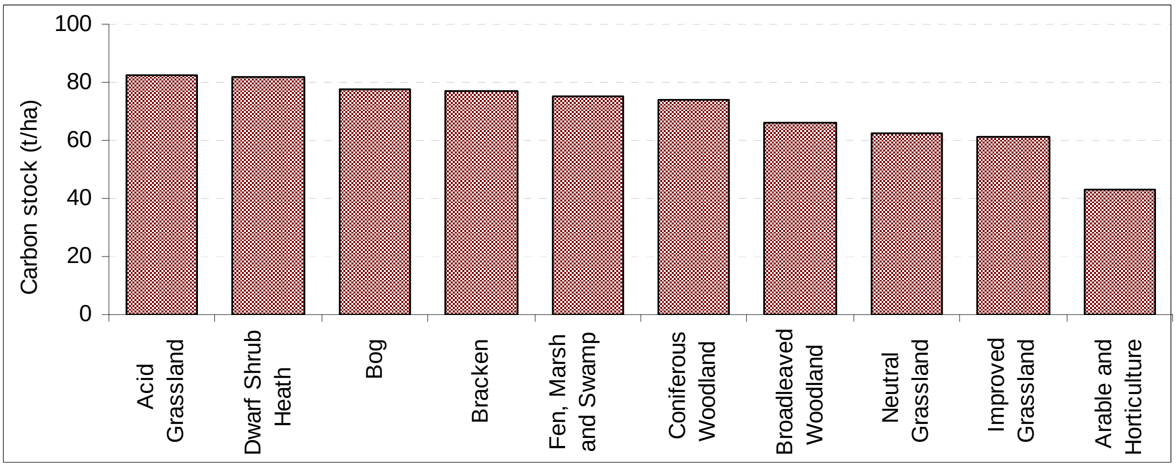
9.8. The opposite pattern can be identified for other land uses. Nearly three quarters of the area of dwarf shrub heath, fen, marsh and bog occurs on soils with 20 per cent or greater carbon content. Even more pronounced is the pattern for semi-natural grassland, where 96 per cent of the grid squares classified within this land use can be seen to have a dominant carbon content of 20 per cent or greater.

9.9. Data collected by the Centre for Ecology and Hydrology as part of the Countryside Surveys can be compared to these findings. Figure 9.3 shows the stocks of carbon in the top 15 cm of soil for different land cover types, averaged across Great Britain. It shows that land cover types most common on upland soils (acid grassland, dwarf shrub heath, bog, bracken, fen, marsh and swamp and coniferous woodland) all occur on land with high stocks of soil carbon (between 74 and 82 tonnes per ha). This is broadly consistent with the analysis by this study described above.

9.10. The CEH data also shows that arable and horticultural crops, which occur predominantly on lowland mineral soils, have the lowest average carbon stocks (43 t/ha), again a finding that is consistent with the analysis in this study. A clear exception to this is the areas of intensive arable and horticulture that takes place on the large areas of the Fens and parts of the Somerset Levels and Lancashire Mosses, where these areas' rich peat soils have been drained to provide land for intensive agricultural production.

9.11. The CEH study differentiates between acid and neutral grassland (showing that while the former is associated with high carbon stocks, the latter is associated with moderate carbon stocks). This study combines the two grassland types as semi-natural grassland (which is strongly associated with soils with high carbon content). Given that the area of semi-natural grassland is dominated by acid grassland concentrated in the uplands, these findings are consistent.

Figure 9.3. Average carbon stocks in the first 15 cm of soil in different land cover types across Great Britain, 2007.



Source: CEH (2008). Countryside Survey: UK Results from 2007

9.12. Overall, the key conclusion is that the association between carbon levels and land use that is evident from these data is likely to be primarily due to the spatial distribution of land uses between less agriculturally productive peat and organo-mineral soils in the uplands, and more productive mineral soils in the lowlands. Exceptions to this rule are areas such as the Fens, where drainage of lowland peat soils have given rise to favourable conditions for arable production. These data on their own do not demonstrate a strong causal relationship between land use and carbon content. Nevertheless, as discussed below some land uses and management activities are more suitable to soil carbon conservation.

How land use and management impact on service delivery

9.13. The impacts of land use on global emissions of greenhouse gases are understood at broad levels. Soil and vegetation hold large amounts of organic carbon and the way land is used can have a major impact on whether carbon remains stored or is lost to the atmosphere as a greenhouse gas, CO_2.[111] Agriculture emits only one per cent of the UK's emissions of CO_2 compared to 38 per cent of methane emissions and 68 per cent of those from nitrous oxide.[112] Consequently agriculture has a direct role to play in reducing emissions to mitigate climate change and an indirect role in conserving carbon in the soil to protect existing stores and potentially capture additional CO_2.

9.14. While peat soils store the greatest amount of carbon per unit area, their distribution is relatively limited in England. Carbon stored in organo-mineral soils such as gleys, brown earths and podzols, which occupy a much larger area in the uplands of Wales and Scotland (and probably also England and Northern Ireland), is therefore likely to be as significant as that stored in peat soils[113].

9.15. Natural and human-induced changes in the soil environment (depending on temperature, wetness, oxygen availability and the presence of organisms) can alter the release (oxidation) and storage (sequestration) of carbon stored in soil. In this way, different types of land use have the potential to impact on soil carbon storage.

Developed land

9.16. Few large settlements are located on peat soil because of its unstable, waterlogged nature. Impermeable surfaces do not allow for the accumulation of carbon in soils and, although urban greenspace can do so, this study is aware of no data on carbon flux in urban soils. The chief impacts of developed land on soil carbon are therefore likely to be indirect such as from demand for peat as a horticultural growing medium in parks and gardens (covered below). The extraction of aggregates for use in construction often involves reductions in water tables around extraction sites and this may lead to mobilisation of soil carbon from wetlands. It is possible that a similar affect may arise from abstraction for public water supply, although this study can find no research evidence to quantify this.

[111] See for instance Scottish Executive and Welsh Assembly Government (2007)
[112] AEA (2008)
[113] SE and WAG (2007)

Arable and horticultural cropping

9.17. Demand for peat for horticultural production and gardening continues to be a major threat to the UK's peatland resource. Plantlife states that 60 per cent of peat used for horticultural purposes has been extracted from sites in the UK.[114] As noted further below (paragraph 9.36), there is a presumption in public policy that peat extraction should be limited to areas that have already been "significantly damaged by recent human activity", but this allows continued extraction of previously exploited sites leading to continuing release of sequestered carbon back to the atmosphere.

9.18. There are relatively few areas in England and Wales where arable and horticultural production takes place on soils that have high soil carbon content. Notable exceptions are the Cambridgeshire Fens, the Humberhead Levels and Lancashire Mosses. In these areas, past drainage of the peat soils has allowed highly productive cropping to take place, but with a major impact in terms of the loss of stored carbon. The drainage has mobilised the carbon which has oxidised rapidly and regular cultivation and exposure of bare soils to wind erosion has led to a relatively rapid loss of soil material. In these areas, particularly the Fens, loss of soil has led to a major lowering of the land surface (a drop of several metres over the space of 150 years in places), requiring pump drainage to prevent groundwater flooding from adjacent areas. These losses will continue for as long as the low water tables are maintained and soils are cultivated and cropped, until the peat has been entirely eroded. Cropping of these areas accounts for a disproportionately large (given the small areas involved) proportion of the UK's carbon emissions from land use.[115]

9.19. Outside these areas, most arable and horticultural cropping takes place on soils which have low levels of soil carbon. Although this is likely to be primarily because arable cropping takes place in lowland areas on predominantly mineral soils, aspects of land management have a major impact on soil carbon flux. In arable systems, ploughing disturbs soil and stimulates the oxidisation of carbon to CO_2 which is lost to the atmosphere. As a result, it has been estimated that conversion of grassland to arable can result in a 25-43 per cent decrease in soil carbon content.[116] In addition, high crop yields and efficient harvesting machinery results in more effective residue removal and low levels of carbon being returned to the soils.[117]

9.20. An issue of policy relevance is reduction in the area of land set-aside in arable-dominated landscapes. The analysis here suggests that the conversion of long-term set-aside that has regenerated as rough grassland back to cultivated arable land is likely to produce significant losses of soil carbon, although it is not known how this compares to other land use types.

9.21. The planting of short rotation coppice (SRC) as a renewable energy source is a recognised component of the strategy to reduce UK CO_2 emissions. However, SRC systems affect the sequestration and storage of carbon in soils in addition to being a potential replacement for other fuel sources. Studies have shown that SRC has the potential to sequester substantial amounts of carbon, comparable to undisturbed naturally regenerating woodland. These studies suggest that this is more than balanced out by the benefits of the high level of

[114] www.plantlife.org.uk/uk/plantlife-campaigning-change-plants-and-peat.html#2
[115] Mobbs *et al.* (2007)
[116] Humphreys (2008)
[117] Bellamy *et al.* (2005)

biomass per unit area that is produced[118]; however considering only the issue of soil carbon storage, SRC systems are less beneficial than undisturbed woodland.

Grassland

9.22. As with arable and horticultural cropping the drainage of grassland growing on peat soils can lead to major losses of soil carbon as the soil dries out and carbon is mobilised. However, the infrequency of land cultivation and the grassland cover reduce the losses to wind erosion which are so significant under arable cropping.

9.23. Grassland, particularly permanent grassland, gives rise to higher levels of soil carbon than arable and horticultural cropping because of the greater volume of root biomass in soils and the accumulation of organic matter in the absence of cultivation.

9.24. Differences in the intensity of grassland management affect soil carbon levels. More intensive management leads to greater cycling of carbon through plants, leading to greater opportunities for carbon removal in conserved fodder (silage and hay) or livestock. More intensive livestock production systems (for instance dairy farming and pig production) tend to produce slurry rather than farmyard manure from housed livestock. Much less carbon is returned to the soil from slurry than from farmyard manure[119]. Calculations are complex because of the dominance of carbon dioxide as a source of carbon for plant respiration.

Dwarf shrub heath, fen, marsh and bog

9.25. The key issue for this land use type is the close association between the habitats and peat soils. When in good condition, these habitats growing over peat soils have the ability to accumulate large amounts of carbon – up to 0.7 tonnes per hectare per annum[120], which is more than is typical on woodland in the UK. These soils can, however, become a source of carbon when they are degraded, with carbon being lost from peat in various forms including dissolved organic carbon and CO_2 and particulate organic carbon (POC).

9.26. The management of these types of habitat can affect their potential to store carbon. Drainage of peat bogs, which has been widely practiced in the UK in the past, reduces their carbon content as a result of increases in soil aeration and oxidation. Heathland burning, which takes place widely in many parts of the UK, also affects the storage of carbon. Studies in the Pennines have shown a link between soil carbon content and the extent of heathland burning in the area, with areas of extensive burning showing higher levels of dissolved organic carbon loss[121]. Burning can also destroy the 'living skin' of blanket bogs of sphagnum moss and other plans, meaning that they lose their ability to sequester carbon.

9.27. High densities of grazing animals on peat, which is prone to erosion once compacted, can lead to degradation of the peat and carbon losses, along with associated impacts on water quality. This has been experienced in the Peak District National Park – where eroded peat from the area's moorlands (including as a result of overgrazing) has washed into reservoirs, leading to a reduction in

[118] Grogan *et al.* (2001)
[119] Bellamy *et al.* (2005)
[120] Defra (2008)d
[121] SE and WAG (2007)

water storage capacity and drinking water clarity. Low levels of grazing of upland moorland habitats are considered necessary to maintain the biodiversity, landscape and historic environment interest (as well as supporting economic and social activities in remote communities) but this may not be the case for the conservation of soil carbon. Livestock numbers have decreased in recent years[122], almost certainly as a result of the decoupling of support payments from the Common Agricultural Policy. If grazing were to cease entirely, most upland moorland habitats on peat would be colonised by birch and other trees. Research is needed to assess the relative impacts of grazing, other management such as burning, and no management on carbon flux.

9.28. In Wales, the peat and organo-mineral soils of the Cambrian Mountains are a major source of carbon storage in Wales – with the peat soils accounting for some 22 per cent of the national total (some 70,600 hectares). However, as a consequence of past land management it is probable that the Cambrian Mountains are currently releasing more carbon than they are sequestering. This is as a result of the erosion of particulate organic carbon and its release into the many streams and rivers of the area.[123]

Woodland

9.29. Like all other plants, trees remove carbon from the atmosphere through photosynthesis and store it in the plant tissue. The long lifespan of trees, along with the relatively low level of disturbance to woodland soils onto which leaves and other dead material fall, make woodland an important store of carbon.

9.30. Every year it is estimated that the UK's woodlands remove four millions tonnes of carbon (mtc) from the atmosphere and store 150 mtc.[124] However, the value of woodland in climate change mitigation is considered to be greater in terms of its use as an alternative to fossil fuels than its value as a carbon sink, as the forest carbon sink offsets a very low percentage of annual carbon dioxide emissions.[125] Recent studies[126] have found that the most favourable combined levels of carbon sequestration and energy saving come from increasing the proportion of permanent woodland, with the next most favourable land use being from bioenergy crops. These findings reinforce the fact that the value of woodland lies in a combination of its ability to sequester carbon and its potential as an alternative fuel source, rather than in carbon storage alone.

9.31. Afforestation of peat soils can, however, lead to significant losses of stored carbon. Drainage for planting, which is required for conifer plantation forestry but not for broadleaf planting, increases soil aeration, as does the increasing level of evapotranspiration. Ongoing studies in Wales are looking at the effects of woodland/forestry planting over peat, the natural regeneration on peat and the potential removal of conifer plantations from peat, to understand the most suitable approaches to carbon conservation and sequestration. The way in which conifer plantations are restored to actively growing dwarf shrub heath and blanket bog can have a considerable impact on carbon flux. Research is suggesting that ring barking trees, but leaving them in situ, potentially maximises overall carbon storage.[127]

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[122] Defra (2008)e and WAG (2008)
[123] Land Use Consultants (2007)
[124] Defra (2007) d
[125] Forestry Commission (2008)
[126] For example, King *et al*. (2004) in Haines-Young *et al.* (2008)
[127] Colis (2007)

Future pressures on soil carbon

9.32. The lack of a strong evidence base on current influences on carbon flux and levels in soils extends to the understanding of future drivers for change. Nevertheless, Chapter 5 identified the following pressures that are likely to influence carbon flux in soils over the period to 2020 and beyond.

- **Climate change**. Peat soils, already a threatened habitat, are likely to dry out in southern and central locations as a result of drier summers. Better conditions for sustaining peat are likely to prevail further north.
- **Policy and practice for food production**. Concerns over food security could see greater intensity of cropping, bringing marginal land into production, potentially reducing levels of soil organic matter (depending on the practices adopted). It is likely that regulation and incentives will increase the use of favourable soil management practices that would counter this trend.
- **Increased woodland cover**. A rise in the area of woodland planting would see a long-term increase in the carbon sequestered in these soils, as well as in the living plant material.

Actions to address failures in service delivery

Reduction in the extraction of peat for horticultural use

9.33. Conservation bodies and others (through the Peatlands Consortium Campaign) have pushed to reduce the environmental impacts of peat extraction in the UK. Critically, the Government's Minerals Policy Guidance[128] emphasises the impact of peat extraction on biodiversity rather than on the release of stored carbon. The development of alternative growing media to peat has been pursued by many horticultural businesses, with composted green waste offering additional benefits in reduced landfill. Moves to reduce the use of peat in commercial horticulture and the leisure gardening sectors can be thought of as a change in management that will have benefits to the conservation of carbon stored in peat.

Maintaining the condition of soils with high carbon content

9.34. The continued cultivation and intensive cropping of peat soils in areas such as the Fens is disproportionately significant as a cause of carbon loss from soils in England and Wales. In these areas, large-scale changes of land use, from arable and horticultural cropping to wetland or wet woodland, will be required to halt this loss. For the rewetting of these soils to take effect, water retention structures will be needed to ensure that water tables can be maintained (although many of these areas are low-lying and currently benefit from pump drainage). Most of this land is classified as Grade 1 and 2 (the most productive) and changing the use of this land to wetland is likely to push down land values and ongoing profit (although there will be lower costs associated with land drainage). Alternative streams of income such as from tourism may be possible but are unlikely to replace income from cropping. SRC using willow or poplar might be a compatible land use provided it is not grown in areas already under water stress (bearing in mind that these species have high evapotranspiration rates) and will contribute to other environmental services (renewable energy generation).

9.35. There are large areas where land use is compatible with the conservation of soil carbon (such as blanket bog, dwarf shrub heath or woodland), but where climate change and practices such as land drainage, burning and grazing pose an ongoing threat that needs to be addressed by a change in management. Projects to rewet drained areas of peat soils by blocking moorland grips were described in the previous chapter (paragraph 8.58). The rewetting of drained peat soils can involve a period when soil conditions change from aerobic to anaerobic conditions, leading to emissions of methane, which has an impact as a greenhouse gas 20 times that of carbon dioxide. Research is underway to establish the conditions under which this takes place, but it is clear that turning degraded peat soils into those which can positively mitigate climate change is a complex process.

9.36. These projects tend not to be funded through national agri-environment schemes but as local projects, most drawing on funding from water companies and conservation bodies. However, the areas covered are huge and funding per hectare has been very low. Although there are a number of high profile restoration projects, many of them have impacted on small proportions of land. For example, there are 10,000 km of grips on the North Pennines AONB, and

[128] CLG (1995)

6,200 remain to be blocked, despite this being considered an easier site to tackle[129].

9.37. Agri-environment schemes provide opportunities for bringing soils with high carbon content into beneficial management. Around 230,000 ha of the English Uplands are currently under agreement in this way.[130] These agreements typically require continued management through low levels of livestock grazing. Where the schemes reduce livestock densities, they are likely to contribute positively to carbon conservation by reducing soil erosion. The decoupling of mainstream agricultural support from the Common Agricultural Policy since 2004 has reduced livestock numbers in many areas. Again, it is not clear whether continued livestock grazing is necessary or optimal for the conservation of carbon.

Raising carbon levels in other soils

9.38. The sections above have focussed on measures to conserve carbon in peat soils. However, organo-mineral soils, which tend to be under grassland management, hold large quantities of carbon over England and Wales as a whole (concentrated mainly in the uplands) (paragraph 9.41) and all soils have levels of organic matter which are important for their biological functioning and for holding water. Woodland contributes the highest levels of soil organic matter to organo-mineral soils, followed by grassland and then cropped land, suggesting that a change of land use from arable to grassland to woodland will do most to increase soil carbon levels. Compared to measures to safeguard existing soil carbon in peat soils, these changes in land use are likely to have less impact and over a long timescale.

