MANAGEMENT OF THE OTMOOR PROTECTED AREA (OXFORDSHIRE)

(MULTIFUNCTIONAL WETLANDS IN AGRICULTURAL LANDSCAPES: AN EVALUATION OF VALUES, IMPACTS AND THE APPLICATION OF THE ECOSYSTEM-BASED APPROACH) (NR0112)

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Full Report to Defra

NR0112

September 2008

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This document should be cited as:

McInnes, R.J., Crane, M., Rodda, H.J.E., Danks, P.W., Hogan, D.V., and Field, A.I. 2008. *Management of the Otmoor protected area (Oxfordshire)* (Multifunctional wetlands in agricultural landscapes: An evaluation of values, impacts and the application of the ecosystem-based approach) (NR0112 – Full Report). WWT Report to Defra. Project Reference: NR0112. WWT, Slimbridge, UK. p95.

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EXECUTIVE SUMMARY

Introduction

The 'Ecosystem Approach' has been adopted by the Convention on Biological Diversity as a framework for sustainable development. In response to this, the application of an ecosystems approach is being progressed by Defra as part of its commitment to the development of a more holistic and integrated policy framework for the natural environment which ensures that the value of ecosystem services is truly recognised across Government.

Otmoor protected area covers approximately 1100 hectares of Oxfordshire farmland. The site represents one of the most important wetland areas in central-southern England. The area carries a range of designations and consequently differing management practices. Four land designations represented at the site are: a Site of Special Scientific Interest (SSSI), a Royal Society for the Protection of Birds (RSPB) reserve, land under the Upper Thames Tributaries Environmentally Sensitive Area (ESA) and agricultural land outside of the ESA.

Aims and objectives

The information generated by this case study informs the implementation of an ecosystems approach through an assessment of a limited range of ecosystem services and an interrogation of how successfully an ecosystems approach is being applied at the Otmoor protected area. This is achieved through the following objectives:

- identification of policy drivers and stakeholder preferences;
- assessment of four ecosystem services;
- evaluation of uncertainty in assessing ecosystem services and applying an ecosystems approach; and
- overall evaluation of the project methodology and how successfully an ecosystems approach is being applied at Otmoor.

The results presented are not intended to be definitive, but rather illustrate a method which informs the debate on applying an ecosystems approach. The intention has been to demonstrate an approach to implementing and understanding elements of an ecosystems approach. Therefore, whilst the individual outcomes are all open to question, interrogation and potentially refinement, it is the approach taken which is considered more important than the absolute nature of outcomes.

Methodology

The methodology drew upon stakeholder consultation (44 structured interviews) and limited field observations (primarily on land-use and soils) combined with desk-based analysis of readily available data. The main rationale for the approach was to investigate the extent to which existing information could be utilised in understanding the application of an ecosystems approach at Otmoor rather than implementing a large, empirically based study.

Stakeholder preferences and policy drivers

A range of policy drivers influence the delivery of the benefits derived from ecosystem services and the implementation of an ecosystems approach at Otmoor. The views of the majority of relevant sectors of society were canvassed to understand better their understanding of 'ecosystem services' and their awareness of the multi-functional benefits delivered by the Otmoor protected area.

The concept of 'ecosystem services' was alien to the majority of stakeholders interviewed. However when explained as the benefits to people and wildlife provided by a natural area stakeholders were able to identify a range of benefits. The following was generally agreed by those interviewed: conservation of all species should be a priority on Otmoor; flooding should be allowed to occur naturally across all of Otmoor, at least in the long-term; and a large increase in visitors to Otmoor should not be encouraged.

The main areas of disagreement were: achieving the appropriate balance between profitable farming and achievement of biodiversity goals; the extent to which flooding can and should be managed across Otmoor for the benefit of farming and conservation; and the extent to which M40 runoff is responsible for pollution of parts of Otmoor.

The disagreements are primarily policy-related and require further investigation and resolution. **The key question to be answered is what is the appropriate balance between farming and conservation on Otmoor?** If farming practices are a key mechanism for the delivery of conservation objectives then this must be recognised. If policies, such as the Common Agricultural Policy are distorting the market then this needs to be addressed to ensure that the natural systems are valued appropriately.

Conceptual framework
A priority target for an ecosystems approach is the conservation of ecosystem structure and functioning in order to maintain ecosystem services. Based on the terminology adopted in the Millennium Ecosystem Assessment, elements of four ecosystem services (drawn from the only three of the main ecosystem service categories and omitting 'supporting' services) were investigated at Otmoor:

Regulating: Water purification and waste treatment: specifically *the removal of phosphorus and nitrogen.*
Regulating: Natural hazard regulation: specifically *reducing the likelihood of extreme flood events.*
Provisioning: Food: specifically *conversion of light, energy and nutrients into agricultural biomass.*
Cultural: Recreational: specifically *provision of recreational opportunity***.**

These services were selected on *a priori* knowledge of the site and in advance of any stakeholder consultation and do not necessarily represent the most important or economically valuable ecosystems services delivered by Otmoor. In order to quantify, and subsequently determine an economic valuation for, the four ecosystem services it was necessary to understand what was meant by 'ecosystem services'. A conceptual model was employed in the investigations at Otmoor which reduced services to functions, processes and the variables which control relationships among them. Causal chains were derived in order to understand further and illustrate the relationships which exist among ecosystem services.

Assessment of ecosystem services
Each of the ecosystem services listed above was quantified and, where possible, an economic value was calculated. The assessment was undertaken across the four different land designations in order to understand better how different levels of protection influence the delivery of ecosystem services.

Site and ecosystem service specific methodologies had to be developed for the quantification and economic valuation component of this study. Due to limitations in the approach it was not possible to assign an economic value to natural hazard regulation.

Subtle, but not significant differences in the economic value of the ecosystem services were identified for the four different land designations. Food production was the most significant economic benefit ranging between £259 and £355 per hectare per annum. Water purification ranged between £15 and £ 20 per hectare per annum and recreation between £8 and £31 per hectare per annum. These values only reduced slightly under a climate change scenario of wetter winters. For the three ecosystem services assessed the current annual value ranged between £282 and £390 per hectare per annum.

Understanding uncertainty
Data pedigree was assessed to understand better uncertainty and variability. Sensitivity analysis was used to examine the contributions of ecosystem services to the overall value of different land designations on Otmoor. Two climate scenarios were considered in attempt to impose an external stressor on the ecosystem. The sensitivity analysis showed that flood duration and the value of food production per hectare were the input parameters contributing most to output uncertainty. Any further similar analyses would therefore benefit from a focus on these parameters. These parameters not only contributed most to uncertainty, but were also the most important determinants of the overall annual value of land for the ecosystem services assessed. **It should be highlighted that there are considerable assumptions and uncertainties in the analysis conducted as part of this case study all of which are open to challenge**.

Recommendations and conclusions
The importance and relevance of policy drivers and the views of local stakeholders have been assessed. A conceptual and empirical method for quantifying and valuing ecosystem services has been developed. The approach taken in this case study demonstrated strengths and weaknesses. **The outcomes of the assessment of ecosystem services are clearly open to challenge and questioning as no agreed standards have been published or accepted for assessing and valuing ecosystem services and the methodology applied is constrained by data availability.**

A range of recommendations are made based on the results of this study including the need for: improved systematic collection of data relevant to understanding ecosystem services; the development of standardised methodologies and reference sites; and policy development and implementation to become more joined up in order to recognise the multi-functional benefits of protected sites such as Otmoor.

The successful implementation of an ecosystems approach clearly benefits the natural environment and allows society to make better-informed decisions about how to balance economic, environmental and social objectives. Elements of an ecosystems approach are being successfully implemented at Otmoor, such as recognition of certain environmental limits and the recognition by stakeholders of the ecosystem services delivered by the natural environment. However, certain issues still exist, such as potentially conflicting policies, perverse economic incentives and prescriptive management practices which are impeding the full implementation of an ecosystems approach.

This study should be viewed as one of the first stages in an iterative process both at a national level and also at Otmoor. In order to advance an ecosystems approach, the outcomes of this study should now be taken back to stakeholders to canvas comment and generate discussion. It is possible that this may catalyse a more complete application of an ecosystems approach at Otmoor.

HOW TO USE THIS DOCUMENT

This report explores how an ecosystems approach is being implemented at the Otmoor protected area and utilises a methodology for the assessment of ecosystem services to inform this process. The following explains the structure of this document. Each chapter is a synthesis of considerable work. The appendices contain detailed information which should be referenced where appropriate to provide further clarification and background. The primary supporting appendix for each section is emboldened below.

Executive summary
Overall summary of the case study

1. Introduction
Provides background to the research area and the Otmoor protected area. Details research objectives.

Appendix 1
Appendix 5
Appendix 6
Appendix 7
Appendix 8

2. Identification of policy objectives
Describes the main policy drivers which contribute to the health of ecosystems, ecosystem services and environmental limits. Reports on stakeholder interviews and their understanding of the policy context.

Appendix 1
Appendix 2
Appendix 6

3. Assessment of ecosystem services
Describes the evaluation, quantification and economic valuation of a limited range of ecosystem services delivered by Otmoor.

Appendix 1
Appendix 3
Appendix 4
Appendix 5
Appendix 6
Appendix 7

4. Assessment of uncertainty
Evaluates the level of uncertainty in the assessment of ecosystem services, the implications of how this changes with the introduction of an external stressor and recommendations for reducing uncertainty.

Appendix 9

5. Evaluation of an ecosystems approach
Evaluates the methodology applied to the case study and how successfully an ecosystems approach is being applied at Otmoor.

1 INTRODUCTION

1.1 An ecosystems approach

The goal of sustainable development is to enable all people throughout the world to satisfy their basic needs and enjoy a better quality of life without compromising the quality of life for future generations. In '*Securing the future – delivering UK sustainable development strategy*'[1] the UK Government sets out a framework for the pursuit of this goal. Key within this strategy is the need for an integrated policy framework to ensure natural resource protection is achieved within environmental limits.

The Department for Environment, Food and Rural Affairs (Defra) has recognised that today's biggest environmental issues tend to be more diffuse and cross-cutting in nature and require more holistic and integrated solutions[2]. This has provided the impetus for the development of an '*ecosystems approach*' which aims to enable more efficient and effective delivery of natural environment outcomes. Based on the 'Ecosystem Approach' adopted by the Convention on Biological Diversity (CBD) as the primary framework for achieving sustainable development, based on maintaining fully functioning ecosystems (Laffoley *et al.*, 2004), Defra acknowledges that the application of an ecosystems approach will involve conserving, managing and enhancing the natural environment, whilst balancing environmental, economic and social considerations to achieve sustainable development[3].

The CBD's 'Ecosystem Approach' was endorsed at the World Summit on Sustainable Development (WSSD) in Johannesburg in 2002 and is being applied across the European Union as an approach through which to deliver on several environmental directives, strategies and agreements (Apitz *et al.,* 2006). Various definitions have been applied to CBD's concept including:

The 'Ecosystem Approach' is a strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way, and which recognises that people with their cultural and varied social needs, are an integral part of ecosystems' (Maltby, 2000).

However, despite widespread recognition of the CBD's 'Ecosystem Approach', the translation of the concept into policy and subsequent delivery of equitable benefits 'on the ground' remains a challenge (Hartje *et al.,* 2003, Chan *et al.*, 2006, Haines-Young and Potschin, 2007). It has been observed that there is probably no one definition or application of the concept and that its fluidity is a potential strength since the principles which underpin it are not equally applicable in all circumstances (Maltby, 2000, Haines-Young and Potschin, 2007). Defra is committed to the development of an integrated policy framework for the natural environment. The adoption and application of an ecosystems approach, based on the CBD's thinking and which will allow cross-cutting issues such as identifying environmental limits or assessing cumulative impacts, is fundamental to this policy initiative.