9.39. Land management measures to maintain and enhance levels of organic matter in mineral soils include reducing levels of tillage (zero and minimum tillage techniques) and increased incorporation of wood and crop residues (from forestry and crop harvesting operations) and manure into soils.

Summary of the scope for land use to improve service delivery

9.40. The following points emerge from this chapter.

- There is currently no source of data that can be used to map levels of carbon losses from, and sequestration by, soils in England and Wales, nor to establish a suitable environmental limit. This study has used data on the carbon content of soils, at a resolution of one-km^2 to map those areas with highest levels of carbon in the top soil horizon.

- High concentrations of soil carbon are found in the uplands of central Wales, throughout the Pennines of northern England and on Dartmoor in the south west. Concentrations in lowlands occur in peatlands of the Fens and Somerset Levels and on heathland soils in the New Forest and Thames basin.

- Comparison of dominant land use and carbon content at a resolution of one-km^2 by this study, confirmed by data from CEH's Countryside Survey, shows strong associations between dwarf shrub heath and semi-natural

[129] Environment Agency (2007)e
[130] Defra (2008)d

(particularly acid grassland) on soils of high carbon content, reflecting the dominance of these vegetation types in the uplands on peat and organo-mineral soils.

- Conversely, there is a strong association between arable and horticultural cropping and soils with a low carbon content. This is consistent with the dominance of these land uses on the agriculturally productive mineral soils in the lowlands. These associations do not necessarily demonstrate a causal relationship. Nevertheless, land management practice associated with these land uses, with regular soil tillage and use of inorganic fertilisers, contributes to loss of soil carbon. This is a major issue in areas such as the Fens where arable cropping takes place on peat and on organo-mineral soils with high carbon content.

- Based on the findings of research, much of which is ongoing, it is clear that land drainage and regular soil cultivation, practices common under arable and horticultural crops, but also on ley grassland and in land prepared for plantation forestry, lead to losses of soil carbon. Land drainage is also practiced on most improved permanent grassland and on many upland heaths dominated by dwarf shrub heath and acid grassland vegetation.

- The legacy of land drainage is still being experienced on peat soils under arable cultivation, such as those in the Fens, Humberhead Levels and Lancashire Mosses and on many upland conifer plantations. In these areas, whole-scale changes in land use, to allow the rewetting of these soils, will be needed to reverse these carbon losses.

- In other areas with carbon losses, such as on drained, overgrazed and over-burned dwarf shrub heath and blanket bog, major changes in management (within the existing land use) are required. This will involve blocking moorland grips, reducing grazing pressure (or completely withdrawing grazing) and reducing the severity and frequency of moorland burning.

- When considering changes in land use and management to reduce carbon losses, the impact of these actions on emissions of other greenhouse gases, particularly nitrous oxide and methane, needs to be considered. Research on the rewetting of drained peat soils indicates the risk of moving from aerobic to anaerobic conditions leading to emissions of methane, a greenhouse gas 20 times as potent as carbon dioxide.

9.41. Overall, priority changes in land use and management to reduce losses of soil carbon from soils with high carbon content are as follows:

Land use change

- High losses of soil carbon from peat soils under arable and horticultural cropping, as well as from lowland organic soils, should be addressed by large-scale land use change to wetland or woodland uses, both requiring the raising of water tables. These changes will be concentrated in relatively small areas of lowland England such as Fens, Humberhead Levels and Lancashire Mosses.

- Similarly, areas of upland peat soils which have been drained and planted with forestry should be a priority for land restoration to dwarf shrub heat and blanket bog, again requiring the rewetting of the peat soils.

Land management change

- Where current land use is compatible with conservation of soil carbon, but where management is not (such as where uplands habitats on peat have been drained and subject to intense grazing and moorland burning), suitable management regimes should be adopted. Continued grazing need not be part of this regime for carbon conservation (but is likely to be required for biodiversity) and without grazing, a change of land use to woodland would occur over time.

9.42. These actions seek to stem losses of soil carbon, but should also aim to maintain and enhance net levels of carbon sequestration in soils. Further research is needed to identify the extent to which increased immobilisation of carbon in peat soils can be maintained in the face of drier warmer summers.

10. Valuing improvements in services resulting from land use change

Introduction

10.1. This section provides a methodological framework for the economic valuation of changes in the delivery of environmental services brought about by changes in land use and management. It examines how changes in each of the four key services can be valued, and identifies economic values that can be applied to each. It then combines qualitative evidence on the links between land use and environmental services with economic evidence of the value of each of the key services in question, to examine the likely relative magnitude of benefits and costs of land use change.

10.2. The main barrier to estimating the value of changes in service delivery is not the identification of economic values but the quantification of changes in service delivery resulting from changes in land use. Data gaps and scientific uncertainties mean that it has not been possible to quantify the delivery of services in units amenable to valuation. The previous sections show that there are few if any circumstances where a simple relationship between a change in management or land use and an increase in service delivery can be predicted with any confidence. The complexity of land use systems and the close relationship with natural factors such as climate, soil type, geology and topography are key factors complicating the quantification of links between land use and service delivery.

Valuing environmental services – the concept of ecosystem goods and services

Framework for assessing and valuing service delivery

10.3. Defra's *Introductory Guide to Valuing Ecosystem Services* provides a general framework for the assessment and valuation of ecosystem services. Ecosystem services contribute to economic welfare through contributions to the generation of income and wellbeing and through the prevention of damages that inflict costs on society. Both types of benefits should be accounted for in policy appraisal.[131]

10.4. Figure 10.1 shows a simple framework to examine the impact pathway of a policy change.

Figure 10.1: Impact pathway of a policy change.

[131] Defra (2007)g

10.5. The key steps in this framework are to:

1. Establish the environmental baseline.
2. Identify and provide a qualitative assessment of the potential impacts of policy options on ecosystem services.
3. Quantify the impacts of policy options on specific ecosystem services.
4. Assess the effects on human welfare.
5. Value the changes in ecosystem services.

10.6. This approach focuses on the value of marginal changes in ecosystem services rather than their overall value. This makes it relevant to policy changes and avoids problems in assessing the overall value of services necessary for human existence.

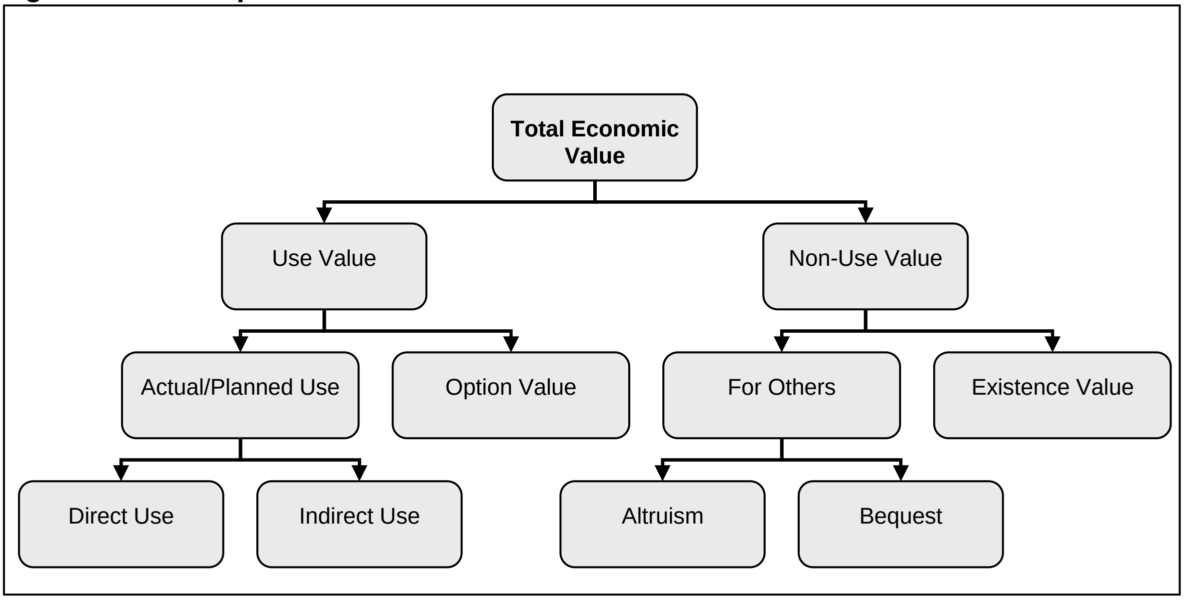
10.7. This study sought to apply this approach to assess the value of changes in environmental services resulting from changes in land use and management in England and Wales:

1. The environmental baseline relates to delivery of the four key environmental services under current patterns of land use and management. This has been mapped and described in the study.
2. The scientific assessment has provided a detailed qualitative assessment of the relationship between changes in land use and management and the delivery of environmental services, based on current knowledge.
3. The study has found that current knowledge does not permit quantification of changes in service delivery resulting from changes in land use and management. Therefore it has not been possible, as originally intended, to define land use change scenarios and quantify their effects on environmental service delivery.
4. The effects of each of the environmental services on human welfare have been examined, and evidence of the economic value of each service reviewed. The findings for each service are presented in separate sections below (paragraphs 10.16 to 10.91)
5. Valuing changes in environmental services is dependent on being able to quantify changes in service delivery (step 3) and to assign unit values to these (step 4). Because it has been impossible to quantify the effects of changes in land use and management on service delivery, it is not possible to value changes in service delivery in monetary terms. However, a more qualitative assessment combining evidence from steps 2 and 4 of this framework is presented in the concluding section to this chapter (paragraph 10.92 onwards).

Components of Total Economic Value

10.8. An assessment of the overall benefits of changes in service delivery requires us to use the concept of Total Economic Value (TEV), considering all of the different benefits that environmental services provide to human welfare. The TEV concept takes account of direct and indirect use values, and non-use values derived from an asset or service, through knowledge of its existence or ability to be used by others. Figure 10.2 provides an illustration of the components of TEV.

Figure 10.2: Components of Total Economic Value.



Source: Defra (2007)

10.9. The four key environmental services bring a variety of benefits to human welfare. These can largely be grouped as:

- **Indirect Use Values** – Regulating services are not used directly but result in improvements in the environmental resources on which humans depend. People derive benefits from a higher quality water environment, more water resources, less frequent flooding and better regulation of the global climate.
- **Non-Use Values** – People derive benefits from improvements in the environment even if they do not use it. This may include valuing the existence of biodiversity and knowing that a high quality environment is available for others, for current or future generations (altruism and bequest values).

10.10. The analysis also needs to take account of:

- **Market Values** – Some services have a financial value directly measurable in the market place, by generating revenues or reducing costs. Examples are the value of commercial fisheries, effects of water quality on the costs of treating drinking water and changes in the value of property resulting from flooding.
- **Non-Market Values** – Other aspects of service delivery may be valued by people but have no direct market. Examples include the ecological value of surface waters and the storage of carbon in soils. While carbon markets are being developed, they currently operate only in certain areas of the economy, though a “shadow price” for carbon has been established, permitting changes in carbon emissions and sequestration to be valued as if a market exists.

10.11. A range of methods is available to value changes in environmental services. The type of valuation technique chosen will depend on the type of ecosystem service to be valued, as well as the quantity and quality of data available. Economic valuation follows two forms:

- **Revealed Preference Techniques** rely on data from market-based transactions that reveal preferences for the services in question. They include market pricing, cost-based approaches, hedonic pricing, the travel cost method and random utility modelling.

- **Stated Preference Techniques** use carefully structured surveys to elicit individual preferences for the good or service in question. In principle they can be used to value a wide range of non-market as well as marketed goods and services. The principal techniques are contingent valuation and choice modelling.

10.12. Using market price data to value environmental services is often relatively straightforward, providing the service can be quantified in biophysical terms. Application of non-market valuation techniques, on the other hand, can be a complex, time-consuming and expensive process.

10.13. An alternative is benefits transfer, which applies economic values generated in one context to another context for which values are required. Such transfers are now essential for the use of environmental values in policy-making[132]. In a study such as this one, constraints of time and budget mean that benefits transfer is the only practical option to value changes in environmental services.

Key methodological issues

10.14. Limitations in our ability to quantify and map service delivery, and in economic valuation evidence, present barriers to making a detailed assessment of the value of changes in environmental services linked to land use and management. Economic valuation faces a series of key issues relating to:

- **Benefits Transfer** – It is not possible in studies of this scale to conduct original valuation work to assess the benefits of land use change. It was therefore necessary to obtain benefit estimates from previous studies to value the changes in question. The robustness of such an approach depends on the context in which the estimates were made and the changes being valued. For each of the key services, it was possible to identify values for this study. However, in some cases the values used were not ideal. For example, to estimate the benefits of low flow alleviation it was necessary to rely on old estimates and make assumptions about their transferability. However, for carbon sequestration, it was possible to identify standardised values which could be used with a much higher degree of confidence.
- **Range of Values Included.** A comprehensive valuation of the benefits of land use change on environmental services requires a variety of use and non-use values to be incorporated and the effects on different receptors and interest groups examined. In each case it was possible to identify the types of benefits of interest and to review evidence of the value of these. However, difficulties in quantifying the range of services delivered made it difficult to value these fully. For some services, it was necessary to focus on aspects that could be mapped and/or quantified through change scenarios. For example, with the provision of water resources, it was necessary to focus on the non-market benefits of alleviation of low river flows rather than on the benefits of water resource development, which are harder to model.
- **Uncertainty.** Valuing the environmental services resulting from changes in land use and management is subject to uncertainty. This is evident at different stages of the assessment process: there is scientific uncertainty about how ecosystems work and the services they deliver; even where services are relatively well understood there may be uncertainties in quantifying them in biophysical terms; there are further uncertainties in the

[132] Defra (2007)g

valuation process. Uncertainty needs to be addressed through interdisciplinary approaches involving ecologists and economists, and needs to be taken account of in the specification of services to be valued and in the information provided to participants in any valuation exercise.

- **Gross and Net Effects.** It is important to assess net changes in environmental service delivery, recognising that changes in land use and management may enhance the delivery of some services while reducing others. This is particularly the case if the analysis is extended beyond the four key regulating services to include other ecosystem services, some of which may involve trade-offs.
- **Spatial Distribution of Benefits**. Ideally valuation of the benefits of land use change would adopt a detailed, bottom-up approach which estimates their value in different locations and aggregates this to the regional and national level. Values are often highly location-specific. For example, the value of reduced flooding depends on the location and value of property affected, with huge spatial variations in benefits. There are barriers to adopting such a bottom-up approach, however, due to an absence of local data on service delivery and on local variations in benefits, as well as the complexity and scale of effort required. As a result, it may be necessary to adopt a simplified, top-down approach which assumes that the total value of changes in services due to land use change is proportionate to the area affected; in effect, an even distribution of services may be assumed. This does not permit a sophisticated level of analysis but may not be unreasonable if the land use scenarios are assumed to apply evenly across England and Wales. However, more targeted changes in land use, linked, for example, to the value of property or water resources at risk, could give very different results.
- **Use of Marginal Values**. Economic theory leads us to understand that the marginal value of service delivery varies according to the level of service delivered. For example, if high quality water becomes scarce, we would expect its value to increase at the margin. Therefore it is not strictly correct to assume a constant unit value of an environmental service, and to extrapolate from the margin accordingly. Estimates by Costanza *et al.* (1997) of the global value of ecosystem services have been criticised on this basis, by using marginal values to estimate total service value; similarly, estimates of the unit value of the delivery of a service at the national level may not provide a robust basis for estimating the value of small-scale changes in service delivery. The problem increases with the size of change being considered; for relatively small changes it will be safer to extrapolate from the margin.
- **Aggregation and Double-counting.** When aggregating values, care is needed in identifying overlaps and avoiding double-counting. This is the case for water quality and water resources, where flow rate is a determinant of ecological status; estimates of willingness to pay (WTP) to achieve good ecological status are likely to take account of flow rates as well as other aspects of quality. It is also important to understand the scope of WTP estimates, and the variety of benefits informing public preferences, to avoid aggregating overlapping values.

10.15. The following sections review evidence of the value of the four environmental services.

Regulation of water quality

Benefits of service delivery

10.16. The benefits of water quality can be categorised as follows:

- **Direct use benefits**: avoided costs for treatment of drinking water; better opportunities for amenity and recreational use, such as informal and water-related recreation, bathing, recreational fishing and a more valuable natural environment; returns in commercial fisheries.
- **Indirect use benefits**: better regulation of water systems and related ecosystems.
- **Non-use benefits**: the value attached to better water quality, irrespective of use. These include the existence values derived from biodiversity and the bequest value of passing good water quality onto the next generation.

Valuation of benefits

Estimating different benefits

10.17. A comprehensive assessment of water quality effects might take account of the impact of land use on:

- The capital and operating costs incurred by the water companies in removing nutrients and pesticides from drinking water.
- The additional recreational value of improved water quality. This may be measured in terms of willingness to pay per recreational user.
- The effects on the value of recreational and commercial fisheries. This can be measured using functions linking the value of recreational fisheries to fish catch, and, for commercial fisheries, using market prices for fish.
- The value of changes in ecological water quality and freshwater biodiversity, based on evidence of willingness to pay. This may be measured through stated preference techniques to assess the value to householders of improvements in water quality. (e.g. in £ per km of river achieving certain standards);
- The amenity values for local residents, based on willingness to pay higher prices for properties or rented accommodation near clean water (hedonic pricing method).

10.18. In practice it may be difficult to distinguish between these benefits in the valuation exercise. For example, the public's willingness to pay for water quality may include elements of non-use and use value, including the benefits for particular user groups such as recreational fishermen.

Non-market benefits of water quality improvements

10.19. The key evidence base on the non-market benefits of water quality improvements is provided by the National Water Environment Benefits Survey, commissioned as part of the collaborative programme for research on the economic analysis for the Water Framework Directive (WFD), and undertaken by NERA and Accent (2007). This was used in Defra's Regulatory Impact Assessment of the WFD.[133]

[133] Defra (2008)a

10.20. This study used stated preference techniques to establish the public's willingness to pay (WTP) for improvements in water quality by the WFD. It focused on non-market benefits arising from improvements in surface water quality, and excluded groundwater as well as market benefits such as reductions in water treatment costs. The figures include non-use and use benefits, including biodiversity, amenity and recreational values.