Defra's Natural Environment research programme aims to collate and analyse the interdisciplinary evidence base relevant to an ecosystems approach, and demonstrate how an ecosystems approach can be applied in practical terms through a series of case studies. This research programme forms an integral component of Defra's action plan for protecting and enhancing the natural environment[4]. The importance of this approach is also reflected in the cross-Government Public Service Agreement (PSA) framework which aims to 'secure a healthy natural environment for today and the future'.[5] This report describes the approach, outcomes and recommendations of a case study of the Otmoor protected areas in Oxfordshire undertaken as part of this research programme.

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[1] http://www.sustainable-development.gov.uk/publications/pdf/strategy/SecFut_complete.pdf
[2] http://www.defra.gov.uk/wildlife-countryside/natres/eco-backvis.htm
[3] http://www.defra.gov.uk/wildlife-countryside/natres/pdf/v061218.pdf
[4] http://www.defra.gov.uk/wildlife-countryside/natres/pdf/eco_actionplan_exe.pdf
[5] http://www.hm-treasury.gov.uk/media/1/3/pbr_csr07_psa28.pdf

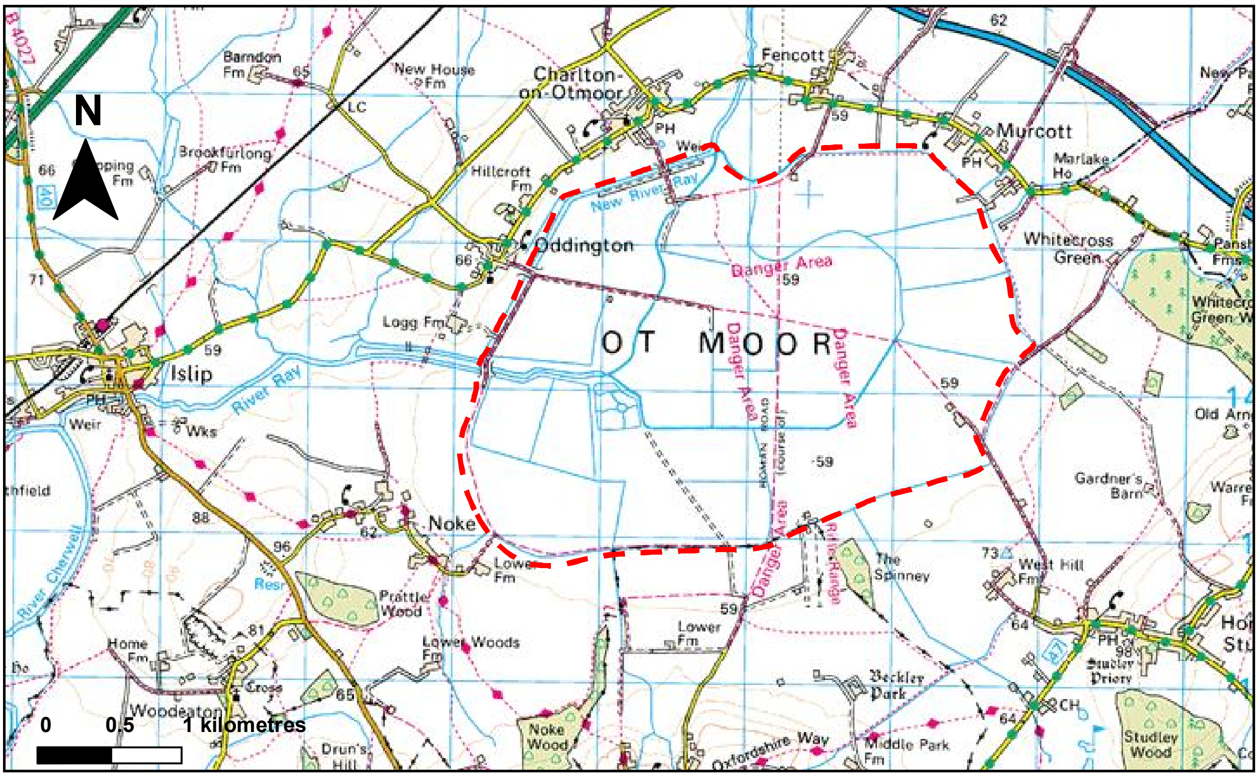
1.2 Otmoor protected area

The Otmoor protected area (NGR SP5814) is situated upstream of the confluence of the River Ray and the River Cherwell less than 10 km to the north-east of Oxford. The Otmoor wetland covers an area of approximately 10 km^2 in the River Ray catchment, a tributary of the Cherwell with a catchment area of 287 km^2. Otmoor is located in the lower reaches of the Ray, approximately 3 km from the Cherwell confluence, in the form of a shallow bowl-like depression. A summary of the physical characteristics and land designations is provided in Appendix 1.

Within the main part of Otmoor there are virtually no permanent domestic dwellings. The land use is dominated by agriculture and conservation management, which in turn depends on agricultural management practices. The study site focuses on 824 hectares of land within an Outer Ring Ditch which acts as a hydrological boundary between the main, low lying are of Otmoor and the surrounding relatively higher land (Figure 1). The land within the Outer Ring Ditch can be assigned to one of four land categories based on designations and land management, namely:

- the Upper Thames Tributaries Environmentally Sensitive Area (ESA) (excluding the land within the RSPB Otmoor Reserve and the Otmoor Site of Special Scientific Interest);
- the Royal Society for the Protection of Birds (RSPB) Otmoor Reserve;
- the Otmoor Site of Special Scientific Interest (SSSI), which predominantly occupies land owned by the Ministry of Defence (MoD) Estates; and
- non-ESA land.

Figure 1. Otmoor limit of the study area (dotted red line), topography, surface drainage and surrounding villages. (Reproduced with permission from the Ordnance Survey under licence No. 100031955).



The four land designations are of unequal size. The exact areas are shown in Table 1. It must be noted that these values do not represent the full extent of each of the designation types, only the areas within the boundary of the study area. For instance, the SSSI covers a total of 211.6 hectares of which only 160.0 hectares lies within the study area boundary. Also, it should be noted that the designations are not exclusive. For instance the RSPB reserve includes land which is also covered by ESA agreements.

Table 1. Extent of land designation types at the Otmoor study site.

Land designation	Area (ha)
ESA	357
RSPB reserve	210
Otmoor SSSI	160
Non-ESA	100
Total	824

1.3 Objectives

This case study forms part of a suite of research projects commissioned by Defra which aim to assist in describing how an ecosystems approach could be incorporated into future environmental and cross-governmental policies. The work undertaken does not apply the Ecosystem Approach *per se* but investigates elements of it within the context of a protected wetland area and assesses the implications of these in the context of applying an ecosystems approach. The case study has the following four sub-objectives:

1. To demonstrate approaches for identifying policy objectives for a protected site that takes into account the views of stakeholders, including the owners (RSPB), visitors, local residents, local farmers, local authorities, the MoD, Thames Water, the Environment Agency and Defra.
2. To demonstrate a method for measuring, predicting and communicating the actual and potential cumulative impacts of different stressors on these policy objectives, based upon common monetary and ecological currencies.
3. To demonstrate a method for identifying, predicting and valuing the ecosystem services provided by the site. The ecosystem services will be defined by the criteria contained in EFTEC (2006) and Millennium Ecosystem Assessment (2003) and evaluated through analysis of technical concepts undertaken in Geographic Information System (GIS).
4. To evaluate the applicability of elements of an ecosystems approach against the current level of understanding of a protected area and to demonstrate a prioritisation framework for balancing policy objectives against the value of ecosystem services and potential impacts that takes data and model uncertainty into account.

2 IDENTIFICATION OF POLICY OBJECTIVES

2.1 Introduction

Defra have stated their commitment to developing and applying an ecosystems approach and recognise that there are already good examples of best practice in policy-making that are broadly consistent with such an approach[6]. An ecosystems approach should not seek to impose a single, rigid definition, rather, it should promote a generic approach that can be applied in a wide range of policy areas and decision-making contexts, based on the following core principles[6]:

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

Not all of these principles will be relevant in all contexts and to all stakeholders, but where they are relevant they should be observed. At Otmoor a range of local, regional and national policy objectives contribute to the maintenance of ecosystems and the delivery of ecosystem services. The context for these and their relevance to stakeholders is discussed below.

2.2 Policies and drivers

An ecosystems approach should apply the principles outlined above and seek to integrate the management of land, water and living resources in order to promote conservation and sustainable use in an equitable way. Thus, the application of an ecosystems approach should help to reach a balance among the three objectives of the CBD, namely:

- Conservation of biodiversity;
- Sustainable use of natural resources; and
- The fair and equitable sharing of the benefits arising out of the utilization of genetic resources.

A range of policy objectives exist at a national level which drive decisions and actions at a local level at Otmoor and help in delivering on the three objectives identified above. The protection of important habitats and wildlife is covered under European legislation by the Birds Directive and the Habitats Directive. Broader, integrated ecological objectives, based on river basin districts, are addressed through the Water Framework Directive. This far-reaching piece of legislation requires actions to be integrated into plans and programmes of measures, drawing upon the active contribution of local communities and interested parties, which will restore and maintain good ecological status of rivers, lakes and wetlands.

Prior to the introduction of the single farm payment and the decoupling of production from support, the Common Agricultural Policy contributed to the ploughing and drainage of parts of Otmoor. Today, the CAP still has implications for the land management practices across all of Otmoor. Under the UK Government's vision for reform of the CAP over the next 10 to 15 years, agriculture should become an industry which is fundamentally sustainable and an integral part of the European economy. Agriculture should be rewarded by the market for its outputs, not least safe and good quality food, and by the taxpayer only for producing societal benefits (such as a range of ecosystem services) that the market cannot deliver. Agriculture should also be environmentally-sensitive, maintaining and enhancing landscape and wildlife and tackling pollution[7].

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[6] http://www.defra.gov.uk/wildlife-countryside/natres/eco-actionp.htm
[7] http://www.defra.gov.uk/farm/policy/capreform/pdf/vision-for-cap.pdf

Activities at Otmoor are also regulated under a range of national Acts of Parliament. These Acts control actions and provide a legal framework for the protection and enjoyment of the environment. The following represent a range of some of the Acts relevant to activities at Otmoor:

- Pollution Prevention and Control Act 1999
- Water Resources Act 1990
- Wildlife and Countryside Act 1981
- Countryside and Rights of Way Act 2000
- Town and Country Planning Act 1990

In addition to Acts of Parliament, there are several national government strategies, guidance documents and plans which apply to Otmoor. Many of these take a holistic and integrated approach in order to deliver on cross-cutting benefits to a multiplicity of stakeholders. These approaches include:

- UK Biodiversity Action Plans
- Conserving Biodiversity: The UK Approach
- Making Space for Water
- Securing the Future
- Planning Policy Guidance PPS25

Other government departments, beyond Defra, such as the Department for Communities and Local Government and the Department for Transport, are also responsible for policies which can have significant impacts on activities within the natural environment. An example of this is the Secretary of State for Transport's decision in 1985 to rule, following a public enquiry, that the route of the M40 motorway should not cross Otmoor.

2.3 Stakeholder responses

2.3.1 Introduction

In order to assess understanding and application of the principles of an ecosystems approach and the relevance and importance of the policy objectives and drivers, the following stakeholders were interviewed face-to-face or by telephone between December 2006 and March 2007:

- RSPB staff and volunteers
- Natural England
- Environment Agency
- Ministry of Defence
- Local Government staff responsible for biodiversity
- District and Parish Councillors
- Farmers
- Local residents
- Visitors to Otmoor

The focus of the interviews was on understanding one of the core principles of an ecosystems approach, namely ensuring that the value of ecosystem services is fully reflected in decision-making. Key issues of relevance and concern to local stakeholders, and which are delivered through the ecosystem services the site performs, were identified through a review of a range of information including web-based information searches of local media, initial discussions with key land owners such as the RSPB, and historical reviews of published information such as Treymayne and Lackie (2001). This initial desk-study identified the key issues which formed the focus of the questions asked of the stakeholders. The individual questions asked of the stakeholders were intended to garner information on: the level of understanding of the ecosystem services the site provides; perceptions of the interactions which exist among the different ecosystem services; and the appreciation of the policy drivers which contribute maintaining Otmoor as a healthy ecosystem. A full evaluation of the stakeholder responses is provided in Appendix 2.

2.3.2 Summary

The following were generally agreed by those interviewed in this project:

1. Conservation of all species should be a priority on Otmoor, with species or habitat rarity being the criterion used to rank conservation priorities.
2. Flooding should be allowed to occur naturally across all of Otmoor, at least in the long-term (bunds[8] around the RSPB reserve currently prevent natural flooding).
3. A large increase in visitors to Otmoor should not be encouraged.

The areas of agreement are relatively consistent to with the principles of an ecosystems approach where the conservation of biological diversity should be delivered within environmental limits. The importance of Otmoor, as one of the most important wet grassland sites, and especially locations for breeding waders, in south-central England is clearly reflected by the views of the stakeholders interviewed.

The following are the main areas of disagreement between different stakeholders:

1. The appropriate balance between profitable farming and achievement of biodiversity goals.
2. The extent to which flooding can and should be managed across Otmoor for the benefit of farming and conservation.
3. The extent to which M40 runoff is responsible for pollution of parts of Otmoor.

Disagreement 1 above impinges directly on CAP reform issues and requires further collection of data to evaluate an appropriate way forward at Otmoor. The question to be answered is what is the appropriate balance between farming and conservation at Otmoor? If farming is to be rewarded by the market for its outputs, then the taxpayer should bear the cost for the wider societal benefits, such as biodiversity, that the market cannot deliver. However, an option being pursued at Otmoor is that the conservation objectives (such as delivery of Biodiversity Action Plan targets) can be achieved through the purchase or leasing of land by conservation organisations such as the RSPB. However this approach has potentially serious implications for socio-economic and cultural aspects of the management of natural resources and delivering genuine sustainability. Additionally it undermines one the core principles of the CPD Ecosystem Approach which states that cultural *and* biological diversity should be considered as central components.

Disagreements 2 and 3 reflect past, current and future water quantity and quality on Otmoor. Disagreement 2 demonstrates the potential conflict among different ecosystem services. Flooding at the wrong time of year can de detrimental to both agricultural production and also to nature conservation interest (e.g. excessive spring flooding can be deleterious to ground nesting waders such as Lapwing). However, intensification of drainage and the rapid removal of flood waters can compromise the quality of wet grassland habitats. The wider benefits (in terms of both reducing flood peaks downstream and the ability of Otmoor to remove nutrients and sediments from flood waters) delivered by flooding need to be understood in the context of the agricultural management practices at the site. This requires holistic thinking and, in the context of both global changes in food production and climate, potentially adaptive management.

The relationship between the M40 and Otmoor is local cause célèbre (Emery, 1983). Disagreement 3 highlights this local conflict of interest, or direction in which the finger of blame for pollution should point. Historical concerns appear to have resurfaced in relation to this issues during the stakeholder engagement.

Local stakeholders and visitors value the landscape and wildlife aspects of Otmoor and are in agreement with the main governmental policy drivers for the area. No-one interviewed during this project wanted to change the overall character of Otmoor, except to "change it back" to what some perceive to have been a more natural condition in the past. The main points of friction between some local stakeholders and government policy centre on the appropriate balance between farming and conservation. All parties agree that farming is essential to maintain the conservation and landscape value of Otmoor, but farmers believe that their reasonable economic interests are given insufficient priority by government departments and agencies. In particular, farmers would like more research on the quantity and quality of water on Otmoor and would like

[8] Bunds are slight elevations (usually less than 30cm high) adjacent to ditches which act to reduce inundation to neighbouring land.

further evidence-based discussion of how the quantity of water should be distributed across Otmoor during floods.

3 ASSESSMENT OF ECOSYSTEM SERVICES

3.1 Introduction

Ecosystems services, which are indispensable for both the natural environment and for human well-being, result from interactions and processes within the ecosystem (de Groot *et al.*, 2006). Wetlands are composed of a number of *biophysical structures* such as soils, water, plant and animal species. Within wetlands the interactions among and within the biophysical structures result in ecosystem *processes* such as denitrification, decomposition or primary production. The interactions among and within these different components allow the wetland to perform certain *functions* (de Groot, 1992; Maltby *et al.*, 1996; McInnes *et al.*, 1998). The degree to which a wetland delivers ecosystem *services* depends on its functional properties (e.g.*,* biotic and abiotic components) and relationship between and among ecological components and processes. This conceptual framework is described in more detail in Appendix 3.

Based on *a priori* knowledge of the site, the following ecosystem services were investigated as part of this case study:

Regulating: Water purification and waste treatment: specifically *the removal of phosphorus and nitrogen*.
Regulating: Natural hazard regulation: specifically *reducing the likelihood of extreme flood events*.
Provisioning: Food: specifically *conversion of light, energy and nutrients into agricultural biomass.*
Cultural: Recreational: specifically *provision of recreational opportunity***.**

This selection represents a sub-set of a much wider suite of benefits derived from this area. For instance the water purification and waste treatment service has not considered the potential removal of any heavy metals, organic chemicals or pathogens that are present. Similarly, natural hazard regulation has focussed on only one component, namely relatively high magnitude flood events. Additionally the ecosystem services assessed may not necessarily be the most important ones. They were selected in order to demonstrate the application and understanding of the core principles of delivering an ecosystems approach.

A simple causal chain has been constructed for each of the ecosystem services considered (Appendix 4). This assists in understanding the drivers behind each of the services, both in terms of the bio-physical processes and the influence of policy drivers on them. In this study these have been simplified and are open to further expansion and interrogation, and may not consider all the factors which affect Otmoor, or all the inter-dependency of relationships which exist among the numerous environmental and social variables. However, they provide a useful method for understanding the interactions among ecosystem services and the interdependencies present in the environment.

Detailed analysis of each of the four ecosystem services considered has been undertaken. This is presented in Appendix 4. An attempt has been made to quantify each service and to provide an economic value associated with the quantification. **The results presented are not intended to be definitive, but rather illustrate a method which informs the debate on applying an ecosystems approach**. With further research and resources the approach could be refined to produce a more accurate valuation. Below is a summary of the key information derived for each ecosystem services assessed.

In order to evaluate better the policy drivers, each ecosystem service is considered for the four different land designations across the Otmoor protected area. With all the assessments, a limited component of the ecosystem service has been investigated. Consequently this should not be considered a comprehensive evaluation of all aspects of the ecosystem service under consideration.

3.2 Regulating: Water purification and waste treatment

3.2.1 Introduction

Within this study, the regulating service 'water purification and waste treatment' considers the retention, recovery and removal of excess nutrients, with a specific focus on the removal of nitrogen (N) and phosphorus (P). The analysis does not consider the removal of organics, sediments, heavy metals or other compounds or the role Otmoor could play in mitigating any impact of pollutants generated by the M40.

3.2.2 Quantification of the ecosystem service

No specific process studies or data were undertaken or were available for Otmoor, which means that the quantitative evaluation of the water purification service was achieved through extrapolation of data from studies elsewhere. Some processes, such as denitrification, are known to be extremely variable both spatially and temporarily, and require substantial research and/or monitoring resources in order to predict confidently the impact on water quality. Therefore, the precautionary principle has been applied in this study; where published data are available from apparently similar wetland systems elsewhere, mean values are rounded down, or the lower end of a range of values is quoted. Where processes have been little-studied and/or results are not quantifiable, the contribution of the process is acknowledged but no figures are given. A full description of the approach undertaken in provided in Appendix 4 including an extensive literature base.

In general, different processes are responsible for the removal of N and P from groundwater and surface waters, either by temporary storage within the wetland or by permanent export from it. Some indication is given below of what might be considered a conservative value for functions where research evidence is available. The land surface at Otmoor is not uniform and homogeneous. A simple field reconnaissance visit indicated that the hydrology, and hence the biogeochemistry, of these areas would differ. Therefore, estimates for N and P removal and storage distinguish between 'flat' areas and 'depressions' based on this assumption. (Note: references for these estimates are provided in Appendix 4).

The following N-storage and export processes were considered (with estimates of impact):

- Plant uptake: 50 kg ha^{-1} a^{-1}
- N-fixation in soil organic matter: positive but not quantifiable.
- Adsorption of N as ammonium: positive but not quantifiable.
- Denitrification: 70 or 105 kg N ha^{-1} a^{-1} on level ground; 105 kg N ha^{-1} a^{-1} in depressions.
- Ammonia volatilisation: positive but not quantifiable.

The following P-storage and export processes were considered (with estimates of impact):

- P storage by plant uptake: 20 kg P ha^{-1} a^{-1}.
- P storage by adsorption and precipitation in the soil: positive or negative effect but not quantifiable.
- P storage by retention of particulates: highly variable and probably positive though not quantifiable.
- Phosphine emission: 2 kg P ha^{-1} a^{-1}.

In addition, it was estimated that N and P exported by land management approximated to 15 kg N ha^{-1} a^{-1} and 3 kg P ha^{-1} a^{-1}

In summary of N and P storage and export

- Total N removed by storage and export: 170 kg N ha^{-1} a^{-1} on flat land, 190 kg N ha^{-1} a^{-1} in depressions.
- Total P removed by storage and export: 25 kg P ha^{-1} a^{-1}.

The potential of land for the removal of N and P is calculated by multiplying these storage and export values by the areas of land concerned. In the case of P, this includes all of the land, while for N, separate calculations are made for depressions and flat land, the rates being slightly higher in depressions. The areas occupied by depressions are those shown in Table 2 for 0.5 m out of bank flood depth. Flat land is calculated by difference from the total area for each land designation type. The values calculated for N and P removal are given in Table 3.

Based on the quantification process, it is suggested that Otmoor has the potential to remove or store in excess of 143,000kgN and 20,000kgP on an annual basis. This represents a potential sink for nutrients which otherwise would have potentially found their way into local watercourses and ultimately the River Ray, adversely impacting on in-stream water quality. However, this analysis has not attempted to evaluate the long-term potential for Otmoor to act as a nutrient sink. It is worth noting that as Otmoor acts as a sink for nutrients, and as such has the potential to improve water quality downstream, the nutrient balance of the site may well, over time, change. If excessive nutrients are introduced to Otmoor then the ecological character may well alter towards a highly eutrophic system. It should be noted further that this is a potential value and actual removal and storage would depend on the water quality being delivered to the site and the duration of contact between flood waters from the River Ray and the surface of Otmoor.

Table 2. Areas (ha) of land designation types at Otmoor.

Land designation	Total area	Depressions	Flat land
ESA	357.0	71.0	286.0
SSSI	160.0	21.9	138.1
RSPB	210.0	28.2	181.8
Non-ESA	100.0	15.7	84.3

Table 3. Potential annual N and P removal (kg a^{-1}) from land designation types at Otmoor.