10.21. The survey assessed WTP for improvements in water quality from "low" to "high", the latter encompassing "high" and "good" ecological status. Respondents were shown maps that depicted the area of catchments (rather than the number, length or size of bodies) with low or high quality under different scenarios.

10.22. The study estimated, using conservative assumptions, that the public's WTP to achieve "high quality" over 100% of the area of England and Wales (compared to 15 per cent in 2007) amounted to £1,020 million per year. The present value of these benefits, capitalised over time, was estimated at £29 billion.

10.23. These estimates are much larger than those in the earlier RIA of the WFD, which estimated the total annual benefits of improved river quality, including angling, non-use and recreational benefits at £105 million to £270 million per year (WRC, 2003).

Impacts of agriculture on water quality

10.24. A variety of studies have examined the external costs and benefits of UK agriculture, including its impact on water quality.

10.25. Recent estimates are provided by O'Neill (2007), based on values provided by Garrod (1994) for WTP for water quality improvements. The annual costs of damage by agriculture to the water environment in England and Wales are estimated as follows:

- Nutrients in lakes - £20-33 million
- Damage to informal recreation from poor water quality - £10-23 million
- Damage to fishing from poor water quality - £14-36 million
- Bathing water quality affected by water pollution - £23-42 million
- Amenity loss (including effects on property prices) - £5 million
- Impacts on groundwater - £50-88 million
- Surface water treatment costs - £127-148 million
- Damage to river ecosystems and natural habitats - £183-456 million
- Damage to wetland ecosystems and natural habitats - £13-41 million
- Total - £445-872 million

10.26. These estimates involve a number of assumptions to provide national estimates of damage costs.

10.27. Jacobs[134], in the Environmental Accounts for Agriculture, provide a useful review of the impacts of agriculture on the ecological quality of water bodies and on the treatment of drinking water, and the costs of these impacts on society.

10.28. Households in East Anglia had a WTP of €110 on average for a policy that would reduce phosphorus emissions and thus prevent eutrophication. This

[134] Jacobs (2008)

represents an annual benefit of more than €250 million for the whole region.[135] Several other studies indicate a high WTP to prevent eutrophication.

Water treatment costs

10.29. Data is available on the costs of removing pesticides, nitrates, phosphates and soil from drinking water. Standard cost submissions from water companies to OFWAT are a key source.

10.30. Defra (2006) estimated the total costs of removing pesticides and nitrates from drinking water at £133 million per year in England and Wales between 2005 and 2010, comprising operational costs of £59 million and capital costs of £74 million.

10.31. Total annual capital expenditure for phosphate and soil particle removal in the UK was reported to be £73.5 million; £15.7 million attributable to agricultural phosphorus emissions[136]; however, Jacobs (2008b) considered phosphates not a significant concern in drinking water and that phosphate removal should be excluded from estimates of drinking water treatment costs.

10.32. Jacobs (2008b) used data from OFWAT and other sources to estimate the annual cost of removal of agricultural pollutants from drinking water at £129 million per year. Sixty per cent of nitrate and 85 per cent of pesticide pollution was attributable to agriculture. These figures include capital and operating costs.

10.33. IEEP (2006) cited estimates of savings in drinking water treatment costs through peatland restoration in NW England of between £1.2 and £2.6 million per year.

Groundwater

10.34. Impacts on groundwater are best made with reference to the cost of removing pollutants.

10.35. Estimates of the benefits of improving groundwater quality are made in the partial RIA of the Groundwater Regulations.[137] This notes that potential benefits include:

- Reduced costs in treating groundwater abstracted for drinking (or other purposes) or seeking alternative sources.
- Enhanced ecological or amenity value of associated surface waters.

10.36. The partial RIA notes that a third of public water supplies in England and Wales are from groundwater, but that the proportion varies greatly by region. Seventy-eight per cent of overall GW abstraction is for the public water supply. There are also many thousands of private boreholes, which provide the sole source of water to many households and smaller communities, though these account for a small proportion of overall abstraction. Other abstractors include industrial users and fish farms.

10.37. The RIA estimated the portion of the £133 million total costs of removing pesticides and nitrates from drinking water that could be attributed to groundwater treatment. As a third of water treated is groundwater, it was

[135] Bateman *et al.* (2006)
[136] Pretty (2000)
[137] Defra (2006)

estimated that the costs for groundwater are £41 million per year. Costs of removing pesticides and nitrates from surface waters are therefore £92 million.

10.38. According to the RIA, achieving good ecological status for all groundwater would remove the need for chemical treatment and therefore provide annual benefits of £41 million per annum. However, a time lag would be expected between measures to tackle groundwater pollution and observed improvements in groundwater quality. Estimates were also made of the benefits to surface water quality, although these are likely to overlap with the figures above. In all, it was estimated that the benefits of achieving good ecological status for groundwater in England and Wales could be as high as £1.7 to £5.1 billion, based on the value of annual benefits capitalised over 100 years, and that these exceed the costs of implementing the regulations.

Other market benefits

10.39. A study under the Collaborative Research Programme on River Basin Management Planning Economics[138] investigated the potential market benefits of the Water Framework Directive. The study examined benefits through water abstraction, fisheries and provision of services to recreational users. The report identified a variety of benefits but found few quantified estimates, and concluded that there were uncertainties in assessing and valuing these market benefits.

Evidence on service delivery

10.40. For this study LUC mapped river water quality across England and Wales, identifying areas classed as high, good, moderate, poor, bad or as yet to be classified. Groundwater quality was also mapped as good or poor across England and Wales.

10.41. It was not possible to quantify the effects of land use change scenarios on surface water or groundwater quality. However, the following conclusions were drawn:

- **Regulation of surface water quality**: Land use, and particularly land management, is a primary determinant of water quality. A causal relationship between land use and the WFD ecological status of rivers is clearly shown by the data used in this study.
- **Regulation of groundwater quality**: The relationship between land use and groundwater quality is less clear because of the size of the groundwater areas that are monitored, and the time lag between changes in land use and management and the response of the chemical status of groundwater.

Possible approaches to valuing the effects of land use change

10.42. The benefits of improvements in water quality can be assessed with reference to the following key economic valuation data:

- The public's willingness to pay to achieve good ecological status of surface waters is estimated at £1,020 million per year. This is equivalent to an annual benefit of £12 million per one per cent of the national surface area in which good ecological status is achieved.

[138] Entec (2008)

- The costs of removing pesticides and nitrates from drinking water are currently estimated at £92 million per annum.
- The costs of removing pesticides and nitrates from groundwater are currently estimated at £41 million per annum.

10.43. In order to value the benefits of land use change scenarios, it would be necessary to assess their effect on:

- The proportion of the surface area of England and Wales achieving good ecological status for surface waters.
- The degree to which treatment of surface waters and groundwater is necessary to meet drinking water quality standards.

10.44. The largest potential benefits relate to the non-market benefits of improving the ecological status of surface waters.

Availability of water resources

Benefits of service delivery

10.45. Adequate water resources are vital for people and the economy. Sympathetic land use and land management practices can help to ease pressure on water resources and hence reduce the risk of water shortages. They may also reduce the need for additional investments in water resources or in other actions designed to influence the balance of water supply and demand (such as tackling leakage, metering).

10.46. Maintaining sufficient water levels and flows is important for the ecological quality of surface waters. Sympathetic land use practices may therefore have benefits for biodiversity, landscape and recreational uses (such as angling, boating and other water sports).

Valuation of benefits

10.47. Possible means of valuation of the effects of improved water resource management through sympathetic land management practices include:

- The willingness of recreational users and the general public to pay for greater river flows and higher water levels in the environment.
- Avoided costs of other water resource management activities such as leakage reduction, demand management and building of water resource infrastructure.

Value of water quantity in the environment

10.48. Jacobs (2008b) quote a benefit transfer study[139] which estimated the average social benefit of increased water in the environment to be £0.27 per m^3 per day (£2003).

10.49. A study of the value of flow alleviation in rivers in south-west England[140] provided estimates for fishing and general recreational losses from reduced flows. A contingent valuation (CV) study revealed anglers were willing to pay £3.80 per day to improve low flow. This aggregated to a net value of £5,000 to £32,000 per river per year, depending upon the extent of the low flow, the

[139] Eftec (2003)
[140] Willis *et al.* (1999)

additional number of fishing days, and substitution effects (proportion of additional days transferred from other non-affected river fishing sites). Welfare estimates to restore rivers in south-west England to an environmentally acceptable flow regime (EAFR) for informal recreational users were around 4.7 pence per km per household per year.

10.50. O'Neill (2007) produced national estimates of the benefits of alleviating low flows based on the results of a previous study[141], which measured willingness to pay for low-flow alleviation on all 40 rivers identified as low-flow rivers nationally. O'Neill estimated total willingness to pay at about £115 million per year (2004/5 prices), almost all of which relates to non-use impacts on natural habitats. This is equivalent to £124 million at 2007/08 prices.

10.51. The results of this work were supported by a more recent (2002) study valuing the low flow alleviation benefits at the river Mimram in the context of a programme of measures to tackle all low flow rivers in the Thames region.

10.52. From an ecological and amenity perspective, water quality and water quantity are inter-related, and both determine the ecological status of surface waters. Studies measuring the willingness to pay for improvements in the ecological status of surface waters are likely to capture changes related to both quality and quantity. As a result, the benefits of alleviating low flows are likely to be included in the results of some studies valuing changes in the quality of the water environment, such as NERA and Accent (2007, above).

Water resource development

10.53. Ofwat's 2004 price review assumed that the water companies would spend £3 billion in the period between 2005 and 2010 on addressing issues of water supply and demand. Various water company investment plans estimated the costs (30 year net present value) of measures to address water supply and demand at just over £0.20/m^3 for measures to develop groundwater resources; £0.20-1.20/m^3 for measures to reduce leakage; and just over £0.40/m^3 for development of reservoirs.

Evidence on service delivery

10.54. The above evidence suggests that the value of the effects of land use change on water resources can be estimated if it is possible to assess the implications for:

- The volume of water entering the public water supply and hence implications for the need for investments in water resource infrastructure and/or efficiency measures.
- Changes in the number and length of rivers experiencing low flows.
- Changes in the volume of water in the environment (measured in m^3).

10.55. However, this study shows that land use and management is only one factor in the availability of water resources with rainfall patterns, drainage systems, the location of aquifers, and distribution of water demand (linked to land use) all being critical factors. Therefore the extent to which land use scenarios are likely to affect the delivery of this service is difficult to assess, and even more difficult to quantify.

[141] ERM and Willis (1993)

Possible approaches to valuing the effects of land use change

10.56. The most feasible approach to valuation is likely to focus on the effects of land use change in alleviating low flows in rivers.

10.57. The benefits of alleviation of all low flows are estimated at £124 million annually in England and Wales. This estimate could be used to estimate the benefits of land use changes that result in fewer rivers experiencing low flows.

10.58. Flow rates are a determinant of the ecological status of rivers. The public's willingness to pay to achieve good ecological status should therefore include the effects of addressing low flows as well as other determinants of water quality. Thus the values elicited from the National Water Environment Benefits Survey[142] and used to assess the benefits of water quality improvements under the WFD in Section 3.4 above should be regarded as incorporating the benefits of low flow alleviation. Therefore care is needed to avoid double-counting when assessing the benefits of improvements in the water environment.

10.59. It is likely to be much more difficult to assess the effects of land use on the volume of water entering the public water supply and hence any effects on the need to develop new water resource infrastructure. However, if quantifiable, the capitalised benefits of any such changes can be valued at £0.20-£0.40 per m^3.

Management of flood risk

Benefits of service delivery

10.60. The benefit of tighter regulation of water is to reduce the probability or severity of future flood damage. This should in turn reduce damage to property and agricultural crops, as well as reducing stress and disruption for those affected. It may also reduce the need to invest in other measures designed to manage flood risk, such as engineered flood defences.

Valuation evidence

10.61. The economic benefits of land use change on the improved management of flood risk can be measured through:

- Reductions in the damage caused to property and agricultural crops, measured using market prices.
- The avoided costs of investments in flood defences. The costs of constructing and maintaining flood defences can be estimated in terms of £ per metre.

10.62. Defra provides project appraisal guidance for flood and coastal erosion risk management schemes, which includes guidance on economic appraisal (Defra, various dates). This provides general advice on the valuation of property, agricultural crops and other effects, and on the comparison of costs and benefits. More detailed guidance on valuing the benefits of flood and coastal erosion risk management schemes (the draft 'Multi-coloured Manual') was developed for Defra by the Flood Hazard Research Centre (FHRC) at Middlesex University.[143] Guidance on the valuation of environmental effects of

[142] NERA and Accent (2007)
[143] Penning-Rowsell *et al*. (2005)

flood and coastal erosion risk management schemes has also been developed for the Environment Agency.[144]

10.63. The Foresight Report on Future Flooding[145] presents a range of estimates of the economic damage caused by flooding under different scenarios, and the cost of engineered and integrated solutions (including natural responses) to address the problem. The value of benefits varies from one location to another according to local circumstances and, in particular, variations in the value of property at risk.

10.64. The report estimates that 1.74 million properties in England and Wales are at risk of river and coastal flooding, experiencing annual damage valued at £1 billion. Annual flood management costs designed to mitigate this damage totalled £439 million in 2003/04. Flooding and the damage it causes are forecast to increase as a result of climate change and other factors; this is expected to double the number of people suffering high flood risk by the 2080s, and to increase flood damage costs to between £2 and £20 billion annually under different flood management scenarios.

10.65. The Environment Agency estimates that more than one-tenth of land in England and Wales is at risk of flooding from rivers or the sea, affecting over 4.5 million people and 2.3 million properties. In Wales alone there are 170,000 properties and more than 300,000 people at risk. More than £230 billion worth of property and assets in England and Wales are located in floodplains. Currently, flooding and flood risk management in England and Wales cost around £2 billion a year. This includes annual expenditure of more than £600 million on flood and coastal defences, as well as average damage caused by flooding of £1,400 million annually.

10.66. Defra (2004) estimated the costs of flood damage under a range of scenarios involving different levels of investment in flood defences. The value of flood damage over 100 years ranged from £22 billion under the scenario involving highest levels of investment, to £83 billion under the "do nothing" scenario. The study found that the benefits of investment in flood defences far outweighed the costs – total costs of flood defences and flood damages ranged from £35 billion under the scenario involving greatest investment to £83 billion under "do nothing" scenario.

10.67. National estimates by Jacobs (2008b), in the Environmental Accounts for Agriculture, estimated that agriculture accounts for 14 per cent of flooding, which in turn results in annual flood management costs of £464 million and damage costs of £1 billion in England and Wales (at 2006 prices).

10.68. Some studies have estimated the value of freshwater wetlands and intertidal habitats in creating space for flood water, expressing these as values in £/hectare/year estimate. For example, RPA (2001) estimated a minimum value of £300/ha for flood defence services provided by washlands.

Evidence on service delivery

10.69. In order to inform an economic assessment, it is necessary to assess the extent to which changes in land use affect the:

a) Risk and severity of flood events, and the likely consequences in terms of damage to property and/or agricultural crops.

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[144] EFTEC (2007)
[145] Evans *et al*. (2004)

b) Flood risk and the need to invest in engineered flood defences.

10.70. Halcrow (2008) concluded that the effects of land use on flood risks are often marginal, localised and difficult to quantify.

10.71. The Environment Agency Flood Map has mapped the level of flood risk across England and Wales, which is categorised as:

- Low (annual risk of flooding from rivers or the sea of less than 0.1%).
- Medium (annual risk of flooding of 0.1-1.0% from rivers or 0.1-0.5% from sea).
- High (annual risk of flooding of 1.0% or greater from rivers, or 0.5% or greater from the sea).

10.72. However, while land use and management influence the generation and propagation of flooding at a local scale, this study found insufficient evidence on their impact at a large catchment scale. Nevertheless, it concluded that the differing responses from different types of land are important considerations and that there is a strong case for ensuring that land use and management changes are carefully targeted to help reduce water run-off in the wider catchment and to hold water back within floodplains as part of wider flood management.

Possible approaches to valuing the effects of land use change

10.73. The benefits of flood alleviation vary by location, and depend on variations in the value of property at risk and the degree of flood defence infrastructure in place. Accurate assessments of the benefits of land use change therefore need to assess and aggregate the effects on flooding and flood management activity responses at a local level.

10.74. However, where detailed, locally specific modelling of property damage is impossible, assumptions can be made to assess in broad terms the value of flood alleviation benefits under different land use scenarios. For example, it could be assumed that the costs of flooding vary in direct proportion to the area expected to experience flooding each year. If it were then possible to model the effect of land use change on the area expected to experience flooding, the expected changes in the costs of flooding and flood management could be estimated.

10.75. Under the baseline scenario, the annual cost of flood damage and flood defences in England and Wales in 2007 is estimated at £2 billion. By estimating the cost per hectare of land experiencing flooding, and by modelling the effects of land use change scenarios on the area affected, the benefits of different scenarios could be assessed.

10.76. A slightly more sophisticated approach might disaggregate costs by geographical region and/or broad land use band and examine changes in flood risk in each of the regions or land use bands identified.

10.77. The Environment Agency's National Flood Risk Assessment (NaFRA) supports its aim of reducing flood risk through targeted and prioritised investment. NaFRA provides a spatially differentiated and quantified picture of flood risk throughout England and Wales and can be used to calculate the economic damages caused to properties, the numbers, types and location of property affected and the demographic characteristics of the population at risk. NaFRA cannot be used at a generic national level and was not available to this study.

Storage of carbon in soils

Benefits of service delivery

10.78. The study was primarily concerned with the effect of land use on global climate regulation, rather than on micro-climate effects (such as protection against wind damage).

10.79. The benefits of climate regulation can be examined in terms of mitigation against global climate change. This results in:

- Reduced global damage costs.
- Less need to take alternative mitigation measures, reducing the costs of meeting emission reduction targets.

Valuation of benefits

Shadow price of carbon

10.80. There is now an established evidence base on the damage costs of carbon emissions and hence the value of emission abatement and carbon sequestration. Emission reductions and carbon sequestration can be valued by estimating the value per tonne of CO_2 equivalent (emissions) or per tonne of carbon stored.