Land designation	Depression (N)	Flat land (N)	Total N removal (kg N a^{-1})	Total P removal (kg P a^{-1})
ESA	13,490	48,620	62,110	8,925
SSSI	4,165	23,474	27,638	4,000
RSPB	5,352	30,911	36,263	5,250
Non-ESA	2,974	14,339	17,313	2,500
Total			143,324	20,675

3.2.3 Economic evaluation

There is no universally accepted method for valuing the removal and storage of N and P by wetlands. The approach presented here has its limitations, but again it provides an approach for discussion rather than a definitive outcome. The potential of wetlands to remove N and P may have an economic value equivalent to the costs of removal at treatment plants but only if there is a need to remove nitrates and phosphates from the particular supply (i.e., if levels are above the regulatory thresholds, such as those to meet the requirements of the Water Framework Directive). If quality standards are already met by water supplies before the processes of temporary storage and export from the wetlands there would not be any saved costs.

A range of different cost estimates for the removal and treatment of N and P have been considered (Appendix 4). The value estimates have been based on a unit cost of £8.32 kg^{-1} ha^{-1} a^{-1} for N and a unit cost of £12.00 kg^{-1} ha^{-1} a^{-1} for P.

The different land designation types all possess the potential to remove nutrients and thus improve water quality in the River Ray catchment. However it should be noted that fertiliser application and soil nutrient status will vary amongst these designations. The management of the ESA (including the RSPB land) and SSSI areas will be less intensive in terms of nutrient application. Therefore the utilisation of these areas to remove nutrients will differ both in terms of removal of direct applications and the desirability to use these areas to remove nutrients from flood waters derived from upstream. The potential value of each of the areas is summarised in Table 4.

Based on the values provided in Table 4, the economic value of the removal and storage of N and P by Otmoor could be greater than £1.4m per annum. However, this represents a 'potential' value, i.e. there would need be an input of water across the site on every day of the year the receiving waters to benefit from this reduction in N and P. Outside of times of inundation the exchange between the waters in the River Ray and the surface of Otmoor is limited considerable and hence the potential is reduced. When duration and frequency of inundation are taken into account, and an annual inundation period of approximately two weeks is considered, the economic value associated with removing N and P reduces to an estimate of approximately £12,515 per annum reflecting the shorter duration of contact between the land surface and the flood waters.

Table 4. Potential value of N and P removal at Otmoor across different land designations.

Land designation	Total area (ha)	Potential value N removal (£,000 a^{-1})	Potential value P removal (£,000 a^{-1})	Total potential value (£,000 a^{-1})
ESA	357	516	107	624
SSSI	160	229	48	278
RSPB	210	301	63	365
Non-ESA	100	14	30	174
Total	827	1,060	248	1,441

It should be noted that this value is highly uncertain and presupposes that the removal of N and P are required. However, the water quality in the River Ray can be poor and is subject to substantial inputs of N and P (Neal *et al.*, 2006). Therefore, the removal of nutrients may be required to achieve 'good ecological status' under the Water Framework Directive. However, a strong note of caution is required when considering sites such as Otmoor with regard to their potential to remove nutrients and improve water quality. It is essential the long-term ability of a site to maintain itself as a healthy ecosystem and to operate within environmental limits are considered appropriately.

3.3 Regulating: Natural hazard regulation

3.3.1 Introduction

The regulating service 'natural hazard regulation' considers the control of flooding (both fluvial and coastal) and protection from storms. In the context of this study the focus is on the alleviation of, and protection downstream from, fluvial flood events.

Flooding on Otmoor is common both directly from rainfall (surface water flooding or impeded drainage) or following high flows on the River Ray (see Appendix 4). The flooding is partly due to the low-lying nature of Otmoor but also to the controlling of water levels. The amount of water flowing through Otmoor via a network of drains is heavily controlled and the dynamics of flood waters are governed by water level management practices rather than natural drainage.

The approach attempted within this case study produced results of limited value for the natural hazard regulation ecosystem service. This was primarily due to the complexity of the catchment hydrology and the lack of readily accessible data. Consequently not all the issues associated with this ecosystem service have been addressed.

3.3.2 Quantification of service

Several methods were investigated to understand better the role Otmoor plays in regulating flooding and to understand the role of different land designations on flood hazard regulation. A full description of the process is provided in Appendix 4.

The Flood Estimation Handbook (FEH, Institute of Hydrology, 1999) is the recognised standard methodology for the prediction of flood events for UK rivers. The FEH was interrogated to quantify and evaluate the role of Otmoor in regulating natural hazard resulting from flooding. However, as the catchment descriptors used in the FEH modelling reflect the properties of a catchment as a whole it was difficult to assess the role of Otmoor in terms of its location without conducting empirical studies beyond the scope of this work.

A review of published literature on Otmoor and its role in flooding was also conducted. The published evidence was inconclusive in terms of defining the role Otmoor plays in attenuating flooding downstream, and especially in major urban areas such as Oxford. Acreman (*pers. com.*) suggests that due to the nearby confluence of the River Cherwell, flooding along the River Ray, and particularly at Otmoor, often backs up against high water levels in the River Cherwell. This reduces significantly the value of Otmoor in regulating flooding downstream both in terms of out of bank inundation and the velocity of flood flows.

Further hydrodynamic modelling was conducted to predict the depth of floodwater across Otmoor. The modelling predicted a range of depths and flows across Otmoor depending on the return event frequency. For instance, for a 100-year flood event a depth of 1.56 m and a flow of 67.7 $m^3 s^{-1}$ is predicted. Similarly, for a more frequent 2-year flood event, values of 0.45 m and 30.1 $m^3 s^{-1}$ are predicted for depth and flow respectively (Table 5, see also Appendix 4).

The levels in metres above ordnance datum (m AOD) can also be considered as out-of-bank flood level, based on the assumption that at bankfull the river would be at a 2-year return period flow. This is a reasonable assumption based on research into channel morphology and has been previously used for flood models. The out-of-bank flood levels are simply derived by subtracting the 2-year flood level from the other design flood levels.

A further modelling approach considered the amount of water which can be stored within the different land designations at Otmoor when the Ray is in flood. This assessment of water storage was undertaken using a GIS cell based modelling technique (Rodda, 2005) and a digital terrain model (DTM) of the area derived from Environment Agency LiDAR (light detection and ranging) data.

Table 5. Flood flows and out-of-bank flood depths at Otmoor.

Return Period (years)	Baseline conditions	
	Depth (m)	Flow (m^3s^{-1})
2	0.45	30.1
5	0.77	38.4
10	0.98	44.6
25	1.2	52.3
50	1.37	59.3
100	1.56	67.7
100 + 20%	1.8	80.2

This method approximates flood volumes as it does not consider surface roughness and dynamics of flow. Also the effects of the internal water management system are not accounted for. The calculated potential flood areas and volumes are presented in Table 6. These indicate that on an approximate 1 in 100 year return period event (equivalent to a depth of c. 1.5 m, Table 5) Otmoor stores over 3.25 million m^3 of flood water over an area of 3.77 km^2. Despite this area of inundation, the direct impact to properties within the Otmoor basin is negligible, due to the very low housing density. Similarly, the impact to infrastructure is limited to the inundation of footpaths, bridleways and farm tracks. Productive agricultural land would suffer the highest level of direct impact, with potential damage to grassland and arable crops occurring. The benefit of storing floodwaters at Otmoor to downstream communities could not be defined within the scope of this study.

3.3.3 Economic evaluation

Due to the unusual and complicated flood dynamics, the hydrological benefit of storing water within Otmoor has not been defined. Current knowledge of the flood dynamics of the River Ray suggests that retaining water on the floodplain at Otmoor may have a benefit downstream.

Flood storage volumes for land under different management and designation have been calculated. However, it has been beyond the scope of this Study to undertake a full cost-benefit analysis of the different flooded areas and volumes calculated. This would require a separate study of itself, with the benefits calculated as the expected value of annual flood losses averted. In particular, it would be necessary to define and survey the areas of residential and commercial property which would be subject to reduced damage from flooding as a result of the different areas of land assumed to be flooded on Otmoor. Nevertheless, a brief outline of an approach that could be taken is provided in Appendix 4.

Table 6. The potential areas and volumes of land flooded for different out-of-bank flood depths, taking into account local topographic variation within each designated area.

Land designation	Total Area (km^2)	Area of flooding (km^2)				Volume of flooding (m^3)			
		0.5m	1.0m	1.5m	2.0m	0.5m	1.0m	1.5m	2.0m
SSSI	1.6	0.22	0.45	0.77	0.79	50,512	232,571	540,340	934,840
RSPB	2.1	0.28	0.79	0.93	0.94	87,195	372,088	812,149	1,283,020
ESA	3.57	0.71	1.36	1.52	1.76	52,508	194,015	401,146	627,330
Non ESA	1.0	0.16	0.38	0.43	0.47	224,128	773,995	1,648,808	2,381,214
All Otmoor	8.24	1.36	2.97	3.77	3.96	414,049	1,570,649	3,264,235	5,213,850

3.4 Provisioning: Food production

3.4.1 Introduction

The majority of the Otmoor area is farmed as part of the Upper Thames Tributaries Environmentally Sensitive Area (ESA). Three distinct areas are present reflecting the land management and designation regimes:

- An area of Wet Grassland managed by the RSPB;
- An area of Extensive Permanent Grassland that includes MoD land;
- An area of Permanent Grassland.

An area of arable land, farmed conventionally and not under any ESA management agreement, is also included in the study area. These different land management practices have been evaluated for differences in terms of food production and income. It should also be noted that the grazing practices vital for food production in terms of livestock weight-gain are also essential conservation management tools, without which the necessary sward structure and diversity required for the provision of suitable habitat for breeding waders would be considerably harder to achieve.

3.4.2 Quantification and economic evaluation

It has been possible to produce a theoretical valuation of what might be achieved under each management regime on Otmoor. The value has been calculated by estimating the theoretical live-weight gain achievable by beef cattle during the grazing season and placing a value on the total kilograms of gain from each hectare according to stocking rates permissible within the scheme. Current ESA payment rates for management tiers are shown for each managed grassland unit within Otmoor. On the non-ESA arable land there is the potential to grow either a winter wheat crop if land cultivations can take place immediately after harvest or a spring crop of barley if land conditions determine that autumn cultivations cannot take place. The Farm Management Pocket Book gives average yields for feed winter wheat of 8.25 tonnes per hectare and for feed spring barley of 6.0 tonnes per hectare. Costs of production for both crops would have to be taken into consideration. The values are summarised in Table 7.

There are clear differences between the economic value associated with agricultural food production for the different land designations (Table 8). The range of incomes available from land at Otmoor is between £210 ha^{-1} and £389 ha^{-1}, although the area of light land available is limited, and for most of the ESA a maximum of £350 ha^{-1} is most likely, making wheat growing the economically most attractive option for land use, outside the ESA scheme.

Based on the calculated values, food production at Otmoor may range between £225,345 and £272,755 per annum. Where individual farmers' preference is for livestock-based agriculture, it is very likely that the retention of existing levels of funding will be sufficient to sustain most of the environmental practices necessary to maintain and possibly improve the current state of the SSSI. However, individual farmer preference is not predictable and often does not reflect the best economic option. This is evidenced at

Otmoor by the land management practices adopted by the RSPB, which are intended to provide habitat for a range of bird species rather than provide food for society.

Table 7. Summary of income values for different land management practices.

	Wet Grassland (RSPB reserve)	Extensive Permanent Pasture (Otmoor SSSI)			Permanent Grassland (ESA)		Arable (non-ESA)	
					Heavy Land	Light Land	Wheat	Spring Barley
Live-weight gain kg day^{-1}	0.25 kg		0.5 kg		0.75 kg			
Stocking rate Grazing Livestock Unit (GLU)	0.55 GLU		0.55 GLU		1.6 GLU	1.85 GLU		
Beef animals ha^{-1}	0.5		0.5		2	2.25		
Live-weight gain kg/day	0.25		0.5		0.75			
Value ha^{-1}	£15		Grazing restricted £37.50	No restriction £105	Heavy land £315	Light land £354		
Hay		2.75 t ha^{-1} - 3.75 t ha^{-1}						
Net Income	**£285**	**£327**	**£212**	**£210**	**£350**	**£389**	**£359**	**£235**

Table 8. Potential income for the different land designation types at Otmoor.

Land designation	Total area (ha)	Range (£ ha^{-1})	Range (£ $annum^{-1}$)
ESA	160.0	350 ï 389	56,000 - 62,240
SSSI	210.0	210 - 347	44,100 - 72,870
RSPB	357.0	285	101,745
Non-ESA	100.0	235 ï 359	23,500 - 35,900
Total			225,345 ï 272,755

3.5 Cultural: Recreation

3.5.1 Introduction

Otmoor is an important 'cultural' component of landscape. It is significant in terms of a range of cultural services such as landscape aesthetics and the historic environment. The stakeholder analysis also indicated that Otmoor provided an important recreational resource. The access to areas of high conservation value facilitated by the RSPB and a network of footpaths and bridleways has complemented the overall cultural importance of the area. A variety of recreational activities take place at Otmoor. The principal activities are walking and dog walking, horse riding, cycling or bird watching.

3.5.2 Quantification and economic evaluation

Modelling of information provided by the RSPB on visitor numbers suggests that an average of just over 300 per month visit the site, with just under an average of 300 per month of these visiting specifically to bird watch. Projections over the next five years, based on the time series from 1999 to 2007, suggest that these numbers are quite stable and will neither increase nor decrease significantly unless there are major changes in reserve management. Numbers of dog walkers and walkers on the reserve are low and appear to be declining, while numbers of horse riders and cyclists, although also low, appear to be stable. In summary, the great majority of visitors to the RSPB reserve come to watch birds, and visitor numbers appear to have stabilised at just over 300 per month.

Otmoor, in common with other environmental assets, has both use value (as measured through bird watching and other recreational uses) and non-use existence value. It is not, however, always possible or desirable to express all use and non-use values in monetary terms or even to quantify them in meaningful ways.

A small survey conducted as part of this study sought to understand the likely range of views about Otmoor. Whilst the survey results cannot be used with any validity to assess the use or existence value that is placed on Otmoor it is possible to draw some conclusions. As no entry fee is charged to the RSPB reserve, there is no direct means of establishing the recreational value of at least this part of Otmoor (i.e., the RSPB reserve and its immediate surrounds). Most local people did not wish to pay anything for access to the RSPB reserve whilst about half the visitors expressed a willingness to pay (all within the range of £2 to £5 per visit). The size of the sample and its age and social class bias makes extrapolation to a wider population uncertain. Furthermore, there are no data on the mean distances travelled by visitors to the RSPB reserve and hence their costs incurred in undertaking the visit.

EFTEC (2007) summarises the findings of a number of studies which sought to value recreational visits to wetlands. Each of these studies was set in the context of proposals to improve or create recreational (and other) services and it is questionable whether their results can be transferred from their specific context to this study where there is no proposal to change people's ability to access Otmoor for recreational purposes or to charge for the provision of that service. For the sake of completeness, though, EFTEC assumed that a visit (to the case study of the Wareham Managed Realignment) would be valued at £2 per person, within a range of £0.50 and £5, which is similar to the willingness to pay of those questioned in this study.

No information is available on the proportion of RSPB members within the 300 visitor numbers to the reserve per month so it is not possible to use their subscriptions as a proxy value for the recreational use of the reserve. Considerably more information would be required of visitors to make such an approach meaningful, such as the average number of repeat visits to Otmoor per month, the number of visits to other RSPB reserves and the value placed on other services offered by RSPB membership.

Whilst there are conceptual difficulties to using such proxies to value the existing use and non-use values of a unique area such as Otmoor, they nevertheless could prove to be a useful estimate of the value that society has placed on the RSPB reserve both in terms of its nature conservation and recreational functions, particularly given that the reserve has itself been mostly restored from farmland. A similar-sized area of farmland in southern England would be likely to cost in order of £1m and considerable expenditure, including a £670,000 Heritage Lottery Grant, has been incurred in establishing and managing the reserve. These, discounted to net present values, would provide a minimum estimate of the economic cost of recreating an equivalent asset elsewhere, although they would not account for the 'uniqueness' of Otmoor which is unlikely to be replicated.

It is worth noting that, based on the limited sample size of the stakeholders consulted, the recreational service was not distributed equally across society both in terms of social class or age. Both local people and visitors tended to come from the A/B/C1 social classes, as shown by relatively high median minimum household incomes (locals = £30k [but note that n=5 because most refused to answer this question], visitors = £50k [n=22, with five refusing to answer]) and qualifications. Stakeholders interviewed also tended to be middle-aged or older, with 50% of local people and 66% of visitors aged over 55, and few interviewees with children under 15 in their households (21% of local people and 7% of visitors). This suggests that only certain sectors of society are benefiting from the Otmoor in terms of recreation.

4 ASSESSMENT OF UNCERTAINTY

4.1 Assessment of uncertainty

Crystal Ball[9] (Decisioneering, CO) was used to analyse data uncertainty. The analysis focussed on three of the four ecosystem services and the economic values generated by them for each of the four land designations, under two different climate scenarios. The climate change scenario was used to assess the impact of an external stressor on the ecosystem. (The climate change scenario is described in detail in Appendix 8).

The three ecosystem services included in the analysis were water purification, food provisioning and recreation. Flooding was not included as a service because, as mentioned earlier, there is no reliable information on the value of flood attenuation on Otmoor. However, the influence of flooding on the value of the other three services was included in the analysis. The assessment of uncertainty deals only with the data generated through the evaluations described. As stated before, the assessments are not necessarily comprehensive and therefore inherent uncertainty remains as an artefact of the methodologies adopted.

Water Purification

The following (highly uncertain) assumptions were made:

- Total N removed (kg ha^{-1} yr^{-1})
  - Flat land: triangular distribution with most likely value = 170, minimum = 85 and maximum = 340
  - Depressions: triangular distribution with most likely value = 190, minimum = 95 and maximum = 380
- Cost of N removal at a water treatment plant (£ kg^{-1}): triangular distribution with most likely value = 8.32, minimum = 6 and maximum = 10
- Total P removed (kg ha^{-1} yr^{-1})
  - Flat land and depressions: triangular distribution with most likely value = 25, minimum = 12.5 and maximum = 50
- Cost of P removal at a water treatment plant (£ kg^{-1}): triangular distribution with most likely value = 12, minimum = 7 and maximum = 26

The annual benefit of each land designation to water purification was estimated as the cost of N and P removal at a water treatment plant multiplied by the annual N and P removed in flats and depressions after a flood, taking the extent of flooding and return period into account. The main assumption here is that additional N and P that would need to be treated at a water plant is deposited on the land during flood events.

Food provisioning

The following assumption was made: that cattle rearing or growth of arable crops on the different land designations produced food with the range of values shown previously in Table 7 (Section 3.4). This assumption is likely to be quite robust, with the range of values included in the model due largely to true variability in values rather than overall uncertainty.

Recreation

The following (highly uncertain) assumption was made: that the value of recreation in each of the designated land areas was similar to the value expressed by the willingness of visitors to pay to visit the RSPB reserve, and proportionate to the length of footpath in each area (ESA=5525 m, SSSI=2721.5 m, RSPB=4047 m, non-ESA=3222.5 m; footpaths that demarcate the boundaries between land designations were shared equally between them). The number of visitors to the SSSI was also reduced by 50% to account for the exclusion of visitors from MoD land during use of the firing range. Those RSPB visitors who expressed a willingness to pay were prepared to pay a mean value of £2.38 per visit (standard deviation = £0.96) and this was fitted to a normal distribution. Only 48% of RSPB visitors were willing to pay, and in a small sample (27 people interviewed in one month out of an average of ~300 visitors per month) the 95% confidence interval around this percentage is $\pm$18%; these values were also fitted to a normal distribution.

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[9] Crystal Ball is a spreadsheet-based software programme used for predictive modelling, forecasting and simulations.

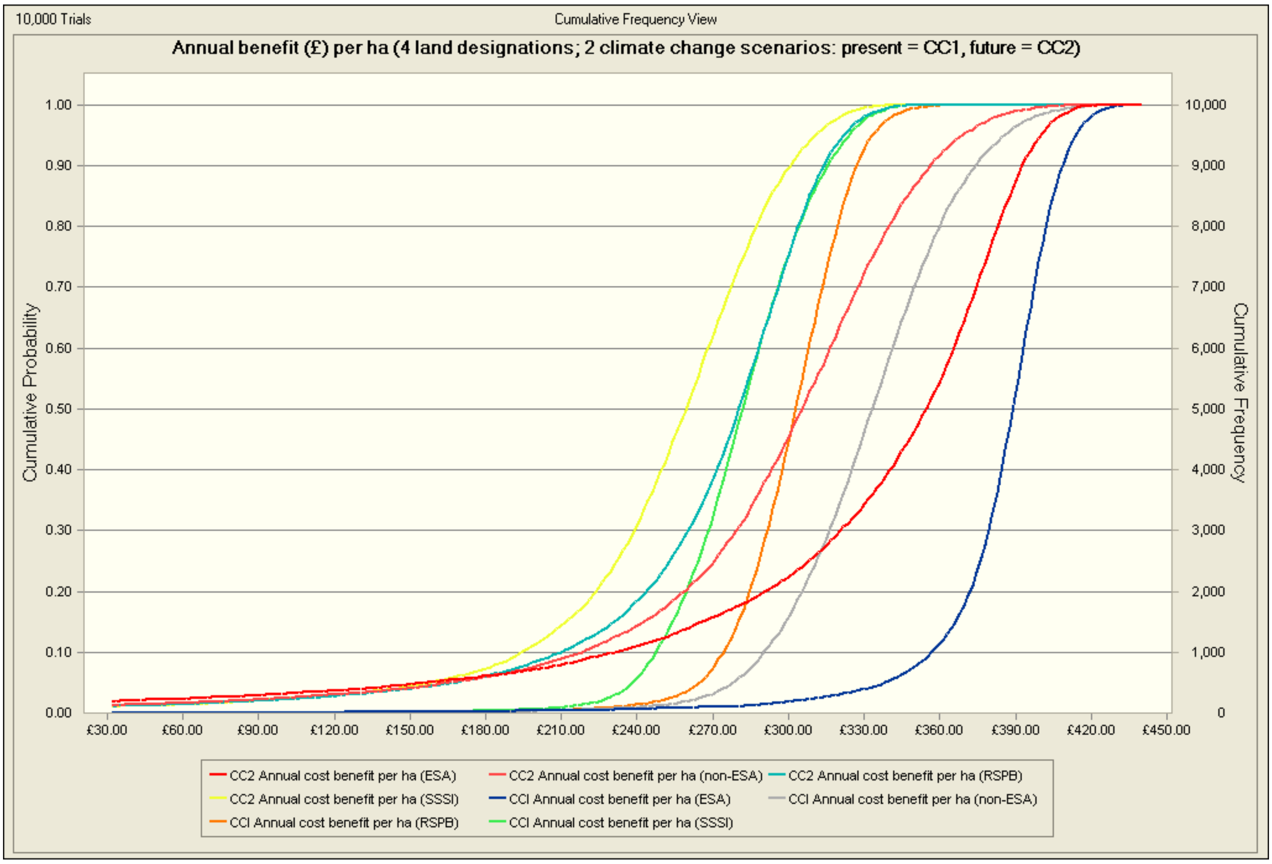
Scenario testing

Two climate change scenarios were assessed based on the flooding of areas shown in Table 6. The assumptions underpinning the climate change scenario is that Otmoor will encountered increased depth, duration and frequency of winter flooding (Appendix 8). The climate change scenario took a duration of flooding based either on a lognormal distribution with a mean of 0.46 months and a standard deviation of 0.6 to represent the present day, or a lognormal distribution with a mean of 1.8 months and a standard deviation of 2.35 to represent a greater duration of flooding under future climate change. These values were themselves based on data for mean and maximum current values for Otmoor. It must be noted that the testing of a climate change scenario introduces a further level of uncertainty into the assessment.