10.81. Defra (2007) has published full revised guidance on how to value greenhouse gas emissions in government appraisals. This is for use in all policy and project appraisals across government with significant effects on carbon emissions. The guidance adopts the concept of the shadow price of carbon (SPC) as the basis for incorporating carbon emissions in cost-benefit analysis and impact assessments. This replaces all guidance referring to the social cost of carbon (SCC).

10.82. Defra proposes a shadow price of £25/tonne CO_2 equivalent to assess the value of greenhouse gas abatement in the UK. This is equivalent to £91 per tonne of carbon.

10.83. A given mass of carbon can be converted into CO_2 equivalent by multiplying by a factor of 44/12 (the atomic mass of carbon dioxide divided by that of carbon) = 3.67.

Value of carbon stored in woodland and forestry

10.84. The value of carbon sequestered in British woodland was estimated in a report to the Forestry Commission[146]. A range of values was applied for the social cost of carbon, reflecting the different conclusions of research regarding this issue:

- Applying a value of £6.67 per tonne, the authors estimated the net present value of carbon currently sequestered in woodlands in Britain at approximately £2.68 billion, based on a discount rate of 3.5 per cent.
- If a value of £14.67 per tonne of sequestered carbon is applied, the net present value is estimated at £5.92 billion, and an average value of £2,098 per hectare of woodland is estimated for all GB woodland.

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[146] Brainard *et al.* (2003)

- Applying a value of £70 per tonne, which was considered at the time to be the accepted value for the social cost of carbon, the net present value of carbon sequestered in woodlands in Britain was estimated at £28 billion, and the average value per hectare of woodland calculated at approximately £10,011.

10.85. Estimates of the value of carbon stored were given for different types of woodlands and for different regions.

Valuing England's ecosystem services – carbon sequestration

10.86. Jacobs (2008a) in a report on England's ecosystem services estimated the value of carbon sequestration by different land uses. The shadow price of carbon was used to estimate the reduction in damage costs elsewhere that result from carbon sequestration. Jacobs used the shadow price of carbon of £25/tonne CO_2 equivalent from Defra guidelines. Annualising the results from the Brainard *et al.* (2003) study for woodland and forestry, they estimated the annual benefits of carbon sequestration in England at £998 million per year.

10.87. These estimates for woodland and forestry far outweighed the estimated benefits from wetlands and peatlands, at £4.6 million and £5.0 million per year respectively.

Evidence on service delivery

10.88. This study mapped levels of soil carbon across England and Wales and described the effects of land use change on carbon storage in soils. However, it was not possible to quantify the effects of land use scenarios on carbon storage.

10.89. The amount of carbon present in different soils is a result of local hydrogeology, climate and historical land use. The study found that land use has a strong influence on the level of carbon flux (whether carbon is being lost or sequestered), and that land management is also a determining factor. In practice, knowledge about the natural cycles of carbon flux in soils and the impact of different land uses and management on it is relatively weak, although those land uses and activities that are clearly detrimental to the conservation of peat soils are well known.

Possible approaches to valuing the effects of land use change

10.90. The economic costs and benefits of changes in land use could be assessed by quantifying their overall effect on net rates of carbon storage in soils.

10.91. The benefits of carbon storage can then be valued using the currently accepted shadow price of carbon (£25/tonne CO_2 equivalent or £91/tonne carbon).

10.92. This service differs from the other three in being "open-ended" – no particular environmental limit or reference level is set against which changes in carbon storage can be valued.

Conclusions on Economic Valuation

Feasibility of valuing environmental services

10.93. The analysis above suggests that, using a benefits transfer approach, it is possible to identify economic values to assess the benefits of land use change with respect to the four key environmental services in question, albeit with varying degrees of certainty, comprehensiveness and robustness.

10.94. However, the principal challenge in valuing the benefits of land use change for environmental service delivery lies in quantifying the delivery of services and in modelling the effects of land use scenarios on levels of service. Scientific uncertainties, limitations in data and other influencing factors made it impossible to quantify the effects of land use scenarios on the provision of the four key services. These gaps and uncertainties mean that any attempt to model changes in service delivery would lack robustness and credibility. As a result, there is no basis on which to attempt to conduct an economic valuation.

Comparison of values of key services

10.95. While it was been possible to value the effects of land use on service delivery, the study provides a basis for comparing the likely magnitude of the value of changes in the environmental services in question. Such an assessment can be made by combining qualitative evidence of the strength of links between land use and service delivery with evidence of the economic value of each service.

10.96. Figure 10.1 compares the expected economic effects of land use change with regard to the four key services examined. The figure confirms the uncertainty in assessing the likely value of benefits for most services. However, some conclusions can be drawn:

- The economic benefits of changes in land use and management to improve surface water quality are potentially high.
- By comparison, the benefits of improving groundwater quality are likely to be relatively low.
- Any effects on water resources are expected to be limited, but where they do occur are potentially of significant value.
- Any effects on flood risk management have the potential to deliver significant economic benefits. While the effects of land use and management are uncertain and probably limited at the catchment scale, there is potential to deliver benefits through targeted change at the local level.
- The effects of land use and management on storage of carbon in soils are also subject to uncertainty but likely to be of high value.

10.97. While the focus of the analysis is on the potential for beneficial changes in land use and management to enhance environmental service delivery, the same conclusions are likely to apply in the opposite direction. For example, any adverse effects of land use change on surface water quality, flood risk or soil carbon levels could give rise to significant economic costs.

Recommendations for future research

10.98. Experience from this study suggests that, to assess the value of changes in environmental services brought about by land use change, the priorities for further research are to improve scientific understanding of the relationship between land use and the environmental services in question, and to develop methods to model and quantify these changes in service delivery in units amenable to valuation. By comparison, existing evidence of the value of these different services is relatively well developed.

Figure 10.3: Expected economic effects of land use change for key environmental services.

Environmental service	Relative value of changes in service delivery	Impact of land use/management on service delivery	Likely benefits of changes in land use/management
Regulation of surface water quality	**HIGH** Non-use benefits of achieving good status estimated at £1.2 billion annually. Additional benefits from reduced treatment of surface waters.	**HIGH** There is a strong link between land use and service delivery, especially in relation to changes in diffuse pollution arising from changes in management of developed land, arable and horticultural cropping and improved grassland.	**HIGH** The economic benefits of improved service delivery and the link to land use/management are both strong.
Regulation of groundwater quality	**LOW** Main value relates to the estimated £41 million cost of removing pesticides and nitrates from drinking water sourced from groundwater.	**UNCERTAIN** Data are not sufficiently fine-grained to establish an environmental limit for groundwater quality and partially as a consequence the relationship between land use and groundwater quality is not always clear.	**LOW** Economic benefits are expected to be relatively low and link to land use is uncertain.
Provision of water resources	**MEDIUM** Benefits of alleviation of low flows are estimated at £124 million annually in England and Wales. There are additional potential benefits through increases in water available for the public water supply.	**LOW** Current evidence suggests a weak link with land use and land management, although future research may provide new evidence. There is a stronger link to demand for water on developed land (not strictly a change in land use or management).	**LOW** Current evidence suggests that the effects of land use and land management change on water resources will be of limited significance.
Management of flood risk	**HIGH** Flooding and expenditures designed to reduce it give rise to annual costs of £2 billion in England and Wales.	**LOW/MEDIUM** Flood Generation – weak effect of land use and management at catchment scale (though there is uncertainty). Stronger effect at a local scale. Flood Propagation – land use and management have a stronger role to play in relation to storage of flood water in floodplains. Avoiding further development in floodplains is also very important.	**MEDIUM** The value of the service is high. Changes in land use and management could have a significant influence on flood risk at the local level, with potential to deliver local benefits. Benefits are uncertain at the catchment scale but likely to be limited.
Storage of carbon in soils	**HIGH** The value of carbon stored in woodland and forestry soils has been estimated at £1 billion annually. Using the shadow price of carbon, net storage of carbon can be valued at £25 per tonne CO_2 equivalent.	**HIGH/UNCERTAIN** There is potentially a strong link between land use/management and levels of soil carbon but a current lack of evidence on precisely which forms of land use and management are most beneficial.	**HIGH/UNCERTAIN** The potential value of changes in soil carbon is high, and land use could have an effect, though this is subject to uncertainty. If they can be quantified, the benefits can be valued using the SPC.

11. Relationships with other environmental services

11.1. So far this report has considered four environmental services most relevant to the Environment Agency's remit. As noted in Chapter 2, Defra is using the ecosystems approach to take a more integrated approach to policy development and delivery. This approach uses the framework of environmental services put forward by the Millennium Ecosystem Assessment (MA) which distinguishes between 31 different services (defined in Appendix 2), categorised under four headings:

- Provisioning services – the products obtained from ecosystems.
- Regulating services - benefits obtained from the regulation of ecosystem processes.
- Cultural services - the non-material benefits people obtain from ecosystems.
- Supporting services - those necessary for the production of all other ecosystem services.

11.2. All the objectives of environmental and land use policy being pursued in the UK are described by these MA services, although in some cases the terms used in the MA are not the familiar ones used in the UK and in other cases, environmental policy objectives can be seen as a combination of separate MA services.

11.3. Biodiversity is a case in point. Biodiversity is not identified as a single service by the MA but instead can be seen as a product of ecosystems as a whole. Key benefits derived from biodiversity, such as genetic diversity, aesthetic appreciation of wildlife and photosynthesis are covered by the MA. However, the importance of biodiversity as an environmental policy goal and an indicator of the state of other aspects of the environment means that it deserves special scrutiny. There are also important functional links between biodiversity and the four key services. This chapter therefore examines the relationship between biodiversity, land use and key services, after which other environmental services are briefly examined.

Biodiversity

11.4. Biodiversity is defined as "*the variability among living organisms from all sources including terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part*"[147]. However, in policy terms a key focus is the distribution of the natural and semi-natural habitats that represent the natural diversity of species and communities, as well as species protection.

Mapping the spatial extent of biodiversity

11.5. There are several ways in which the distribution of natural and semi-natural habitats can be mapped.

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[147] United Nations Environment Programme (1992)

- The areas of these habitats that are judged to be of national importance are designated as SSSIs and these sites provide a ready way of identifying the location of nationally important biodiversity for the purposes of this study[148].

- The location of priority habitats identified for the UK's Biodiversity Action Plan (BAP) were mapped, with GIS data for England identifying individual sites, however it proved impossible in the time allowed to assimilate the BAP priority habitats data into the one-km^2 tile format used by this study. Spatial data on the BAP priority habitats in Wales is not defined at a site boundary level, but rather as indicative areas where each priority habitat is considered significant.

- There is growing interest in the concept of ecological connectivity at a landscape scale, in which corridors and clusters of habitats will aid the movement of species responding to changing climate zones. Work by Natural England and the Countryside Council for Wales is ongoing to map these areas across England and Wales[149] and there are a number of regional and sub-regional projects to develop the concept of coherent networks of sites (such as the BRANCH study in the South East of England and the ECONET project in Cheshire). It is not anticipated that definitive national maps of connectivity will be produced, as this varies with the habitats and parameters used. There was insufficient spatial data to assess this aspect of biodiversity.

11.6. Although it is a simplistic way of portraying the spatial distribution of biodiversity, land designated as SSSI is used here to examine how this service relates to land use and the four key services covered by this study. This is a narrow representation of biodiversity, focussing on the most diverse but rare communities, and it hugely under-represents the totality of biodiversity. Designated sites represent only one policy measure to conserve and enhance biodiversity. Nevertheless, they represent the only way in which priority areas for biodiversity could be assessed spatially here. Figure 11.1 shows the proportion of each one-km^2 tile designated as SSSI. The greatest density of SSSIs occur in extensive tracts of semi-natural habitats in parts of the uplands of Wales (for instance Snowdonia) and England (for instance the North York Moors) , and in areas of lowland heathland (such as the New Forest and Breckland). Lower densities of SSSIs occur throughout England and Wales, including a number of rivers which can be seen as pale green linear features.

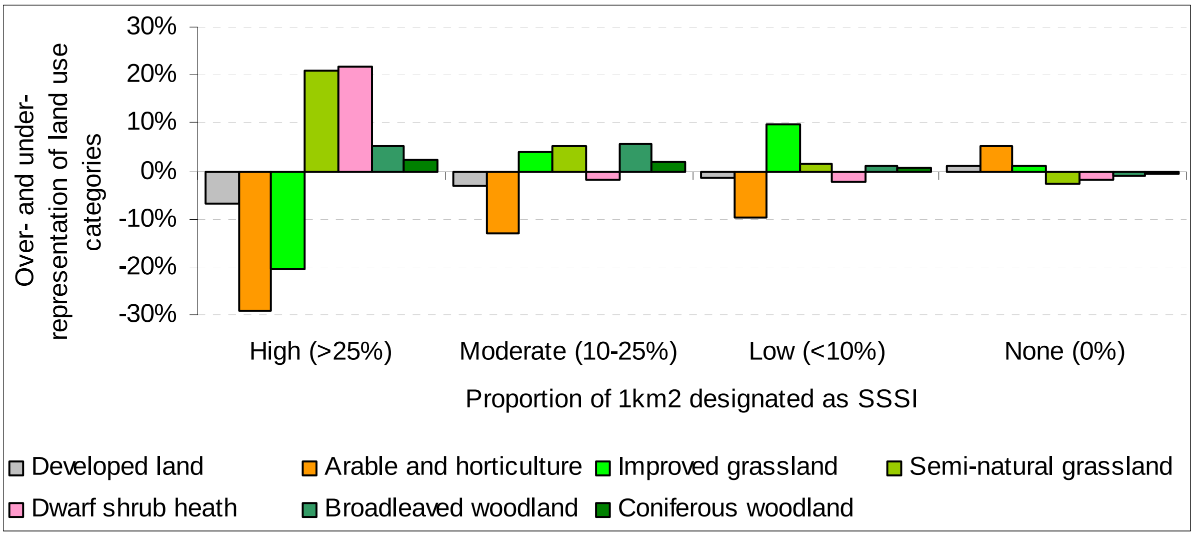
11.7. There was no scope in this study to examine in detail the way that environmental limits might be applied to the current provision of biodiversity. However, in England, the Government has a target to secure 95 per cent of SSSIs in favourable or recovering condition by 2010[150]. In Wales, the Assembly Government has an equivalent target to have 95 per cent of statutory sites managed favourably by 2012. Natural England and the Countryside Council for Wales are monitoring the condition of SSSIs to record progress against these targets. The current proportion of SSSIs in England in favourable or recovering

[148] Sites of European importance are designated under the EU Habitats Directive as Special Protection Areas and Sites of Conservation Importance and sites of international importance are recognised under international treaties.
[149] Including work by Forest Research (www.forestresearch.gov.uk/fr/infd-69plj2) and Dr Roger Catchpole (www.rogercatchpole.net)
[150] This was previously covered by one of Defra's Public Service Agreement (PSA) targets and is now included within the new interdepartmental PSA delivery agreement (No 28) to "Secure a healthy natural environment for today and the future".

condition is 86 per cent, and in 2003 the Welsh estimate was that 47 per cent of sites met this target.[151]

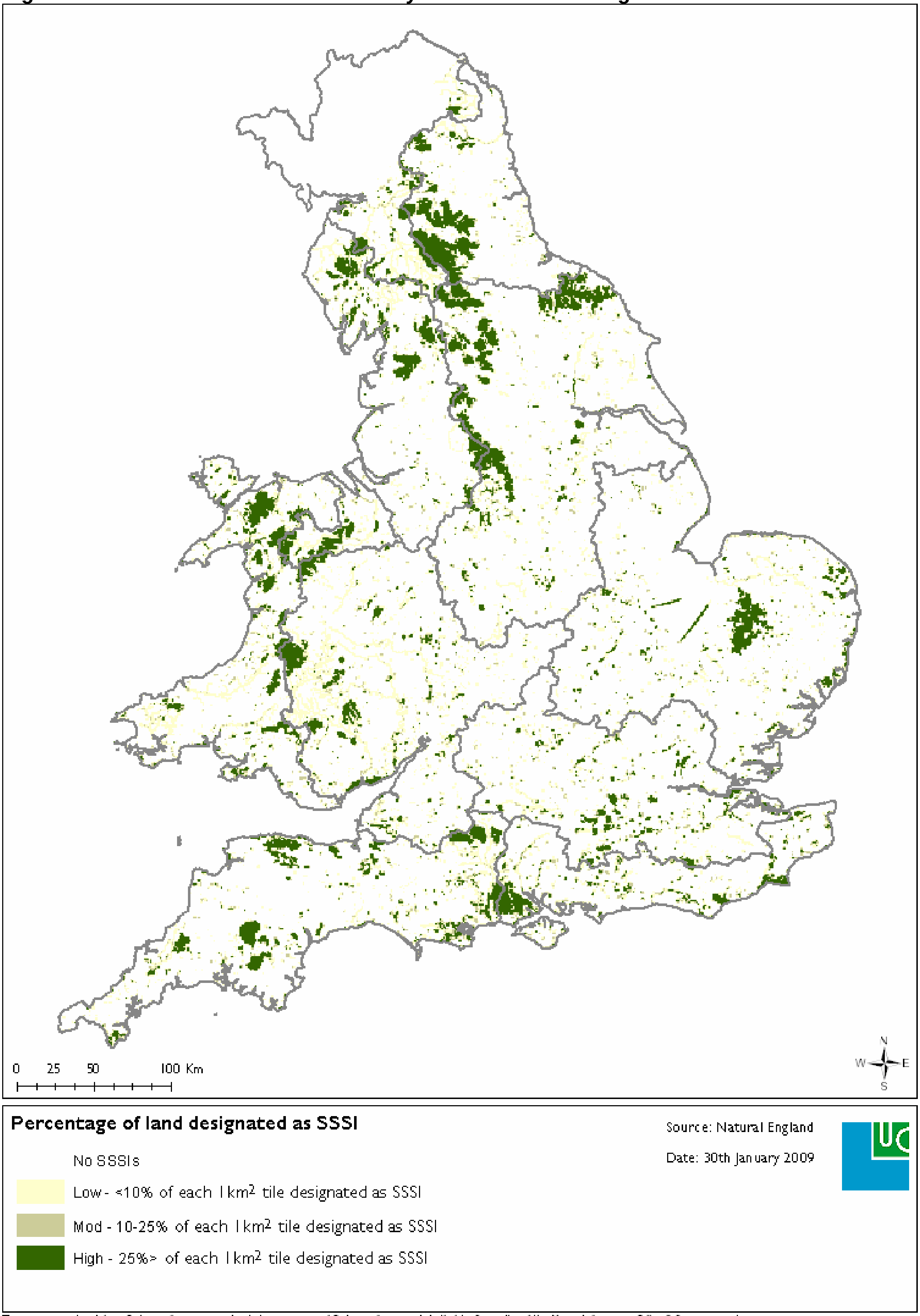
11.8. Figure 11.2 uses the method adopted in Chapters 6 to 9 to show how land use is associated with areas with different proportions of SSSI designation. It shows that areas with highest levels of SSSI designation (above 25 per cent by area) tend to be dominated by dwarf shrub heath and semi-natural grassland and, to a lesser extent, broadleaved woodland. Few of these areas are dominated by arable, improved grassland or developed land. Improved grassland is more significant as a dominant land use in areas with low and moderate levels of SSSI designation. These results are as expected, showing a strong link between biodiversity value (as portrayed by the location of SSSIs) and the presence of semi-natural habitats where human interventions are less intensive.