Overall value of Otmoor land designations

The overall annual financial costs and benefits associated with the Otmoor land designations were estimated as the annual value of water purification (combining all four estimated flood levels and return periods), plus the annual values of farming and recreation, minus the costs to farming and recreation of periods of flooding. Figure 2 shows the result of this simulation using a 1-dimensional Monte Carlo simulation (10,000 trials; Latin hypercube sampling). The median (i.e. 50th percentile) estimated benefit ranges from £260 ha^{-1} for SSSI land (10th percentile = £159 and 90th percentile = £301) under an estimated future climate change scenario (CC2) to £390 ha^{-1} for ESA land (10th percentile = £358 and 90th percentile = £409) under current climate conditions (CC1).

Figure 2. Annual benefit per hectare from 1-dimensional Monte Carlo simulation.



Sensitivity analysis showed that flood duration and the value of food production per hectare were the input parameters contributing most to the uncertainty in these estimates of economic value. Any further similar analyses would therefore benefit from a focus on these two parameters. These parameters not only contributed most to uncertainty, but were also the most important determinants of the overall annual value of land (Figure 3), and were amongst the most reliable estimates for model parameters.

Data pedigree was assessed in order to rationalize between data variability and data uncertainty. Hence, when 2-dimensional Monte Carlo analysis was used to separate parameters on the basis of variability and uncertainty (based on data pedigree assumptions presented in Table 9), there was only a very limited effect on forecast estimates, so 1-dimensional Monte Carlo estimates is likely to be sufficient for analyzing these data. The data pedigree assessment utilized a matrix adopted by van der Sluijs et al. (2003) and based on earlier work by Funtowicz and Ravetz (1990). Four categories were used to estimate data pedigree, to assign a score and to describe as uncertain or variable:

- **Theoretical structure**: (4) established theory, (3) theory-based model, (2) computational model, (1) statistical processing, (0) definitions.
- **Data input**: (4) review, (3) historic/field data, (2) extrapolated, (1) calculated, (0) none.
- **Peer acceptance**: (4) total, (3) high, (2) medium, (1) low, (0) none.
- **Colleague consensus**: (4) all but cranks, (3) all but rebels, (2) competing schools, (1) embryonic field, (0) no opinion.

Table 9. Estimated pedigree of data (based on approach in Van der Sluijs *et al.*, 2003 and Funtowicz and Ravetz, 1990). A score of 1=low pedigree and 4=high pedigree (see Table 10 for justification of scores).

	Estimated data pedigree					
Data/estimates	**Theoretical structure**	**Data input**	**Peer acceptance**	**Colleague consensus**	**Mean score**	**Variable or uncertain ?**
N & P removal (flats & depression)	1	2	2	2	1.75	Uncertain
Cost of N or P removal	1	1	2	2	1.5	Uncertain
Area of flooding	3	3	2	3	2.75	Variable
Value of food production	4	4	3	3	3.5	Variable
Number of visitors						
RSPB reserve	4	4	3	3	3.5	Variable
Rest of Otmoor	1	1	2	2	1.5	Uncertain
Willingness to pay for recreation						
RSPB reserve	2	2	1	2	1.75	Uncertain
Rest of Otmoor	1	1	1	1	1	Uncertain

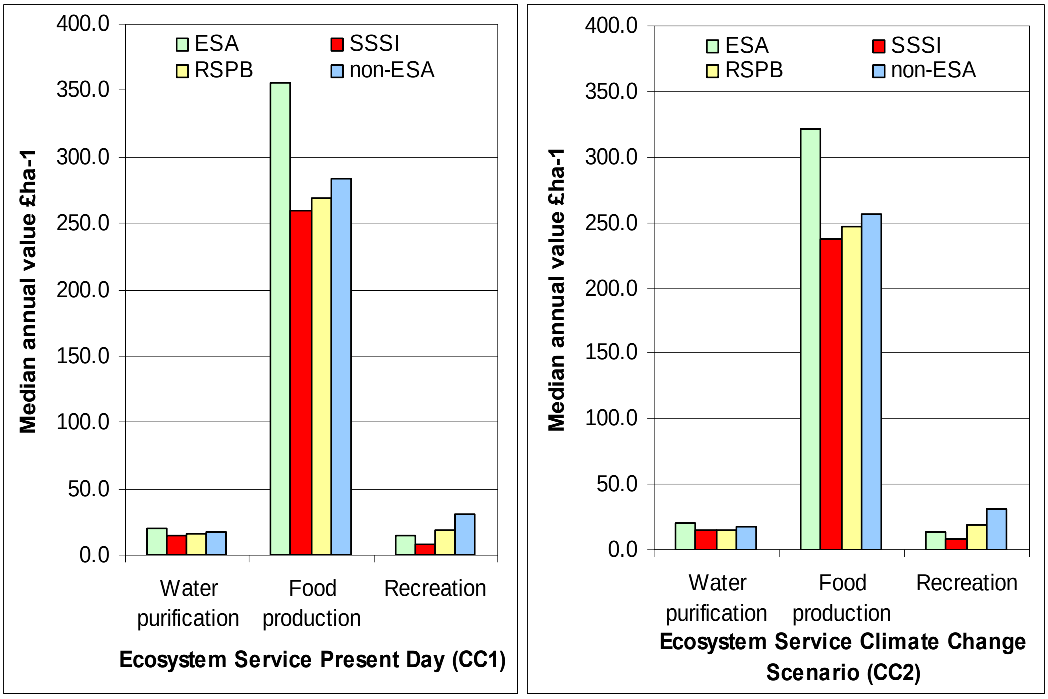
There are many assumptions and uncertainties in this analysis; all the data, with the possible exceptions of area of flooding, value of food production, and number of visitors to the RSPB reserve, contain substantial uncertainties, as described in the data pedigree assessment, and are subject to challenge. Despite this, the analyses show quite clearly that of the input parameters included here, farming is very likely to contribute most to the economic value of Otmoor, with at least the possibility that there is a substantial economic contribution from purification of water through removal or nutrients. This latter function is based on highly uncertain data and should be treated with caution. The potential direct economic contribution of recreation on Otmoor is negligible when compared to farming and, possibly, water purification. However, it is worth noting that agricultural production, especially influenced by the CAP, may well reflect a market distortion which undervalues the natural system and the other benefits provided.

The methodologies used to quantify and subsequently apply economic values to the ecosystem services contain inherent uncertainties. The ecosystem services are maintained by complex interactions among environmental and social parameters. Not all of these interactions will have been assessed to a high level of confidence within the scope of this study. Uncertainties in the results of the analysis conducted as part of this study could be reduced by:

1. Directly measuring the removal of N and P during flooding events on the SSSI and determining whether this removal would otherwise need to be performed by a water treatment works.
2. Collection of more data for particularly sensitive input parameters such flood duration and the value of farm outputs.

An extension to the analysis could be inclusion of the costs of flooding to homes and businesses other than farming if Otmoor did not retain flood water. This has not been possible to do in this project because of disagreement between experts on whether there is any such contribution by Otmoor. However, if Otmoor did prevent such flooding then this would become a major component of the cost-benefit analysis.

Figure 3. Median annual value of each of the land designations based on water purification, food provisioning and recreation for the present day and under a climate change scenario.



5 EVALUATION OF AN ECOSYSTEMS APPROACH

5.1 Introduction

Defra recognise that the adoption of an ecosystems approach should deliver more effective and efficient outcomes for the management of the natural environment. The approach should also allow better informed decision-making which balances economic, environmental and societal objectives (Defra, 2007).

The evidence to support the implementation of an ecosystems approach can take many forms: scientific research, analysis of stakeholder opinion, statistical modelling, public perceptions and beliefs, anecdotal evidence, and cost-benefit analyses; as well as a judgement of the quality of the methods that are used to gather and synthesise the information.

Evidence for policy development is usually considered to comprise three components[10]. First is hard data (facts, trends, survey information). The second component is the analytical reasoning that sets the hard data in context. Third is an evidence base comprising stakeholder opinion on an issue or set of issues. This tripartite approach allows identification of any weakness in the hard data on which policy options may be based; it is then possible to fall back upon the analysis that underpins the data. If there is any weakness in the analysis, or any risk that others could bring an alternative interpretation to the table, then there is a need to go back to the stakeholders in order to understand the different interpretations that could give rise to different analyses of the same set of data.

In undertaking this project, the tripartite approach has been adopted and formalised by using the approach to environmental assessment that facilitates an awareness, identification and incorporation of uncertainty as recommended by Van der Sluijs *et al.* (2003). Hard data were identified and collated. Analytical reasoning and modelling was applied to these data. Stakeholders were consulted in order to understand the local context and implications of the policy drivers. By adopting this approach it is possible to specifically address and relate the role of uncertainties in the context of policy advice and to provide useful assessments of uncertainties.

5.2 Methodological observations

5.2.1 Data and methodological constraints

The assessment of ecosystem services is an essential component of the application of an ecosystems approach (Laffoley *et al.,* 2004). This study was predicated on the fact that limited new empirical studies would be conducted. An attempt was made to utilise existing data and methodologies whenever possible in order to assess their utility for future application.

The availability of the appropriate data and standard, agreed methodologies varied across the four ecosystem services assessed (Table 10). Information on food production was the most accessible and unequivocal, but is still open to interpretation. Limited directly relevant site-specific information was available for the three other ecosystem services (with the fortunate exception of data on visitor numbers being provided by the RSPB for part of the site, which is unlikely to be the case for most other sites). Routinely collected information on *inter alia* hydrology, water quality, nutrient processes, and recreational activity are either absent or in a form which requires considerable manipulation to identify the benefits delivered by Otmoor. Similarly, despite several published studies across the ecosystem services assessed, agreed methodologies are limited for quantifying the benefits. No agreed standards have been published or accepted, and consequently a range of potential approaches exist. This results in either the need for expensive, time-consuming studies to be undertaken on a site by site basis or 'rough and ready' estimates to be conducted which will always, and understandably, be subject to criticism if they lead to contentious policy and management proposals.

[10] http://www.defra.gov.uk/science/how/evidence.htm

Despite a substantial, and growing, body of published information on the economic value of wetlands (EFTEC, 2006), there is no agreed methodology for assessing each of the ecosystem services considered in this study (de Groot *et al.*, 2006). An economic valuation can be assigned to each ecosystem service; however, the data requirements for robust estimates are likely to preclude use of the approach in short term investigations. Alternatively, the degree of uncertainty arising from using data with clear limitations can undermine the estimated values that are generated.