Figure 11.2. Under- and over-representation of land use categories in relation to the density of land designated as SSSI.



[151] CCW (2004)

Figure 11.1. The distribution and density of SSSIs across England and Wales.



11.9. Turning to the relationship between biodiversity and delivery of the four key services covered by this study, Figure 11.3 shows how levels of failure of these services varies with the density of land designated as SSSI. Figures highlighted in bold show where levels of service failure are significantly more or less than is expected, compared to the density of SSSIs across all areas.

Figure 11.3. Proportion of one-km tiles containing different levels of SSSI that exceed the limit for different services.

Failure in service delivery	SSSI high (>25%)	SSSI mod. (10-25%)	SSSI low. (<10%)	SSSI none (0)
Poor or bad river water quality	8.2%	3.4%	9.5%	78.9%
High or moderate risk to water resources	**6.8%**	3.3%	8.5%	81.4%
High or moderate sensitivity to flood generation	8.5%	3.6%	11.0%	76.9%
High or medium flood risk	**10.8%**	**5.0%**	**12.4%**	**71.7%**
Soil carbon in top horizon greater than 10%	**34.6%**	**5.1%**	8.8%	**51.5%**
Total area of land	8.7%	3.5%	9.6%	78.3%

11.10. Notwithstanding the limitations of the data as a measure for biodiversity, the following conclusions can be drawn from Figure 11.3:

- Over England and Wales as a whole, nearly 80 per cent of one-km^2 tiles do not contain any land designated as SSSI (the bottom row and final column of Figure 11.3). As a result, the majority of areas failing each of the services occur on land that is not designated as SSSI.
- The strongest association is between SSSIs and soil carbon. Areas with the highest density of SSSI (more than a quarter of each one-km^2) are much more likely than expected from their overall distribution to have soil carbon levels in excess of 10 per cent (35 per cent of one-km^2 with more than a quarter SSSI, compared to nine per cent of all one-km^2 tiles with more than a quarter SSSI). This is due to the large areas of SSSIs found on the upland moorlands of England and Wales, which have large areas of peat soils.
- Risks of over-abstraction or low river flows are slightly less in areas with a high density of SSSIs (6.8 per cent compared to the 8.7 per cent). Conversely, levels of flood risk are slightly greater on all areas containing SSSI than expected (comparing the fifth to the bottom row in Figure 11.3). Because these differences are small, caution should be exercised in drawing conclusions. However, the lower risk to water resources may be linked to the high density of SSSIs in the uplands. The slightly higher flood risk may reflect the significant number of river SSSIs.
- Levels of failure for river water quality and high sensitivity to flood generation show no relationship with the density of SSSIs (percentages in the second and third rows of Figure 11.3 are broadly the same as the corresponding percentages in the bottom row).

11.11. As noted earlier, SSSI designation is only one aspect of biodiversity, but is the aspect for which there was best spatial data for this study. The main reason for the lack of clear associations between the presence of SSSIs and the four services is likely to be the relatively poor spatial resolution (one km^2) of the data.

11.12. However, at a finer scale (within individual parcels of land), close relationships between biodiversity and high levels of service delivery are likely. As the chapters on the individual services have shown, the innate characteristics and land management practices on semi-natural habitats (for instance lower levels of inputs and lower stocking densities) mean that their impacts on services are lower than for the more intensively managed land use types. High water quality, low flood generation and accumulation of soil carbon, in particular, are likely to be associated with habitats of high biodiversity value such as semi-natural woodland, dwarf shrub heath and unimproved grassland. Poor water quality and low river base flows are a threat to biodiversity. It is likely that these impacts would become evident at a finer scale of analysis.

Other services

11.13. The remainder of this report provides an overview of other principal environmental services, using the four-way framework developed by the Millennium Ecosystem Assessment (paragraph 10.1).

Provisioning services

11.14. The provision of water resource can be classified as a provisioning service (fresh water – see Figure 3.3) and was covered as one of the key services in this study.

11.15. The provisioning services also include the production of food, fibre and energy. Food production has historically been a primary objective for land use policy (for instance underpinning the Common Agricultural Policy). After a period of large surpluses in the production of many agricultural foodstuffs during the 1980s and 1990s (at an EU scale) when food production was not a public policy objective, concerns over food security in the face of growing global consumption and climate change are raising the profile of this provisioning service.

11.16. Land was the main source of fibre and conservable energy before fossil fuels took over this function during the industrial revolution. Now, concerns over the impact of fossil fuels on the climate are renewing interest in the production of plant and animal-based fibres and biomass crops.

11.17. Data on the provision of these services comes directly from land use data and from surveys of agricultural and forestry production (paragraphs 4.23 to 4.28), is regularly updated and is spatially detailed. The concept of environment limits does not apply directly to these services at a fine-grained scale, but issues of self-sufficiency and strategic surpluses of food and energy can be applied at a national level.

11.18. The provision of these services from land usually requires relatively intensive forms of land use such as arable cropping, with large areas of land given over to extensive agriculture, and intensive grassland management (but not necessarily, since gathering of wild food and harvesting timber from semi-natural woodland need not). The land management goals for producing these three services are not closely compatible with those of the four key services covered by this study.

11.19. There is thus a greater likelihood of incompatibility between land use objectives for food, fibre and energy and the four key services covered by this study and also with biodiversity. However, that does not mean that land uses that deliver high outputs of these commodities will inevitably fail to deliver other services. As noted earlier (paragraph 6.19), large areas dominated by arable and horticultural cropping are apparently providing good water quality despite the high inputs of pesticides and fertilisers. As noted earlier (paragraphs 7.33 and 9.22), biomass energy production from short rotation coppice (SRC) can contribute positively to flood risk management and the sequestration of soil carbon.

11.20. Nevertheless, appropriate land management will normally be the key to ensuring that the delivery of these provisioning services is compatible with other services.

Other regulating services

11.21. Regulation of water quality, management of flood risk and storage of soil carbon are all regulating services (soil carbon is an aspect of the MA service of climate regulation), covered in detail in this study.

11.22. Other MA regulating services include the control of air quality, soil erosion, disease and pest regulation and natural hazards. With the possible exception of disease and pest regulation, these services are often considered 'natural resource' services.

11.23. Air quality is regularly monitored across England and Wales and thresholds have been set for a range of pollutions[152] broadly equivalent to the compliance monitoring of water quality for the Water Framework Directive. Air quality is affected by point sources of pollution (particularly industrial emissions) and diffuse sources (such as road traffic) and is strongly affected by climatic conditions (such as levels of air movement and sunlight). Developed land is the primary source of air pollution, although livestock farming is a key source of methane.

11.24. Soil erosion is closely related to water quality (being both a source of pollution and a contributory factor), to flood risk and to storage of soil carbon. There is no established monitoring programme for soil erosion across England and Wales although monitoring of sediment levels in surface waters might be considered as a useful proxy measure. Similarly, there are no established environmental limits for soil erosion or quality that can be applied to all soils.

11.25. The other regulating services (pests and disease regulation and natural hazard regulation) have relatively little connection to the key services covered by this study or to different types of land use.

Cultural services

11.26. The cultural services include a wide range of aesthetic and experiential services and can be summarised as covering public recreation, education, cultural heritage, landscape quality and sense of place.

11.27. Measuring most of these services requires subjective judgement based on qualitative criteria (the exception being levels of public recreation and access which can be directly measured). The levels of provision of these services that are acceptable will be based on perceptions and societal values rather than the functioning of natural systems. Services such as landscape quality and sense of place are complex amalgams of a range of stimuli that are difficult to measure directly. Nevertheless, data is available on the condition of scheduled monuments (from English Heritage and Cadw) and assessments are made of landscape quality and changes in landscape character (for instance the Countryside Quality Counts assessments prepared for Natural England). But in general terms, data on the state of these services is less spatially detailed and

[152] UK Air Quality Objectives for protection of human health. See www.airquality.co.uk/archive/standards.php#std

more dependent on subjective assumptions than that for the regulating services.

11.28. Land use and management are critical factors in landscape quality, sense of place and cultural heritage and, in general terms, the intensification of land use and the replacement of historic and locally distinctive patterns of land use and practices with standardised forms have diminished the quality of these services. Features such as hedgerows and other traditional boundary types are also important in defining characteristic landscape types. As with biodiversity, semi-natural land use types and low intensity forms of management will generally contribute most to these cultural services and to the four key services. However, the spatial targeting of interventions may not necessarily coincide. For instance the location of interventions needed to maintain an iconic view or an archaeological feature may be completely different from those needed to enhance water quality or flood risk management, suggesting that conflicts may arise.

Supporting services

11.29. The supporting services cover the formation of soils, photosynthesis, primary production (assimilation of energy and nutrients by organisms) and nutrient and water cycling. All of these are essential natural processes underpinning the other services and all are closely involved in land use and management. None of these are routinely measured at any level of spatial detail across England and Wales although all of them, to a greater or lesser extent, are captured in measures of the provisioning and regulating services.

Conclusions on the relationships with other services

11.30. The following conclusions emerge from this chapter.

- The Millennium Ecosystem Assessment (MA) framework of environmental services has been adopted by Defra as the basis for the ecosystem approach. It can be easily applied to the UK's environmental and land use policy objectives, accepting that some policy objectives such as biodiversity are covered by several individual MA services.

- Biodiversity is a critical goal of land use policy and should be thought of as an overall product of ecosystems, rather than a single service. In the context of this study, the delivery of biodiversity is difficult to measure in a meaningful way. Analysis of the spatial association between the density of SSSIs (which is but one aspect of biodiversity, but the one for which spatial data exists) and the four key services covered by this study proved largely inconclusive, almost certainly because of the low resolution of the spatial data.

- At a finer spatial scale of individual land parcels, there is likely to be a stronger association between semi-natural habitats (such as semi-natural woodland, dwarf shrub heath and unimproved grassland) and the four key services, particularly water quality, low levels of flood generation and accumulation of soil carbon. Poor water quality and low river base flows are likely to have negative impacts on biodiversity and on the functioning of ecosystems as a whole.

- Although not analysed in detail by this study, there are likely to be similar positive associations between the four key services and other regulating services and the cultural services.
- Three of the provisioning services (food, fibre and energy) are associated with intensive land uses and there is a potential incompatibility with the four key services, most other regulating services and the cultural services. This incompatibility can be addressed by targeted land management measures to reduce the negative impacts of food, fibre and energy production.

12. Findings and conclusions

12.1. This chapter presents the overall findings of the study. It draws on the evidence from the preceding chapters to present and discuss key findings in relation to:

- gaps in evidence;
- the setting of environmental limits;
- the overall effects of land use and management;
- priority areas for targeted interventions;
- land uses and their scope for delivering multiple services.

12.2. The chapter then sets out 13 key conclusions to support the development of the Environment Agency's strategic policy towards land use in England and Wales.

Findings

The effects of land use on environmental services: Gaps in the evidence

12.3. This study explored the inter-relationship between land use and four environmental services of greatest concern to the Environment Agency, namely: regulation of water quality; availability of water resources; management of flood risk; and storage of carbon in soils.

12.4. This study found that knowledge about the influence of land use and management on the delivery of these four key services is patchy.

12.5. Whereas there is good evidence of the direct impact of point source activities on the delivery of the services, the impacts of more dispersed activities and subtler changes of management that occur across whole catchments is less clear. This lack of knowledge does not mean that these dispersed activities are not significant in their effects – it is just that their impacts are often difficult to distinguish from other background influences. Nevertheless there is growing understanding of:

- The effects of diffuse sources of nitrogen and phosphorus on water quality (paragraph 6.19).
- The measurable effect that land use and management can have at a local or small catchment scale on flood generation and, within flood and coastal plains, on flood propagation. The impact of land use and management on the nature of catchment-scale flood events is much less clear (paragraphs 8.14 to 8.17).
- The impact of land management activities on carbon flux in soils, which is the subject of much ongoing research.

12.6. The level of monitoring data available upon which to base research studies varies greatly between the services. Generally, there is good long-term data on water quality and, to a lesser extent, on water resources and flood risk management. Good data on carbon storage in soils, particularly in England, is lacking.

12.7. The complexity of natural systems means that, while it may be possible to model the theoretical impact of land use changes under controlled conditions, the outcomes in a real world situation are often difficult to predict. This applies to issues such as the impact of grazing densities on water infiltration, where the soil type and quality and rainfall characteristics are important factors. Similarly, the impact of different vegetation cover on groundwater recharge is complex, depending on factors such as topography, patterns of rainfall and the state of soils.

12.8. While research has examined the impacts of individual types of land use and management (for instance identifying the hazards to soil quality of outdoor pig rearing and potatoes and the emissions of carbon from drained peat), less research has been done on the effects of broader systems of land use on water and soil. Research is needed on different intensities of farming systems and on different woodland management regimes, where it is only by examining long-term trends and the combination of land uses that valid comparisons can be made.

Setting environmental limits

12.9. The methodology for this study sought to develop a simple pathway involving:

- definition and spatial mapping of service delivery against evidence-based environmental limits;
- analysis of land use and management and its potential effects on delivery of key services;
- identification of changes in land use and management to address failures in service delivery.

12.10. For this study, the most useful indicators of environmental limits for identifying the impact of land use and management on the four key services were:

- **Surface water quality**: The WFD ecological status of rivers provides an environmental limit (with bad or poor status exceeding the environmental limit) to guide land use and management interventions to improve surface water quality (paragraphs 3.36 to 3.40)**.** WFD data on the chemical status of rivers was insufficiently complete for this study but may provide a further indication of limits when more river stretches have been assessed (paragraph 3.41).

- **Groundwater quality:** The best indicator of groundwater quality for this study is the WFD chemical status of groundwater (paragraph 3.44 to 3.48). But this is not sufficiently fine-grained to establish an environmental limit for groundwater quality, to determine the suitability of different land uses (paragraph 6.5).

- **Water resources**: The WFD pressures and risks from abstraction and low flows on surface waters provides an indicative environmental limit for identifying impacts on water resources (with high and moderate risk exceeding the environmental limit) (paragraph 3.58). Again, the relationship between land use and groundwater resources is difficult to determine at the scale at which groundwater areas are monitored (paragraph 7.11).

- **Flood risk**: This was assessed at two levels: that of flood generation in the wider catchment where the Environment Agency Sensitive Catchments Study provides the best indicator of an environmental limit (with high and moderate sensitivity indicative of areas where land use potentially has most impact on flood generation); and flood propagation within river channels and across floodplains where the Environment Agency Flood Map identifies areas at risk of flooding (with Flood Zones 2 and 3 showing areas of greatest flood risk). Using these two sources in combination provides a helpful way of identifying how changes in land use and management are likely to contribute the most to reductions in flood risk (paragraphs 3.71 and 3.81).

- **Soil carbon**: Given the importance of soil carbon to climate regulation, any level of carbon loss, particularly from soils with a high carbon content, is unacceptable, making it easy in principle to set an environmental limit for soil carbon flux. However, there is no fine-grained spatial data to measure levels of carbon flux in the soil, and therefore no way of mapping an environmental limit for carbon losses and gains. Nevertheless, the spatial variation in soil carbon can be compared with land use and with knowledge about how land use and management affect soil carbon, enabling conclusions to be drawn about the likely impact of land use on soil carbon levels (paragraphs 3.88 to 3.94).

Effects of land use and management

12.11. Inevitably, the study found the relationship between land use and the functioning of natural systems to be complex, and the extent to which land use and management are a primary cause of impacts on these systems varies between the services. Differences between the key services covered by this study are as follows:

- **Regulation of surface water quality**: Land use, and particularly land management, is a primary determinant of water quality. A causal relationship between land use and the WFD ecological status of rivers is strongly suggested by the data used in this study (paragraph 6.12).

- **Regulation of groundwater quality:** The relationship between land use and groundwater quality is less clear because of the size of the groundwater areas that are monitored, and the time lag between changes in land use and management and the response of the chemical status of groundwater.

- **Availability of water resources:** Land use and management is only one factor in the availability of water resources with rainfall patterns, drainage systems, the location of aquifers, and distribution of water demand (linked to land use) all being critical factors (paragraph 7.11). Land uses that have a direct influence over water resource management are built-up areas with their inherently high levels of water demand; irrigated crops (particularly horticultural crops); and water storage reservoirs and upland moorland/blanket bog that play a critical role in the regulation of water resources. More generally, the WFD pressures and risks data for surface waters (with areas classified as high and moderate risk exceeding the environmental limit) provides a means of targeting where a positive contribution from land use is most needed.

- **Management of flood risk:** While land use and management can influence the generation and propagation of flooding at a local scale, there is insufficient evidence of their impact at a large catchment scale. Nevertheless, as with water resources, the differing responses from different types of land are important considerations (paragraph 8.14 onwards). There is a strong case for ensuring that land use and management changes are carefully targeted to help reduce water run-off in the wider catchment and to hold water back within floodplains as part of wider flood management.

- **Storage of soil carbon:** The amount of carbon present in different soils is a result of local hydrogeology, climate and historical land use. Current land use has a strong influence on the level of carbon flux (whether carbon is being lost or sequestered), and land management is also a determining factor (paragraph 9.13 onwards). In practice, knowledge about the natural cycles of carbon flux in soils and the impact of different land uses and management on it is relatively weak, although land uses and activities that are detrimental to the conservation of peat soils are well known.

Strengths in the links between land use and management and service delivery

12.12. In summary, this study demonstrates that at the national level:

- **Regulation of surface water quality:** There is good data on the environmental limits and a link can be drawn between land use and management and delivery of this service, particularly in relation to the risks of diffuse pollution arising from developed land, arable and horticultural cropping and improved grassland.
- **Regulation of groundwater quality:** Data is not sufficiently fine-grained to establish an environmental limit for groundwater quality and, partially as a consequence, the relationship between land use and groundwater quality is not always clear.
- **Availability of water resources:** There is good data on the environmental limits but land use and management is only one, and usually not the most significant, determinant in the availability of water resources. Demand for water by households and businesses creates a strong link between developed land and use of water resources and the use of reservoirs to store winter rainfall for summer use has a positive impact on this service. There is currently little evidence that other forms of land use and management have a significant influence on the availability of water, relative to the more significant factors of rainfall supply and public and industrial use.
- **Management of flood risk:** Data is available at the national scale on areas where land management change may have the largest impact on surface water run-off. There is also data on where flood risk from fluvial and marine flooding is highest**.** Whilst there is insufficient evidence of land use and land management impacts at a large catchment scale on flooding, there is a stronger case for targeting of land use and management at the local level, particularly on the scope for using land to store and reduce the speed of peak flows of floodwater.
- **Storage of soil carbon:** There is currently no spatial data on environmental limits and limited knowledge of how land use and management affect carbon in soils. Nevertheless, conclusions can be drawn on the inter-relationships between land use and management and the conservation of peat soils.

Priorities areas for land use or management interventions

12.13. The ecosystem approach, as well as other current policy approaches such as *Making Space for Water*, emphasise the need to look holistically at the way different environmental services combine to deliver multiple benefits. Equally, it is important to look at how failures in the delivery of these services occur together in the same areas, leading to ‘hotspots’ of service failures and challenges to address these through targeted interventions. An assessment can be made of how certain land uses and management practices are responsible for multiple impacts, and where positive changes in land use and management may deliver multiple benefits.

12.14. This section examines the 'co-location' of priority areas for each of the four services as measured by this study. In effect, it 'layers up' those areas where interventions need to be focussed to address the risk of service failures. These separate layers are built up as follows:

- Priority areas for water quality are those where the WFD compliance monitoring data show that the ecological status of rivers is bad or poor.

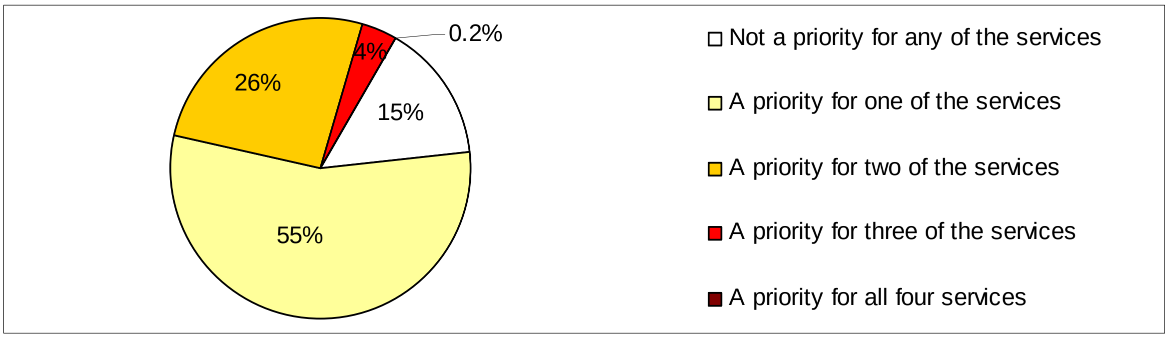
- Priority areas for water resources are those where the WFD pressures and risks assessments suggest a high and medium risk to river water resources from abstraction and low river flows.

- Priority areas for flood risk management are those at high or medium sensitivity for surface water run-off, potentially leading to flood generation, based on the Environment Agency's Sensitivity Catchment Study (but also including urban areas[153]), together with areas at high or medium risk of flooding, as defined by the Environment Agency's Flood Map.

- Priority areas for intervention to safeguard soil carbon are the areas where soils have an organic carbon content in the top horizon above 10 per cent. There is a lack of detailed data on the levels of stored carbon and on rates of carbon flux and as a result delivery against an environmental limit cannot be measured. But the data on carbon content does identify those areas where attention may be focussed to safeguard existing high levels of carbon in soils.

12.15. Figure 12.1 shows the proportions of one-km^2 tiles in England and Wales where one or more of these priority areas occur.

Figure 12.1: Proportions of one-km² tiles where interventions are a priority for one or more services.



12.16. This analysis shows that over three-quarters (85 per cent) of England and Wales lie in areas of priority for at least one of the services and nearly a third (30 per cent) lie in areas which are a priority for more than one service. However, the area where all four services justify priority intervention is small (only 0.2 per cent).

12.17. Co-location of these priority areas does not guarantee that land use or management interventions to address one service will automatically lead to

[153] Developed land was excluded from the Environment Agency's Sensitivity Catchment Study

benefits to all. The impact of measures must be properly assessed and targeted to optimise benefits.

12.18. Figure 12.2 maps the spatial distribution of these different levels of priority for intervention. Key conclusions from this map are:

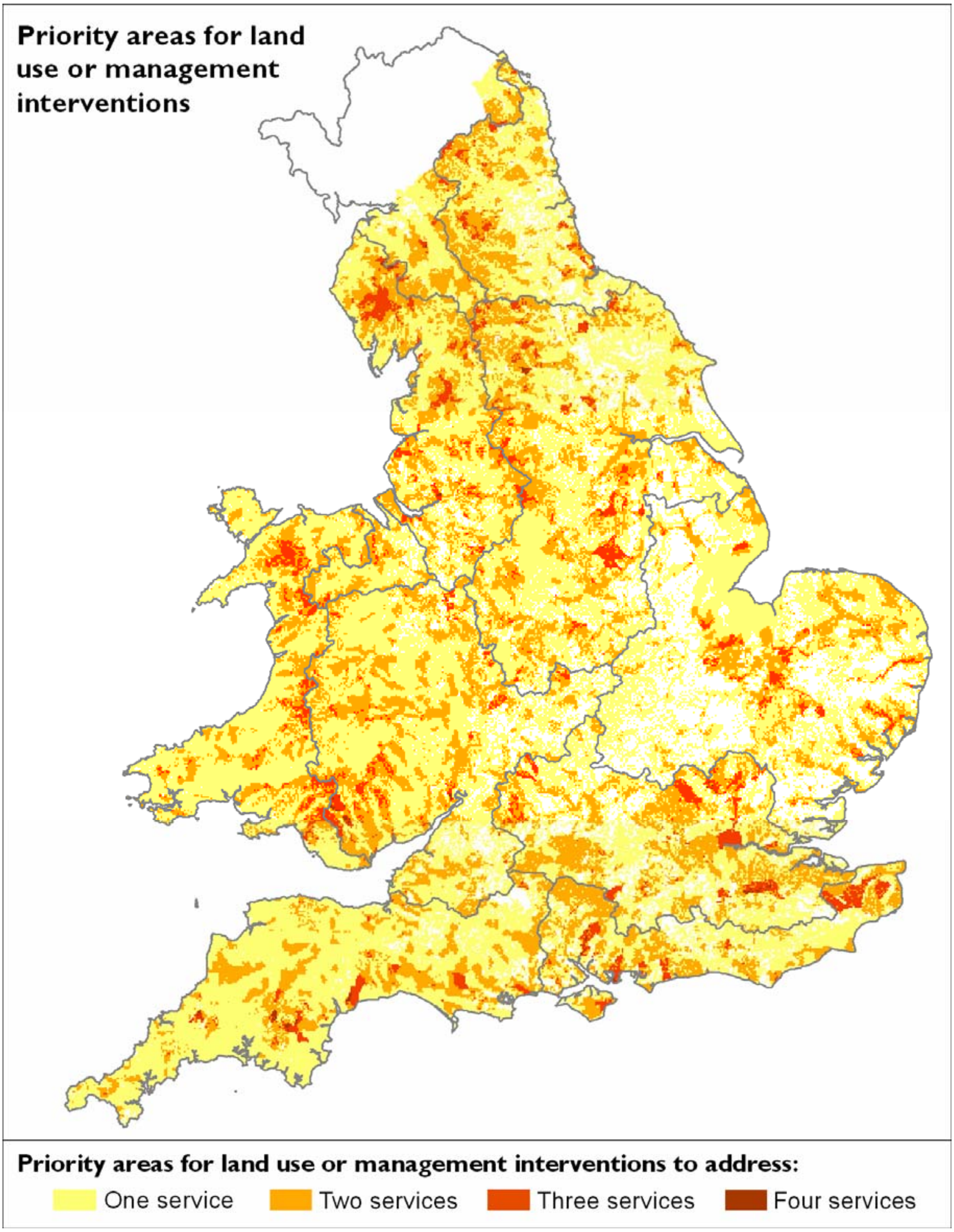
- Priority areas for action for the four services occur in all parts of England and Wales and there is a scattered pattern of relatively small areas where priority areas for the different services overlap, rather than large clumped areas.
- Areas where this study suggests there is little need for intervention in relation to failures or risks to the four services include the Tyne and Wear lowlands in north east England and the Bedfordshire and Cambridgeshire claylands in central England.
- Hotspots where this study suggests intervention is justified to address the failure or risks to several of the services include many upland areas such as the Pennines, Cumbrian Fells in the north west of England, Snowdonia in north Wales and the high ridges above the South Wales Valleys.
- Hotspots justifying intervention for several services also occur in lowland areas including the southern part of the Fens, the North Wessex Downs, the eastern half of the Chilterns together with adjacent areas of the South Suffolk and North Essex Clayland, and the North Downs.

12.19. The reasons for areas being shown as hotspots of intervention are likely to vary. Some of them occur in the uplands where issues such as high rainfall, steep slopes, high grazing densities and the use of sheep dip are causes of service failure or risk. Others occur in the lowlands where abstraction of water for public water supply and diffuse pollution of nitrates, phosphate and crop pesticides are significant.

12.20. A striking conclusion from this concentration of hotspots is that many of the protected landscapes are marked out as priority areas for several services. National Parks such as the Lake District, Yorkshire Dales, Snowdonia and Dartmoor and AONBs such as North Pennines, Forest of Bowland, North Wessex Downs, east part of the Chilterns and Kent Downs stand out strongly. This does not mean that there is a direct causal link between high landscape quality and the failure or risks to key services covered by this study. Rather it is an indication that these landscapes are placed under high expectations of service delivery and occur in areas under high levels of environmental stress. This is particularly the case for National Parks and AONBs in the uplands (where large areas of intensively managed grassland may have impacts on water quality and flood generation) and chalkland AONBs in the south east of England (where high levels of groundwater abstraction for urban water supply, combined with the dominance of arable cropping, lead to high levels of environmental stress).

12.21. Looking to the future, areas such as the South East that face the greatest challenge from climate change and population growth already have areas identified as having multiple priorities for intervention. The scope for addressing these challenges through changes in land use is likely to be constrained by increasing competition for the best quality land for food and energy production and, around existing urban areas, for development. In contrast, the climatic and economic changes facing uplands areas, particularly those in the north where rainfall is forecast to increase and agricultural production will continue to be marginal, may be less severe, increasing the scope for beneficial land use change.

Figure 12.2. Combined breaches of limits for ecological status of rivers, pressures and risks from abstraction and low flows on surface waters, flood generation and flood risk.



See paragraph 12.14 for an explanation of the metadata.

Land uses and delivery of multiple services

12.22. Overall, this study shows that there is a hierarchy of land uses that have the most to the least adverse effects on the services considered here. In order, those that are potentially most to least damaging are: developed land; arable and horticultural cropping; improved grassland; semi-natural grassland, woodland; wetlands, and upland dwarf shrub heath and blanket bog (see for instance paragraph 8.35).

Developed land

12.23. Developed land has the highest intensity of land use (paragraph 4.34). In 2001, 1.2 million ha in England and Wales (eight per cent of the land area) occurred within settlements with a population over 1,500 people. Within built-up areas half of the land area is under hard surfacing, with the proportion of land falling within domestic gardens ranging from a quarter in the Inner London authorities to half in the non-metropolitan authorities across England. The Generalised Land Use database shows a net change to developed uses of around 7,300 ha of land a year between 1985 and 1996, most of which was previously undeveloped. This rate is set to increase rapidly in the future with planned rapid urban growth.

12.24. Developed land is frequently a cause of the breach of environmental limits identified in this study and can affect service delivery in a number of ways:

- **Regulation of water quality**: Developed land is a source of diffuse and point source pollution. Common surface water pollutants include suspended solids, organic compounds, metals, ammonia, and substances exerting a biochemical oxygen demand (BOD), while for groundwaters pollutants include nitrogen (nitrate and ammonia), chlorinated solvents and metals. Typical sources of pollution include inadequate urban drainage leading to flushing of petro-chemicals and other pollutants and sewerage systems releasing sewage into water courses and groundwater (paragraph 6.16).

- **Availability of water resources:** Public water supply is responsible for half of water abstraction from non-tidal waters. Although in recent years increased water demand has been balanced by reduced water leakage, urban growth will lead to more water demand, with much of this growth in areas already suffering from water stress, particularly the South East of England (paragraph 7.20).

- **Management of flood risk:** Many urban areas are built within the floodplain. The high proportion of impermeable surfaces mean that levels of infiltration are lower than for any other land use. Fast removal of water through increased run-off simply accentuates flood peaks and exacerbates flooding downstream (paragraph 8.19).

- **Storage of soil carbon**: Most urban areas are not located in areas of peat soils, although it is important to ensure that any increase in water abstraction does not lower the water table in areas of peat soil (paragraph 9.16).

12.25. Changing the way developed land is managed, in the way resources are used and waste is created, can reduce these impacts. Green Infrastructure (GI) proposals offer the opportunity to introduce new land uses such as woodland and wetlands that can filter pollutants, improve water infiltration and potentially regulate flood flows. Strategic master planning that includes GI offers the opportunity to deliver multiple benefits for the water environment and wider public amenity (paragraph 6.39). Equally SUDS can be used to treat water with low levels of pollution, increase water infiltration and provide areas for temporary flood storage (paragraph 6.42). The way in which new development creates waste and impacts on flood propagation (for instance ensuring that development does not constrict or reduce the area of functional floodplain) can help ensure that environmental limits are not breached.

Arable and horticultural cropping

12.26. Arable and horticultural cropping occupies 37 per cent of the land on farm holdings in England and Wales but only 27 per cent of total land area. It dominates land use in the eastern parts of England which tend to receive the lowest rainfall. Overall, horticultural crops account for four per cent of the cropped area (paragraph 4.40).

12.27. These land uses can adversely affect service delivery and can be the cause of breach of environmental limits, although this study has shown that this is not always the case:

- **Regulation of water quality**: The two main sources of pollution from cropped land are fertilisers and pesticides (primarily as diffuse pollution occurring from misapplication and leaching). The majority of arable farms operate a nutrient surplus. Diffuse agricultural pollution is thought to account for 60 per cent of the nitrogen load in fresh water and 28 per cent of the total phosphorus load. Levels of fertiliser and pesticide (herbicides, fungicides and insecticides) applications are higher on arable and horticultural crops compared to grassland, as are levels of leaching, with higher levels of nutrient uptake under grassland. Equally, soil erosion from cultivated and unvegetated land increases surface water pollution, particularly from pesticides and phosphates that attach to and are transported by soil particles (paragraphs 6.18 onwards).

- **Availability of water resources:** Less than one per cent of total water abstraction in England and Wales is used for crop irrigation. But areas of highest irrigation tend to be in areas of lowest rainfall (the east of England). In East Anglia abstraction for spray irrigation can average 20 per cent of all abstraction in summer. Tall plants with large surface area, such as maize, intercept significant amounts of rainfall while dense and growing crops have the higher levels of evapotranspiration, both reducing the amount of water that infiltrates into the soil (paragraph 7.24).

- **Management of flood risk:** High levels of land drainage, low levels of soil organic matter, erosion of exposed soils and compaction from machinery all contribute to high levels of water run-off. Crops most likely to give rise to high levels of run-off are those with fine seedbeds exposed to winter rain (such as winter wheat), those with large areas of bare soil (such as maize) and row crops (such as potatoes) (paragraph 8.20). In terms of flood propagation, much of the best quality arable land has been removed from the functional floodplain by past land drainage schemes. Where flooding still occurs, this land use offers little hydraulic resistance and does little to slow the flow of water (paragraph 8.41).

- **Storage of soil carbon**: Sixty per cent of peat used in the horticultural industry has been extracted in the UK (paragraph 9.16). Generally arable and horticultural cropping does not take place on peaty soils but there are notable exceptions – the Fens, the Humberhead Levels and the Lancashire

Mosses. In these areas drainage of the peat combined with cropping has led to high carbon losses through wind blow and oxidation: in some areas surface levels have dropped by several metres over the last 150 years. These losses will continue so long as low water levels are retained (paragraph 9.18).

12.28. On most cropped land, targeted small-scale changes in land use such as the creation of rough grass or woodland buffers across steep slopes or beside rivers, and improvements in land management, such as more precise application of inputs or the use of minimum tillage techniques, can enable continued arable and horticultural cropping that does not breach environmental limits. An exception to this, where this land use is fundamentally incompatible with the storage of soil carbon, is where arable and horticultural cropping takes place on peat soils.

12.29. **Short rotation coppice (SRC):** Short rotation coppice is included here as it is most commonly grown on past arable soils. Compared to arable production SRC has little adverse effect on water quality as inputs are minimal other than during the first year of establishment. Indeed belts of SRC can act as a pollutant trap. SRC may also play a role in flood regulation, by encouraging water infiltration and by slowing the rate of flow across the floodplain, but it must be located in the right area. However, it should not be planted in areas of water shortage as it has very high rates of evapotranspiration, especially in the case of willows.