Table 10. Summary of data and information sources.

Ecosystem service	Data availability	Quantification methodologies	Economic valuation methodologies
Water purification	Good literature base and published empirical studies. Limited site-specific data. No site-specific studies of nutrient dynamics. No routine collection of data necessary for site evaluation.	Many published studies. No single, accepted method for quantification of N and P storage and removal.	Some published examples. No single accepted method for valuing N and P storage and removal.
Natural hazard regulation	Broad literature base and published empirical studies. Some site-specific studies but not in terms of flood regulation. No routine collection of data necessary for site evaluation.	Many published studies. Published accepted methodologies on estimating flood events. No single, accepted method for quantification of the downstream benefit of flood regulation.	Some published examples. Published guidance on flood defence projects and flood hazard valuation. Accepted methodologies require substantial study.
Food production	Good data availability from published sources. Handbook estimates used and assumed to reflect actual *in situ* farming returns.	Payment information readily available on Defra website.	Some published examples. Theoretical methodology exists. Potential disjunct between theoretical value and actual value.
Recreation	Limited comparable data available in published literature. No routine collection of data necessary for complete site evaluation. Fortuitous data available from RSPB monitoring.	Limited relevant examples from published literature. No single, accepted method for quantification of recreational benefit.	Some published examples of recreational value of wetlands, but few of direct relevance to Otmoor. Several economic methodologies available for consideration. No single accepted method for valuing recreational activity.

Based on the tripartite approach for developing policy discussed above, the first element, hard data, could be considered weak for both Otmoor and for applying an assessment of ecosystem services within wetland environments. Of principal concern is the lack of collection of the appropriate site-specific data upon which an assessment of ecosystem services can be conducted and the absence of agreed and standardised methodologies to follow. Without these two components, understanding fully the benefits derived from the natural environment, and their subsequent incorporation into policy objectives, remains problematic.

5.2.2 Causal chains

The causal chains present a simplification of the interactions that exist in the natural environment. The production of causal chains assists in understanding some of the challenges faced in implementing an ecosystems approach. One factor has been identified as being universal to the four causal chains: land management. However, this one factor is driven by a range of processes and policies. Some of the processes and policy drivers are beneficial to more than one ecosystem service, others result in compromise. For instance, the hydrological regime which results in flooding at Otmoor may generate a degree of natural hazard regulation and assist in removing nutrients from the River Ray, but it may also reduce agricultural production and make recreational access problematic.

The causal chains also assist in identifying knowledge gaps, especially in understanding processes which aid identification of future monitoring effort and applied research needs. For instance, despite the plethora of publications on nutrient dynamics, there is still no single, agreed method for identifying and predicting N and P removal from wetlands. The absence of such a methodology is exacerbated by the lack of routine site-specific collection of the information necessary to make informed estimates on the benefits being delivered.

The biodiversity interest at Otmoor is of national significance. The appropriate land management is essential if this conservation interest is to be maintained and enhanced. If the linkages, demonstrated through the causal chains, between ecosystem structure and functioning are poorly understood, and the data required for this understanding is of questionable utility, then the balance between conservation, sustainable use and an equitable share of the benefits arising from Otmoor may be undermined. Maintaining this balance is a key principle of the ecosystems approach.

5.2.3 Reasoning and modelling

The analysis undertaken contains many assumptions and uncertainties. Consequently all the data are subject to challenge. Despite this, the analyses indicate clearly that the land management practice in the form of farming contributes most to the economic value of Otmoor. Uncertainties in the results of the analysis conducted could be reduced primarily by:

- Collection of more data for particularly sensitive input parameters such flood duration and the value of farm outputs.
- Directly measuring the removal of N and P during flooding events on the SSSI and determining whether this removal would otherwise need to be performed by a water treatment works.

The modelling techniques employed in this study are all standard and relatively easy to replicate, using off the shelf software such as Crystal Ball and ARC-GIS. The intention has been to demonstrate an approach to implementing elements of an ecosystems approach. Therefore, whilst the individual outcomes are all open to question, interrogation and potentially refinement, it is the approach taken which is considered more important than the absolute nature of outcomes.

5.3 Participatory framework

The first principle of the practical application of the CBD's Ecosystem Approach is that objectives of management of land, water and living resources are a matter of societal choice (Maltby, 2000). The overriding view of decentralised, local stakeholders is that the conservation importance of Otmoor should be maintained, that flooding should be encouraged to reduce flood risk elsewhere and that increased recreational use should be discouraged. These objectives are compatible with a variety of national policy objectives, including national biodiversity action plans, Planning Policy Guidance 25: Development and flood risk, and elements of the Water Framework Directive. However, there are national policy drivers, such as the Countryside and Rights of Way Act 2000 and Natural England's health campaign which advocates accessing the natural environment in order to realise health benefits, which could conflict with the local views.

The resolution of such potential conflicts should be based on an understanding of the limits of the functioning of the site and achieved through an appropriate balance between the conservation of the ecological interest and use of the natural diversity at Otmoor. The stakeholder analysis has indicated that this process is relatively successful at Otmoor but, despite this, should not be taken for granted. The implications of national policies need to be carefully communicated to local stakeholders and the implications, and benefits, need to be clearly spelt out. Reciprocally, it is crucial that the multi-functional benefits delivered by a site such as Otmoor are truly recognised and accounted for in decision making.

5.4 Evaluation and application

A primary objective of this study has been to evaluate the applicability of the principles of an ecosystems approach (*sensu* Defra) as against the current level of understanding of a protected area and to demonstrate a prioritisation framework for balancing policy objectives against the value of ecosystem services.

Despite subtle differences among the four different land designations, in economic terms, the key driver on the site is the land management for food production. The significant, nationally important biodiversity interest is dependent on the agricultural practices for delivery. These practices are enshrined in the conservation management plans and underpinned by policy drivers such as the CAP. The delivery of conservation goals is also influenced by the flood dynamics, the water quality in the river Ray and the level of human disturbance across the site. A possible conclusion from this study is that to ensure that the wetland conservation interest are maintained in perpetuity the economics of agricultural production, including their role in protecting and enhancing biodiversity, need to be resolved and delivered by the market to the local land manager. Whilst there are some concerns across both the SSSI and the RSPB Reserve, in general terms this is occurring at Otmoor. This confirms that key policy objectives are being prioritised through ecosystem service delivery. However, an alternative analysis is that economic value of agricultural production represents a market distortion and the natural system is relatively undervalued. If this market distortion persists biodiversity could become compromised.

Management of the area is devolved to local owners, tenants and stakeholders. However, whilst this is a form of decentralisation, there is still influence (and in some cases perceived interference) from government agencies where national policies are being enforced by local officials. The resolution of a balance between agricultural production and conservation management would lessen these concerns.

Change management, one of the principles of the ecosystems approach, is in evidence at Otmoor. On-going and evolving agri-environment schemes are altering the land management practices. The historical drainage of much of the area is slowly being removed and, in the case of the RSPB Reserve, the pump drainage is being utilised to keep areas wet. The hydrology of the site and the length of the growing season are being affected by climate change. In the light of this, the RSPB is considering future options for the accommodation of a more natural flood hydrology through the removal of bunds and a reduction in the pumping regime.

The current site management across the four designation areas does not fully consider all forms of relevant information. As discussed above, the evidence for understanding a range of ecosystem services is not readily available. The stakeholder engagement also identified a tension between the traditional, indigenous knowledge of the long-standing farming community and the government officials and conservation managers. Whilst this is not unexpected, it is important that the local knowledge is better utilised and the stakeholders possessing a significant history of managing the area are more gainfully engaged.

Enhancement of other ecosystem services, such as improving water quality in the River Ray through nutrient removal, improving access for recreation or utilising Otmoor's potential storage capacity to attenuate floods downstream, must consider the overriding importance of agriculture and its beneficial relationship to conservation delivery. Thus the policy drivers need to be prioritised in order not to compromise the ecological integrity of the site. Conversely, the desires of local people to access more freely the MoD land needs to be balanced with the national requirement to train military personnel In the case of the Otmoor protected area the priority must be to conserve and enhance the ecological interest through appropriate agricultural policies and payment schemes. This should be prioritised against other drivers unless the net benefit of, for instance, fundamentally altering the area is the choice of society.

As a result of climate change wetland areas are increasingly being considered as carbon sinks. This ecosystem service may prove to be significant both currently and into the future.

5.5 Conclusions and recommendations

Defra is seeking to move towards an ecosystems approach in order to conserve, manage and enhance the natural environment. This involves shifting the focus of policy-making towards a more holistic agenda and seeking to ensure that the value of ecosystem services is fully reflected in policy and decision making. This case study has investigated elements of an ecosystems approach within the context of a protected area.

Based on the information derived through this case study it is possible to assess how successfully an ecosystems approach is being implemented at Otmoor ('successes') and also how current practices diverge from the principles of an ecosystems approach ('failures') (Table 11).

Table 11. Analysis of convergence with ('successes') and divergence from ('failures') an ecosystems approach.

	Implementation of an ecosystems approach at Otmoor protected area
'Successes'	Stakeholders recognise that Otmoor provides many benefits. Some ecosystem services are recognised and reflected in decision-making. Decision-making is devolved to several levels. Some environmental limits are recognised and respected.
'Failures'	Several policy drivers do not recognise the inter-connected nature of the natural environment. Perverse incentives may exist which promote agricultural production at the expense of maintaining and enhancing biodiversity. Ambiguity exists regarding the identification and evaluation of ecosystem services. Opportunities for a more effective delivery of environmental outcomes are being missed. Prescriptive rather than adaptive management is routinely applied

Whilst not exhaustive, Table 12 demonstrates the strengths and weaknesses of the approach taken to assessing ecosystem services in this case study and the implications for the application of an ecosystems approach within similar protected wetland areas.

Table 12. Strengths and weaknesses of the approach adopted in assessing this case study.

	Assessment of the approach to the Otmoor protected area case study
'Strengths'	Able to assess the views of local stakeholders. Recognition by stakeholders of the effects of local management on adjacent areas. Ecosystem services broken down into understandable functions and processes. Simple causal chains assisted in understanding multi-dimensional issues. Identified major economic benefits derived from the natural environment. Assessment of uncertainty.
'Weaknesses'	Only assessed a limited sub-set of ecosystem services. Difficult to balance value of local versus national interests (e.g., local desire for access to SSSI and MoD need for an operational firing range). Lack of data for key parameters makes estimation of values problematic and reduces their credibility. Cost of obtaining these data on a site by site basis likely to be prohibitive. No accepted or standardised methodologies. Unable to assess fully the interrelated nature of ecosystem services. May not have focussed on the most important ecosystem services.

The importance and relevance of policy drivers and the views of local stakeholders has been assessed. A conceptual and empirical method for quantifying and valuing ecosystem services has been developed. The outcomes of the assessment of ecosystem services are clearly open to debate and questioning. The principle adopted has not been one of absolute accuracy in quantifying ecosystem services, but rather the development of a framework which provides an insight into the issues relating to implementing an ecosystems approach.

An ecosystems approach, when applied appropriately, can provide a comprehensive integration of human management activities thereby achieving sustainable use of ecosystem services and maintaining ecosystem integrity. The application and implementation of the approach is still in its infancy and this has been reflected in the outcomes of this study.