Improved grassland

12.30. Improved grassland covers a quarter of the land area of England and Wales (paragraph 4.44). It is the dominant land use in the lowland areas of Wales and the western parts of England and is a strong component of the uplands of England and Wales. These areas receive high levels of rainfall and this influences the response of land to the environmental services. It includes both permanent pasture and grass leys that receive high levels of inputs and grazing. This land use can result in failures in service delivery and the breaching of some environmental limits:

- **Regulation of water quality**: Overall levels of nitrate and pesticide pollution are significantly less than those associated with arable. But this land use still causes breaches of environmental limits for water quality. Sources of pollution include the spreading of animal slurries and pesticides (animal health products such as sheep dip). Ploughing of long-term grassland can lead to a flush of nutrients that cannot be taken up by growing vegetation (paragraphs 6.24 to 6.28).

- **Availability of water resources:** The structure of soils under grassland tends to be better than under arable and infiltration levels can be up to six times higher on long-established permanent grassland, aiding aquifer recharge. But grazing levels compact the soil and surface run-off can be 12 times greater on over-grazed compared to under-grazed grassland (paragraph 7.29).

- **Management of flood risk:** The above points equally relate to the management of flood risk, contributing to flood generation. Increasing use of the New Zealand grazing systems for dairy cattle on intensively managed grasslands, where cattle are kept out all year and strip-grazed, is likely to increase run-off levels in the critical high rainfall winter period. Outdoor pigs can be particularly damaging to soil structure when kept on unsuitable soils (paragraphs 8.24 and 8.25). In terms of flood propagation, as for arable, many areas of improved grassland have been removed from the functional floodplain through land drainage schemes and offer little hydraulic resistance to flood water (paragraph 8.42).

- **Storage of soil carbon:** The accumulation of soil carbon is typically lower than for dwarf shrub heath and for woodland and, where the land is periodically cultivated, is also likely to be less than for semi-natural grassland, although levels will generally be higher than under the regular tillage associated with arable production. (paragraph 9.23). Also much less carbon is returned to the soil from slurry (often applied to improved grasslands) than from farmyard manure (more often applied to semi-natural grasslands).

12.31. Overall, the extent of impacts from this land use varies greatly with the intensity of land management activities. Levels of land drainage and agricultural inputs, density of grazing, and the ways in which these are managed are all important. It is therefore not the case that improved grassland, as a land use type, inevitably leads to failures in service delivery. Instead targeted improvements in management activities, such as increasing water infiltration to reduce run-off and reduced fertiliser applications, can addresses failures of several services.

Semi-natural grassland

12.32. This land use occurs in large areas of the uplands of England and Wales and in smaller areas in the lowlands, usually on land considered unproductive for agriculture (paragraph 4.49). According to the Countryside Survey 2007 it accounts for 16 per cent of the land area (14 per cent in England and 23 per cent in Wales). The intensity of land use varies meaning that land management activities are important in determining the impacts of this land use type. Where grazing densities are low and where land is not artificially drained, this land use can contribute very positively to the four services:

- **Regulation of water quality**: In many cases no fertilisers (organic or inorganic) will be applied, Unimproved grasslands can therefore provide useful 'buffers', protecting water resources from more intensive land uses, The main issues will be the misapplication of organic manures and pollution from sheep dip. Unimproved grasslands are common in the uplands where high rainfall and steep slopes increase the risk of surface run-off and leaching of pesticides (paragraph 6.29).

- **Availability of water resources**: These grasslands tend to be most common in areas of high rainfall. As for improved grasslands, grazing levels are a key determinant of water infiltration (paragraph 7.29).

- **Management of flood risk**: The level of water infiltration will also affect flood generation. Semi-natural grassland can generally be expected to have the lowest grazing levels and therefore the lowest levels of soil compaction amongst the grasslands. In terms of flood propagation most of the few remaining areas of semi-natural grassland in floodplains are likely to fall within the functional floodplain (for instance the extensive areas of wet grassland in the Somerset Levels and Moors, the coastal plan of the North Kent Marshes and remnant areas within the Broads) (paragraph 8.43). Indeed, the biodiversity value of these habitats is dependent on high water tables and shallow winter flooding.

- **Storage of soil carbon:** Permanent grassland gives rise to higher levels of soil carbon than arable because of the greater volume of root biomass in the soils and the accumulation of organic matter in the absence of cultivation**.**

12.33. Semi-natural grasslands, if appropriately managed, can make positive contributions to the delivery of all four services considered here.

Woodland

12.34. Woodland covers some 9.2 per cent of the land area of England and Wales (paragraph 4.56). Approximately half of this is broadleaf woodland, 30 per cent conifer, with the remainder being mixed woodland and woodland open space. Large blocks of conifer woodland occur in the uplands of Wales and England (and in a few lowland areas) whereas broadleaved and mixed woodland is distributed more evenly and in smaller blocks. As with dwarf shrub heath, the intensity of land use tends to be low and soils generally undisturbed, meaning that woodland can be a positive contributor to the delivery of the four services:

- **Regulation of water quality:** Semi-natural broadleaf woodland can bring positive benefits for water quality. It will generally receive no artificial additives and can act as a sink for nutrients draining off adjacent land. Commercial conifer plantations, on the other hand, may have detrimental effects. They may receive nutrient additives during the establishment phase and clear felling operations can lead to nutrient leaching, both through soil disturbance and the absence of vegetation to take up released nutrients. Drainage instigated at planting can have a long-term impact, speeding the removal of water. Sediment loss can also occur, although best practice should avoid this. Whole tree harvesting has been shown to reduce the nutrient status of forest soils (paragraph 6.31).

  Large stands of conifers may also contribute to soil acidification by encouraging the deposition of sulphurs and nitrogen held within precipitation as a result of the burning of fossil fuels. The coincidence of commercial forestry plantations with areas worst affected by acidification (Cumbria, the Pennines and Central Wales) partly reflects the fact that base poor soils in these areas are unable to neutralise the large quantities of acid pollutants they receive (paragraph 6.33).

- **Availability of water resources:** Trees have high levels of water use and therefore can adversely affect groundwater recharge. Conifers lose between 25 and 45 per cent of annual rainfall by interception and an additional 300 to 350 mm due to transpiration. The equivalent figures for broadleaves are 10-25 per cent and 300-390 mm. In the uplands, at the catchment level, the additional water used by a complete cover of mature conifer can lead to a 15-20 per cent reduction in stream flow. These impacts can be greater in the lowlands, where a conifer plantation can reduce the annual volume of aquifer recharge by 70 per cent or more compared to grass. By comparison the impact of broadleaves is much less and some species in certain soils may actually increase the volume of groundwater recharge (paragraph 7.33).

- **Management of flood risk**: By the same token, woodland cover plays a valuable role in reducing flood generation by reducing surface water run-off (paragraph 8.31). Woodland, in appropriate locations, can help mitigate flooding by slowing surface water run-off and encouraging infiltration (for instance as woodland belts in upper catchments) and slowing flood flow, and providing temporary flood storage areas (for instance as wet woodland in floodplains) (paragraph 8.45).

- **Storage of soil carbon:** The long lifespan of trees, along with the relatively low disturbance of woodland soils, which receive high levels of organic matter from leaf fall and dead wood, make woodland soils an important store of carbon. However, afforestation of peat soils in the uplands can lead to major losses of soil carbon through increased soil aeration and evapotranspiration. The way in which conifer plantations in these situations are restored to peat bog and dwarf heath can have a considerable impact on carbon flux. Research suggests that ring barking trees, but leaving them in situ, potentially maximises soil carbon storage during this process of change (paragraph 9.31).

12.35. There are clear differences between broadleaf woodlands and coniferous plantations in service delivery. Broadleaf woodlands can help water purification, the build-up of soil carbon, reducing run-off and regulating waters within the floodplain. In certain circumstances they may also assist aquifer recharge. They therefore bring positive benefits to service delivery. By comparison conifer plantations may contribute to soil acidification, may lead to increased run-off during establishment and clear felling and may significantly reduce groundwater recharge. They can, however, reduce run-off (flood generation) during their growth phase and do assist in the build-up of soil carbon. In addition, there may be biodiversity benefits.

Dwarf shrub heath, fen, marsh and bog

12.36. This land use covers 4.6 per cent of the land area of England and 10 per cent of Wales (paragraph 4.53). It is concentrated in the uplands, where it occurs in large areas. It also occurs on lowland heaths and as wetland habitats in small areas across England and Wales. The intensity of land use is generally low. As a result, where land management ensures that this land use is in good condition, it can make a positive contribution to services, especially that of carbon storage:

- **Regulation of water quality:** There is a coincidence between this land use and areas of high water quality, reflecting the general lack of nutrient inputs. But degraded areas of dwarf shrub heath and blanket bog (where vegetation has been damaged by burning or overgrazing or the water table has been lowered by drainage) can pose a risk through increased soil sediment wash or turbidity from eroding peat, potentially threatening aquatic life and requiring filtration of water before it is used for public water supply (paragraph 6.30). Nevertheless, these risks to water quality are lower than those posed by improved grassland and arable cropping.

- **Availability of water resources:** Here, the high levels of organic material in the underlying soils, especially peats, absorb water during periods of high rainfall and release it slowly helping to regulate river flows. Nevertheless, where the land has been drained (with the use of grips cut deep into the peat) water is shed at a much greater speed. In addition, where peat is eroded as a result of overgrazing, peat wash into storage reservoirs can lead to a reduction in water storage capacity (paragraph 7.31).

- **Management of flood risk**: For the same reasons as above, these organo-mineral and peaty upland soils play an important role, when not drained, in storing large amounts of water for 'slow release'. These upland areas are therefore important regulators of water flows, although once saturated water will run straight off leading to the rapid swelling of upland rivers (paragraph 8.26).

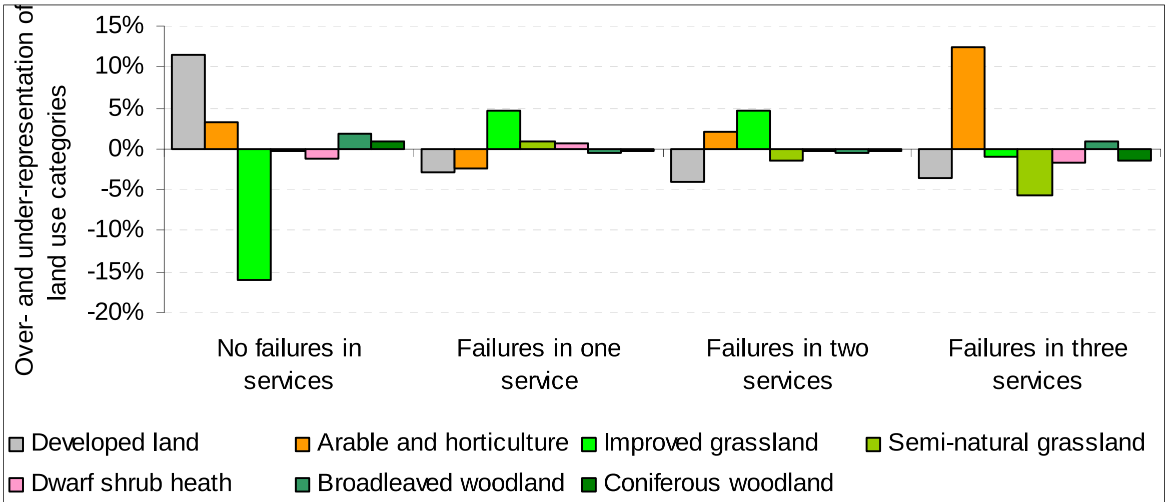
- **Storage of soil carbon**: When in good condition, these habitats growing over peat soils have the ability to accumulate large amounts of carbon – up to 0.7 tonnes per hectare per year - more than a typical woodland in the UK. But these soils can become a source of carbon release if degraded, with carbon lost in various forms including dissolved organic carbon and CO_2, as a result of drainage, burning, and erosion from high animal grazing numbers. Indeed, it is estimated that many areas of drained and burnt peat are currently releasing more carbon than is being sequestered (paragraphs 9.28 to 9.28).

12.37. Clearly, the state of the peat and organo-mineral soils that underlie this land use is of critical importance. Where these soils have been drained (a product of land management), erosion and colouration of water results, the drainage responses to rainfall and snowmelt are faster (diminishing long-term release of water to rivers and increasing flood generation) and soil carbon is quickly mobilised and lost. Under these circumstances of land management, the environmental limits of all four services are likely to be breached. Yet if appropriately managed these habitats are a source of pure water, help regulate water flows and are vital carbon sinks of national importance.

Combined levels of service failure and land use

12.38. Figure 12.3 analyses the associations between the main land use types and high and moderate breaches in environmental limits for the three services (excluding soil carbon for which there is no suitable measure of an environmental limit), using the same methodology as that used in Chapters 6 to 9.

Figure 12.3. Under- and over-representation of land use categories in relation to combined high and moderate breaches of environment limits for ecological status of rivers, abstraction pressures on rivers, flood generation and flood risk.



12.39. Figure 12.3 needs to be interpreted cautiously. Firstly, it must be remembered that an association between a land use and delivery of a service does not necessarily imply a causal relationship. Secondly the figure portrays a combination of different associations which may act to cancel each other out.

12.40. As a result of these factors, many of the clear trends in association between land use types and delivery of services do not appear when the services are combined. Indeed, some of the patterns shown in Figure 12.3 appear to be contrary to the conclusions reached in relation to the impacts of different land use types. Figure 12.3 shows that developed land is associated with fewer failures of the three services than one would expect, and it shows only a slight trend for dwarf shrub heath, semi-natural grassland and woodland to be positively associated with low service failures. However, the figure does show a strong association between arable and horticultural cropping and areas that breach the environmental limits for all three services.

12.41. The overall conclusion from Figure 12.3 and the preceding section is that links between land use types and combinations of service failures are complex. Other factors such as rainfall, topography, patch size and underlying geology are often as, or more, important than land use. The way in which land is managed can strongly influence the response of a particular land use, with issues such as land drainage, the intensity of inputs and the way they are applied being particularly important.

Conclusions

12.42. The conclusions arising from this study are arranged under 13 headings as follows:

1. Application of the concept of ecosystem services
2. The value of environmental limits
3. The importance of spatial data
4. A hierarchy of land uses affecting service delivery
5. Policy interventions in land use and management
6. Circumstances where failure in a single service justifies large-scale land use intervention
7. Circumstances where the multiple benefits to different services justify large-scale land use intervention
8. Changes in small-scale land use and land management to achieve improvements in single or many services
9. The importance of spatial targeting and fine-grained knowledge
10. The role of protected landscapes in service delivery
11. How drivers of change will influence future service delivery
12. The potential value to society of improvements to services
13. Strategic approaches for delivering multiple benefits

1. Application of the concept of ecosystem services

12.43. This study adopted the principles set out in Defra's Action Plan for embedding an ecosystems approach in environmental policy.[154] It applied these to four core areas of the Environment Agency's remit (paragraph 3.3) which match closely with the Millennium Ecosystem Assessment's (MA) framework of ecosystem services. These four key services are the regulation of water quality (one of the MA regulating services), provision of water resources (one of the MA provisioning services), management of flood risk and the storage of soil carbon (both included in the MA regulating services).

12.44. The study focussed on the role that land use and management play in determining the state of these four services. By comparing the delivery of each of these services at a common spatial scale and by using a common

[154] Defra (2007)d

methodology to relate these to dominant land use types, this study has shown how land use acts on these services separately and in combination, clearly showing 'hotspot' locations where land use contributes to multiple-failures of service delivery.

12.45. These findings suggest that the concept of ecosystem goods and services is highly relevant to core areas of the Environment Agency's work, both to support an integrated approach for development of the Agency's own policy on land use, and also to provide a common platform of evidence for comparison with the work of other agencies such as Natural England and the Countryside Council for Wales.

2. The value of environmental limits

12.46. This study used the pressure-state-response model and concept of environmental limits (paragraph 3.15) and applied these spatially at a scale of one-km^2 across England and Wales (based on an approach used in part of the East of England – paragraph 3.26). The concept of environmental limits is increasingly cited as a requirement for evidence-based environmental policy and is a core principle behind Defra's use of the ecosystem approach (paragraph 1.8). There are relatively few published examples of where this has been applied in practice (paragraph 3.14).

12.47. Notwithstanding issues of data availability and robustness (covered below), this study shows that mapping data on environmental outcomes and relating these to defined limits provides an objective and consistent way of identifying areas where delivery of environmental services is falling short of acceptable levels and where policy interventions relating to land use or management are required.

12.48. Providing that suitable data are available, this methodology can be applied more widely, particularly where the ecosystem approach requires a consistent method to enable valid comparisons between services to be made.

3. The importance of spatial data

12.49. This study drew on a wide range of national spatially differentiated datasets. Although not all these datasets can be used to measure delivery against defined environmental limits (paragraphs 3.81 and 3.92), and not all provide complete geographical coverage (paragraph 3.41), it is significant that the data on the water-based services (quality, resource availability and flood risk) are available at a finer level of spatial detail, and with a higher level of scientific confidence than is currently available for many other environmental services, particularly for those which come under the MA's cultural services (paragraph 10.17). Compliance monitoring by the Environment Agency for the Water Framework Directive is the principal reason why there is a strong evidence base for water services.

12.50. There is currently insufficient data to map the flux of soil carbon (indeed evidence on overall national trends is conflicting – paragraph 3.95) and more research will be needed before this can be addressed.

12.51. A second layer of evidence, which can be obtained from research as opposed to direct observation, is needed to demonstrate how land use and management impacts on the status of environmental services. Here, the confidence level in the evidence base is much more variable.

- Land use is known to have an impact on water quality, but the diffuse nature of much pollution means that the precise impact of different forms of land use is less clear (paragraph 6.19). Nevertheless, measures that can be taken to improve failures in water quality are relatively well understood (paragraph 6.37 onwards).

- The availability of water resources is determined principally by levels of precipitation, water storage in surface and groundwaters, and losses/uses such as evapotranspiration and human consumption (paragraph 7.13). With the notable exception of urban and industrial consumption of water, most forms of land use have relatively little (or slow and dispersed) impact on water resource availability, particularly on the recharge of aquifers. This means that the scope for applying research knowledge on how land use and management can increase aquifer recharge is of limited use to address most forms of water shortage (paragraph 7.37).

- There is growing policy and research interest in the relationship between land use and flood generation and the storage of flood water (paragraph 8.7). To date it has proved difficult to demonstrate that changes in land use or management have a significant impact on major flood events at a catchment scale by attenuating or desynchronising peaks in flood run-off (paragraph 8.16). However, there is greater confidence in the measures that can be taken to manage the risks of flooding at a local scale and to hold floodwaters in flood and coastal plains (paragraph 8.46 *onwards*).

- While there is little doubt that land use and management (particularly levels of land drainage and soil cultivation) are a major determinant on the flux of carbon in soils, research on how changes in land management can affect soil carbon is in its infancy, with a large number of research programmes underway (paragraph 9.13).

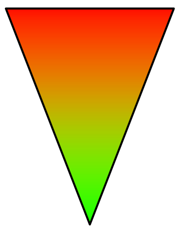
12.52. Key topics where better knowledge is needed to provide confidence in assumptions about the impact of land use and management on the four services are therefore:

- recharge of aquifers through the infiltration of rainfall;
- attenuation of flood peaks through reductions in flood run-off;
- immobilisation of soil carbon through changes in land drainage and soil cultivation.

4. A hierarchy of land uses affecting service delivery

12.53. If the combined impacts of the different land use types are viewed in the round, it is possible to rank the main types from those that have the most to the least adverse effect on service delivery (paragraph 11.19 onwards):

- Urban areas and other developed land — most negative
- Arable and horticulture
- Improved grassland — to
- Semi-natural grassland
- Woodland
- Dwarf shrub heath, fen marsh and bog — most positive



12.54. However, this does not mean that land uses at the top of the list inevitably lead to failures in service delivery, or that land uses at the bottom of the list are free from the risk of negative impacts. For instance, arable and horticultural cropping is the dominant land use on nearly a quarter of areas with good water quality (paragraph 6.19). The way these land uses are managed is critical, with management activities, such as land drainage on dwarf shrub heath (paragraph 9.27), having the potential to impart significant negative impacts.

5. Policy interventions in land use and management

12.55. The competition for land of the highest productive capacity and the differences in land value that arise directly from different uses, means that there is a hierarchy of policy interventions in land use and management.

- In general terms, changes in the way land is managed that enable current land uses to continue are preferred, providing these management practices can deliver the required service.
- Where changes in management are insufficient, small-scale changes in land use (such as those associated with the introduction of sustainable drainage systems in urban areas or the creation of woodland belts on farmland) are needed.
- Where these in turn are incapable of achieving the desired improvement in environmental services, larger landscape-scale changes in land use (such as the conversion of arable farmland to permanent grassland) are demanded.

12.56. This study points to three different categories of policy response which link the hierarchy of interventions above with the levels of service failure. In the context of this study, which has focussed on the links between land uses and service delivery, it makes sense to consider the circumstances where land use changes are justified first (the opposite order to the hierarchy of interventions listed above). These categories of policy response are summarised below before being described further in the following numbered sections.

- Circumstances where failure in a single service justifies large-scale land use intervention.
- Circumstances where the multiple benefits to different services justify large-scale land use intervention.
- Targeted changes in small-scale land use and land management to achieve improvements in single or many services.

6. Circumstances where failure in a single service justifies large-scale land use intervention

12.57. This study identified two circumstances where a failure in a key environmental service can only be addressed by an intervention that dictates land use change at a landscape scale. These circumstances are as follows:

- Loss of the major stores of soil carbon that remain on lowland peat soils currently drained and under arable cultivation. This carbon loss can only be halted by the rewetting of these soils and their conversion to wet grassland or reed bed (paragraph 9.35).
- Areas of flood and coastal plains that are at high risk of flooding and provide a valuable service for the holding back of water during flood events. These should not be converted to urban or industrial development (paragraph 8.47).

12.58. In addition, Defra is keeping under review the measures necessary to protect water quality around major public boreholes, aquifers and reservoirs. It may be that land management measures will be sufficient to safeguard Groundwater Source Protection Zones (paragraph 6.40) and Water Protection Zones (paragraph 6.47). It is possible that the conversion of arable and horticultural cropping and intensive grassland management to extensive grassland may be deemed necessary to safeguard the high standards of water quality needed in these areas.

12.59. These instances where land use change is required to address the failure of individual services affect relatively small areas of the country. It is difficult to quantify the size of these changes but, as an example, arable and horticultural cropping takes place on around 1,796 km^2 of land in England and Wales where peat is present (Figure 9.1), accounting for 1.2 per cent of total land area.

12.60. This study finds no evidence that sweeping changes across entire landscapes or regions is necessary to correct failures in water quality, the availability of water resources, flood risk or carbon storage in soils. But there is a need for targeted remedial action. Indeed, changes in land management will be absolutely critical if changes in land use are to be avoided.

7. Circumstances where the multiple benefits to different services justify large-scale land use intervention

12.61. There are a greater number of circumstances where the combination of benefits that can be achieved by a change in land use are likely to be sufficient to warrant land use change. Examples of these circumstances are:

- Many of the chalk and sandstone catchments around major urban areas show signs of poor water quality (paragraph 3.46), poor water resource availability (paragraph 3.63) and a sensitivity to flood generation (paragraph 3.72). In these areas, a large-scale change from arable and intensive grassland to low input extensively grazed grassland could boost water quality (paragraph 6.50), increase levels of aquifer recharge (paragraph 7.46) and attenuate flood run-off (paragraph 8.67). This change is already a target in England for enhancement of biodiversity and landscape quality (creation of semi-natural grassland), the protection of buried archaeology and provision of public access through the Environmental Stewardship scheme.

- The high land quality on many coastal plains and beside estuaries means that arable and horticultural cropping, protected by flood banks and pump drainage, dominates these areas (paragraph 8.67). The cost of providing this flood protection, and the potential to generate flood water storage and the recreation of semi-natural habitats such as wet grassland or salt marsh, provide a strong justification to allow some areas to flood more freely through a process of coastal realignment (paragraph 8.64 onwards).

- In floodplains, there is growing interest in the benefits of establishing wet woodland on land now used for arable cropping and grassland to provide hydraulic resistance to flood water (paragraph 8.44). While the evidence of the benefits to flood propagation may be insufficient on its own to warrant this land use change, the additional benefits to water quality (paragraph 6.53) and sequestration of soil carbon (paragraph 9.30), combined with benefits for biodiversity all add up to a persuasive argument in favour of wet woodland creation at targeted locations.

12.62. By considering the cumulative benefits that can be achieved to a range of different services, this study has found that land use change may be appropriate across a larger area than where these services are considered in isolation. This shows the benefits of an ecosystems approach, where it is the synergy between the multiple benefits to a range of services that provide the best overall outcomes.

8. Changes in small-scale land use and land management to achieve improvements in single or many services

12.63. This report has identified a number of small-scale changes in land use (changes within parcels of land that do not result in an overall change at a landscape scale) and changes in management necessary to correct, or contribute to overcoming, failures in one or more services. Examples of these changes are as follows.

- On urban and industrial land, the use of (SUDS) and biobeds are needed to reduce run-off of poor quality water into surface waters (paras. 6.41 and 8.49).
- On arable and horticultural crops and improved grassland, lower and better targeted inputs of inorganic fertilisers, pesticides and animal manures will reduce diffuse pollution of surface waters (paragraph 6.42 onwards).
- On arable and horticulture crops and improved grassland, the use of buffer strips across slopes and beside watercourses and use of soil cultivation techniques will increase water infiltration, reduce the speed of flood water run-off and increase aquifer recharge (paragraphs 7.39, 7.46 and 8.50).

12.64. The extent to which these changes can correct failures and result in services being delivered above the environmental threshold varies between services.

9. The importance of spatial targeting and fine-grained knowledge

12.65. This study shows that failure of a service is often due to a combination of natural factors with particular land uses or management practices. It is rarely the case that a change in land use or management will improve a service regardless of other factors such as soil type, slope, land drainage or the proximity of other features. If a change in land use or management is to be successful in addressing the needs of several services, it is essential that its location is carefully targeted to optimise these benefits. This is particularly the case for the second and third of the three policy interventions described above (Conclusions 7 and 8).

12.66. As an example, this study has shown that buffer strips of rough grassland on farmland, or as part of SUDS on developed land, can be effective at reducing surface run-off (reducing the risk of flood generation), increasing soil infiltration (contributing to aquifer recharge) and reducing soil erosion (protecting water quality in streams) and can also increase biodiversity. However, these benefits will only accrue if the buffer strips are placed in suitable locations. A buffer strip created at the top of a slope will have little benefit on surface run-off and erosion. Buffer strips that succeed in delaying run-off from one catchment, but result in synchronising the flood peak from that catchment with the peak from another catchment at the river confluence, could increase rather than reduce downstream flood risk.

12.67. Targeting of interventions in land use and management requires good knowledge of the pressures and responses of services at a fine enough spatial scale, together with a means of delivering these interventions in appropriate locations through schemes and programmes. This involves engagement with land owners and managers to ensure measures are adopted where they will do most good.

10. The role of protected landscapes in service delivery

12.68. There is a striking coincidence between many of the areas identified as 'hotspots' of multiple potential for intervention and areas designated as National Parks and AONBs (paragraph 11.19). This is an indication of the high levels of environmental stress facing these landscapes. There is also a high degree of synergy between the changes in land use and management that are needed to address failures in the services covered by this study and the practices needed to conserve and enhance biodiversity, retain landscape character and protect the historic environment.

11. How drivers of change will influence future service delivery

12.69. Many of the drivers of change reviewed in Chapter 5 point to increased pressure on the services covered by this study. Climate change and increased urban development will tend to act in concert, increasing competition for use of the best quality land (for development, energy and food production, constrained by increasing flood risk on low-lying land) and will put semi-natural habitats in areas such as the south east of England under increased stress. In these areas, policy interventions to correct failures in service delivery will need to become increasingly robust to overcome these growing negative influences.

12.70. In other areas future changes in climate, economic demand and public policy are likely to reduce the pressure on services and support the changes in land use and management needed to address service failures. For instance, wetter conditions facing the uplands of Wales and northern England and the predicted decline in the viability of farming on marginal land in these areas will facilitate the changes in land use and management needed to address failures in service delivery.

12. The potential value to society of improvements to services

12.71. Chapter 10 set out a method for estimating the economic benefits of correcting failures in the four services covered by this study. While it has not proved possible, at a sufficient level of confidence, to calculate these values, the chapter provides a qualitative assessment of where land use change has the greatest potential to lead to economic benefits from improvements to service delivery.

- Addressing poor surface water quality has the potential for high economic gains and is strongly reliant on land management to address failures in quality. Targeted interventions in land management are therefore likely to be effective in producing benefits to society.

- Improving poor groundwater quality would result in a lower economic gain (derived from reductions in water treatment costs) and, at the scale of analysis used by this study, the link with surface land use is less clear-cut. The scale of economic benefits resulting from changes in land use or management are therefore less significant than for surface water quality (although they may still be justified).

- An increase in water resources would have economic benefits (though less in value than for surface water quality) but the contribution that changes in land use and management will make to achieve this are considered relatively low. The benefits derived from land use and management interventions are therefore considered to be less than those for surface water quality.

- Reducing the risk of flooding would generate major economic benefits. The contribution of changes in land use and management across catchments as a whole is currently unclear. But the zoning of land in floodplains and on coasts to prevent development on inappropriate sites and to store floodwater could give rise to moderate levels of benefit, particularly at a local scale (to protect assets from flooding). This study concludes that these changes could have a moderate level of economic benefit which is likely to be greater than for water resources and groundwater quality but probably less than for surface water.

- The lack of knowledge about current change in soil carbon or the optimum forms of land use and management for soil carbon make it difficult to assess the benefit that might be derived from improvements to soil carbon. However, economic valuations of the carbon stored in woodland and forestry soils alone suggest a high potential benefit from this service.

12.72. Overall, this study suggests that targeted land use and management interventions to address water quality, flood risk and soil carbon will give rise to higher economic benefits than those for groundwater quality or provision of water resources. Interventions that lead to improvements to more than one service will obviously be more cost-effective than those that address only one service.

13. Strategic approaches for delivering multiple benefits

12.73. This study has demonstrated the benefits of taking an integrated approach to land use policy. This approach should be taken forward through delivery mechanisms that recognise the synergies achievable through targeted interventions in land use and management.

12.74. The draft River Basin Management Plans published by the Environment Agency in December 2008 represent a major step forward in the identification of measures to achieve good status for the Water Framework Directive. While focused primarily on water quality, these plans take account of the impact on the water environment of designated nature conservation sites. Through Catchment Abstraction Management Strategies (CAMS), the Environment Agency can address problems of low water resource availability caused by over-abstraction. Similarly, Catchment Flood Management Plans provide a means of reaching agreement over priorities for flood protection and flood risk management.

12.75. These documents should focus on achieving their outcomes. But it is essential that, at the level of delivery of measures on the ground, full account is given to the impacts of these measures on other policy domains and environmental services.

12.76. The two principal means by which public objectives for land use and management are delivered on the ground are the planning system (for developed land) and agri-environment and woodland schemes (for farmed and wooded land). Both of these already seek to address a range of environmental services but both will benefit from a greater understanding of pressures facing the water environment and soil carbon.

12.77. The Environment Agency will need to continue to work with its partners, particularly regional and local planning authorities (in relation to development control) and Defra, the Welsh Assembly Government, Natural England, Countryside Council for Wales and the Forestry Commission (in relation to agri-environment and woodland schemes) to ensure that the policies and programmes operated by these bodies are equipped to optimise the benefits to the suite of environmental services covered by the Environment Agency's remit.

Appendix 1: References

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Appendix 2: Millenium Ecosystem Assessment typology

Source: Defra (2007). Securing a healthy natural environment: An action plan for embedding an ecosystems approach. PB12853*. (Adapted from Millennium Ecosystem Assessment Ecosystems and Human Wellbeing: General Synthesis)*

Ecosystem services are the benefits people obtain from ecosystems. These include provisioning, regulating and cultural services that directly affect people and the supporting services needed to maintain other services. Many of the services listed here are highly interlinked (primary production, photosynthesis, nutrient cycling and water cycling, for example, all involve different aspects of the same biological processes).

Provisioning services.

These are the products obtained from ecosystems, including:

- **food**. This encompasses the vast range of food products derived from plants, animals and microbes.
- **fibre**. This is derived from materials such as wood, jute, cotton, hemp, silk and wool.
- **fuel**. Wood, dung and other biological materials serve as sources of energy.
- **genetic resources**. This covers the genes and genetic information used for animal and plant breeding and biotechnology.
- **biochemicals, natural medicines, and pharmaceuticals**. Many medicines, biocides, food additives such as alginates and biological materials are derived from ecosystems.
- **ornamental resources**. Animal and plant products, such as skins, shells and flowers are used as ornaments, and whole plants are used for landscaping and as ornaments.
- **fresh water**. People obtain freshwater from ecosystems and therefore the supply of freshwater can be considered a provisioning service. Fresh water in rivers is also a source of energy. Because water is required for other life to exist, however, it could also be considered a supporting service.

Regulating services.

These are the benefits obtained from the regulation of ecosystem processes, including:

- **air quality regulation**. Ecosystems both contribute chemicals to and extract chemicals from the atmosphere, influencing many aspects of air quality.
- **climate regulation**. Ecosystems influence climate both locally and globally. For example, at the local level, changes in land cover can affect both temperature and precipitation. At the global level, ecosystems play an important role in climate by sequestering or emitting greenhouse gases.
- **water regulation**. The timing and magnitude of run-off, flooding and aquifer recharge can be strongly influenced by changes in land cover, including, in

particular, alterations that change the water-storage potential of the system such as the conversion of wetlands or the replacement of forests with croplands or croplands with urban areas.

- **erosion regulation**. Vegetative cover plays an important role in soil retention and the prevention of landslides.
- **water purification and waste treatment**. Ecosystems can be a source of impurities (e.g. in fresh water). However, they can help in the filtering out and decomposition of organic wastes introduced into inland waters and coastal and marine ecosystems and can also assimilate and detoxify compounds through soil and sub-soil processes.
- **disease regulation**. Changes in ecosystems can directly change the abundance of human pathogens, such as cholera, and can alter the abundance of disease vectors, such as mosquitoes.
- **pest regulation**. Ecosystem changes affect the prevalence of crop and livestock pests and diseases.
- **pollination**. Ecosystem changes affect the distribution, abundance and effectiveness of pollinators.
- **natural hazard regulation**. The presence of coastal ecosystems such as mangroves and coral reefs can reduce the damage caused by hurricanes or large waves.

Cultural services.

These are the non-material benefits people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation and aesthetic experiences, including:

- **cultural diversity**. The diversity of ecosystems is one factor influencing the diversity of cultures.
- **spiritual and religious values**. Many religions attach spiritual and religious values to ecosystems or their components.
- **knowledge systems** (traditional and formal). Ecosystems influence the types of knowledge systems developed by different cultures.
- **educational values**. Ecosystems and their components and processes provide the basis for both formal and informal education in many societies.
- **inspiration**. Ecosystems provide a rich source of inspiration for art, folklore, national symbols, architecture and advertising.
- **aesthetic values**. Many people find beauty or aesthetic value in various aspects of ecosystems, as reflected in the support for parks and scenic drives and in the selection of housing locations.
- **social relations**. Ecosystems influence the types of social relations that are established in particular cultures. Fishing societies, for example, differ in many respects in their social relations from nomadic herding or agricultural societies.

- **sense of place**. Many people value the ‘sense of place’ that is associated with recognised features of their environment, including aspects of the ecosystem.

- **cultural heritage values**. Many societies place high value on the maintenance of historically important landscapes (‘cultural landscapes’) or culturally significant species.

- **recreation and ecotourism**. People often choose where to spend their leisure time based, in part, on the characteristics of the natural or cultivated landscapes in a particular area.

Supporting services.

Supporting services are those that are necessary for the production of all other ecosystem services. They differ from provisioning, regulating and cultural services in that their impacts on people are often indirect or occur over a very long time, whereas changes in the other categories have relatively direct and short-term impacts on people. (Some services, like erosion regulation, can be categorised as both a supporting and a regulating service, depending on the timescale and immediacy of their impact on people.)

- **soil formation**. Because many provisioning services depend on soil fertility, the rate of soil formation influences human wellbeing in many ways.

- **photosynthesis**. This process produces oxygen, which is necessary for most living organisms.

- **primary production**. The assimilation or accumulation of energy and nutrients by organisms.

- **nutrient cycling**. Approximately 20 nutrients essential for life, including nitrogen and phosphorus, cycle through ecosystems and are maintained at different concentrations in different parts of ecosystems.

- **water cycling**. Water cycles through ecosystems and is essential for living organisms.

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