The following broad recommendations are made based on the results of this study:

- There is an urgent need for improved systematic collection of data relevant to understanding ecosystem services;
- In the absence of empirical data there needs to be agreement on the use of surrogate data;
- Standard methodologies (such as those proposed by Maltby (in press)) need to be developed and implemented in order to quantify ecosystem services;
- A portfolio of reference projects / sites should be established to assist both in communicating the benefits of applying an ecosystems approach and in understanding ecosystem functioning and integrity;
- The focus of future research and development should be on the implementation of the approach rather than the absolute value of outcomes;
- Policy development and implementation must become more joined up (and extend out of DEFRA to other government ministries such as health and education) and recognise the multi-functional benefits of protected sites such as Otmoor; and
- The principles of the ecosystems approach needs to be extended beyond protected sites to all of the natural environment, including wetlands, irrespective of their conservation status.

This study should be viewed as one of the first stages in an iterative process both at a national level and also at Otmoor. In order to advance an ecosystems approach, the outcomes of this study should now be taken back to stakeholders to canvas comment and generate discussion. It is possible that this may help them to resolve some or all of the outstanding differences in opinion and to alter their views or land management practices. Or, it might stimulate them to focus on particular aspects of Otmoor land management where there is still a level of uncertainty which impedes decision-making and to provide or request resources to address these limitations.

ACKNOWLEDGEMENTS

The following people are thanked for their help with project:

Neil Lambert of the RSPB is gratefully thanked for his many contributions and that of his staff. Without his co-operation this project would have never got off the ground.

Bruce Tremayne is thanked for allowing the authors to access his wide ranging knowledge and understanding of Otmoor.

All the interviewees are thanked for their patience and time.

All the landowners and farmers who allowed the researchers involved in the project access to the land.

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APPENDIX 1 – OTMOOR PROTECTED AREA

Introduction

'*This boggy common*'
Alexander Croke, 1787

The description of Otmoor provided by Alexander Croke in the late 18th Century is still true in the early 21st Century. Otmoor is a wetland (Tremayne and Lackie, 2001). This fact has shaped its evolution and continues to dominate its functioning today. The 'boggy' nature of the moor has driven the land management practices, the distribution of the local population and the wildlife within the area. Otmoor, whilst not blessed with dramatic scenery or a high public profile has been, and for many of the locals still is, considered 'unique' among lowland wetland sites in England (Emery, 1983).

Physical characteristics

Otmoor (NGR SP5814) is situated upstream of the confluence of the River Ray and the River Cherwell less than 10km to the north-east of Oxford (Figure 1). The Otmoor wetland covers an area of approximately 10 km^2 in the River Ray catchment, a tributary of the Cherwell with a catchment area of 287 km^2. Otmoor is located in the lower reaches of the Ray, approximately 3 km from the Cherwell confluence (Figure 1) in the form of a shallow bowl-like depression. The majority of the Ray catchment is underlain by impermeable Oxford Clay and river alluvium with smaller areas of limestone (White limestone, Corallian, Cornbrash, Portland and Purbeck beds) to the south, east and north (Figure 2). This is reflected in the distribution and extent of soils in the catchment (Figure 3). The details of which are summarised below (Table 1). More details of the soil map units are provided in Appendix 5. The whole of Otmoor is underlain by impermeable Oxford Clay with clayey soils developed in river alluvium, and classified as Fladbury series. The soils at Otmoor are mapped as Fladbury 1 association (813b) on the national soil map (1983), as shown in Figure 3 for the Ray catchment. The impermeable nature of most of the catchment means a river flow regime very responsive to rainfall, although in the lower reaches with gentle gradients flow velocities are low and flood waters can back up from the confluence with the Cherwell when the level of the river is high.

Figure 1. Location map for Otmoor and the River Ray catchment.

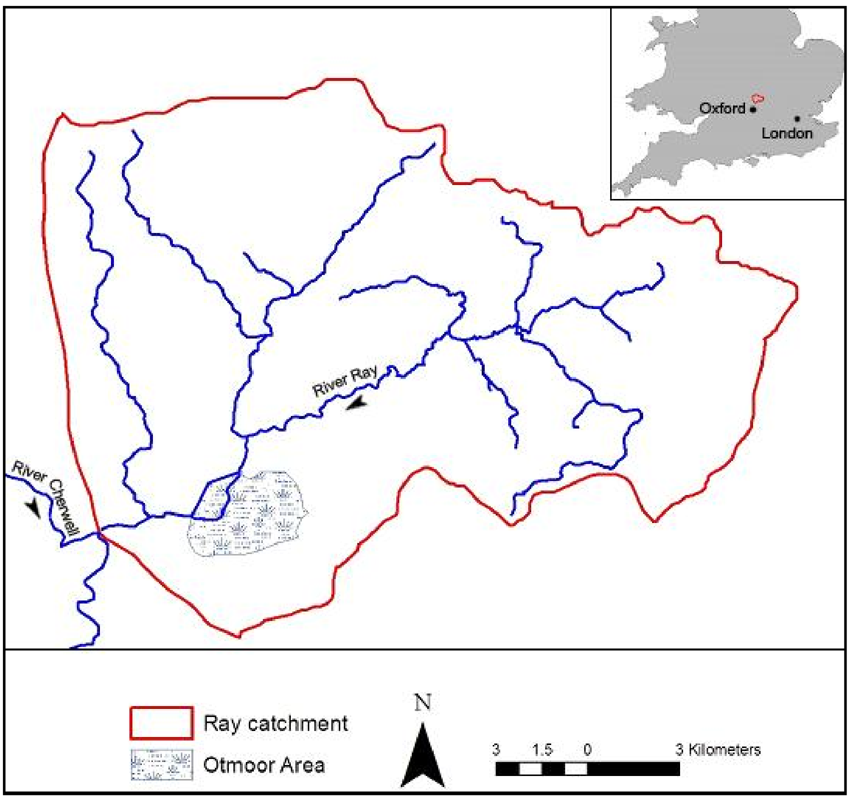
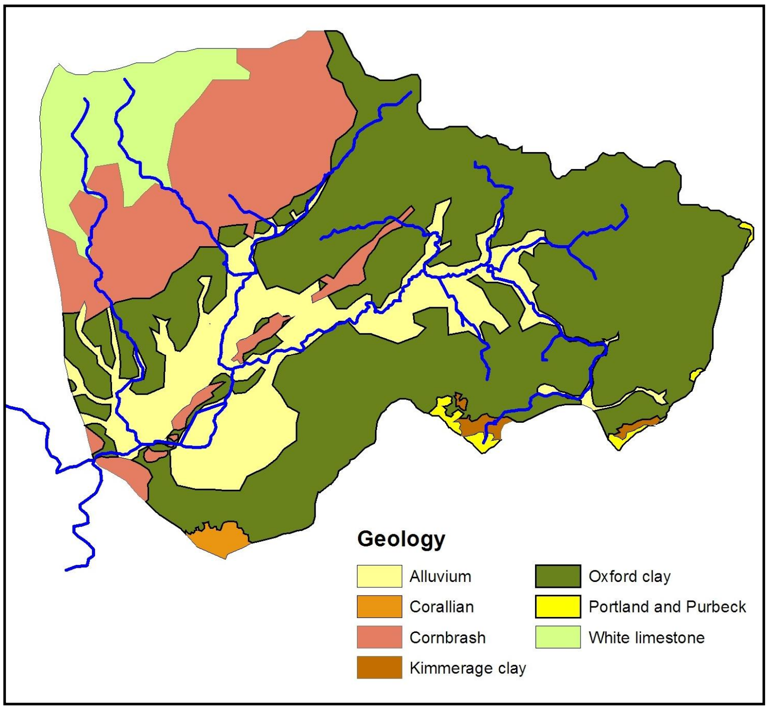


Table 1. Soils of the River Ray catchment.

Major soil group	Extent (km^2)	Percentage cover	Description
Lithomorphic soils	6.28	2.2	Shallow calcareous soils
Pelosols	19.40	7.0	Clayey soils
Brown soils	66.82	24.0	Well drained, permeable soils
Surface-water gley soils	145.56	52.3	Poorly drained soils of low permeability
Groundwater gley soils	40.34	14.5	Poorly drained soils affected by a groundwater table

The original path of the River Ray would have taken an anastomosing route through Otmoor (Sear *et al.*, 2001). There is evidence that the extensive flooding experienced in 1872, when the entire moor was inundated, was commonplace and a regular occurrence (Gibb and Partners, 1994). However, the area has been extensively drained over the past 200 years starting with the digging of the inner and outer ring ditches

Figure 2. Geology map of the Ray catchment, based on information from British Geological Survey (1968, 1982, 1994 and 2002).



between 1815 and 1820 following the passing of the Enclosure Act. In the 1940s the New River Ray drain was deepened but Otmoor remained classed as land with very severe limitations which restricted use to permanent pasture or rough grazing (Grade 5) (MAFF, 1968) until pump-draining commenced in the late 1960s. The pump-drainage was instigated by Harold Righton (a local farmer) at Noke and resulted in the drying out of much of the south west and north east of the moor to facilitate arable farming.

Flooding on Otmoor is common both directly from rainfall (resulting in drainage being impeded and surface water ponding to occur) and from overbank inundation following high flows in the River Ray. Given that the topographic variation across the moor is less that 0.5m, the flooding is partly due to the low-lying nature of Otmoor but also to the internal management of the water levels. Extensive flooding across Otmoor has occurred as recently as January 2007 (Figure 5). Currently, surface flooding is manipulated and controlled by the internal drainage network to facilitate conservation and grassland management.

Figure 3. Soil map of the Ray catchment, based on information provided by the Soil Survey of England and Wales (1983). (For full descriptions of soil types see Appendix 5).

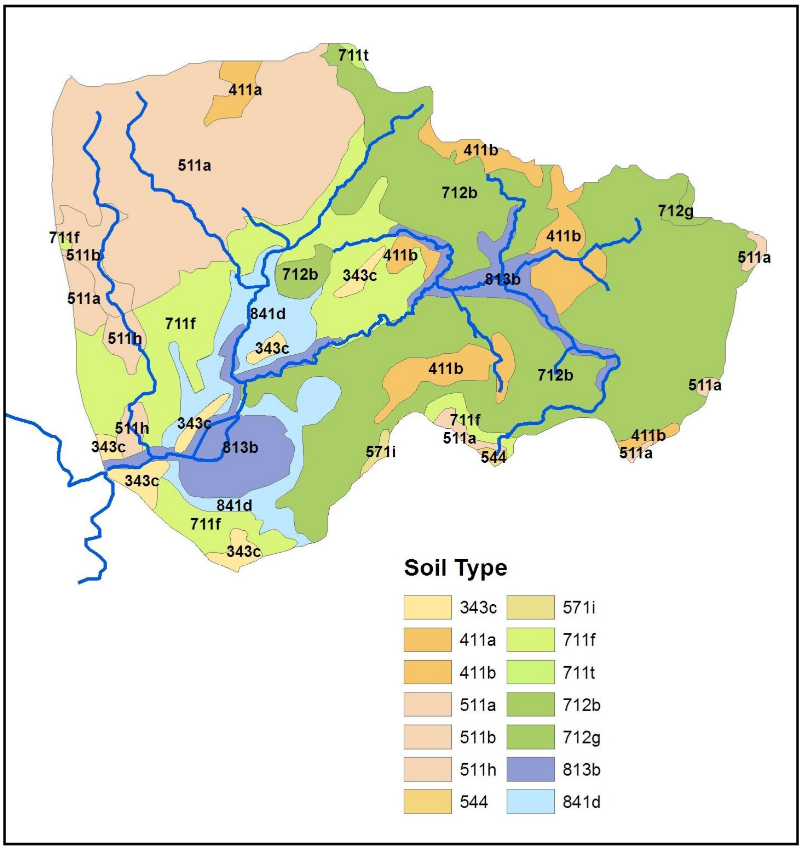
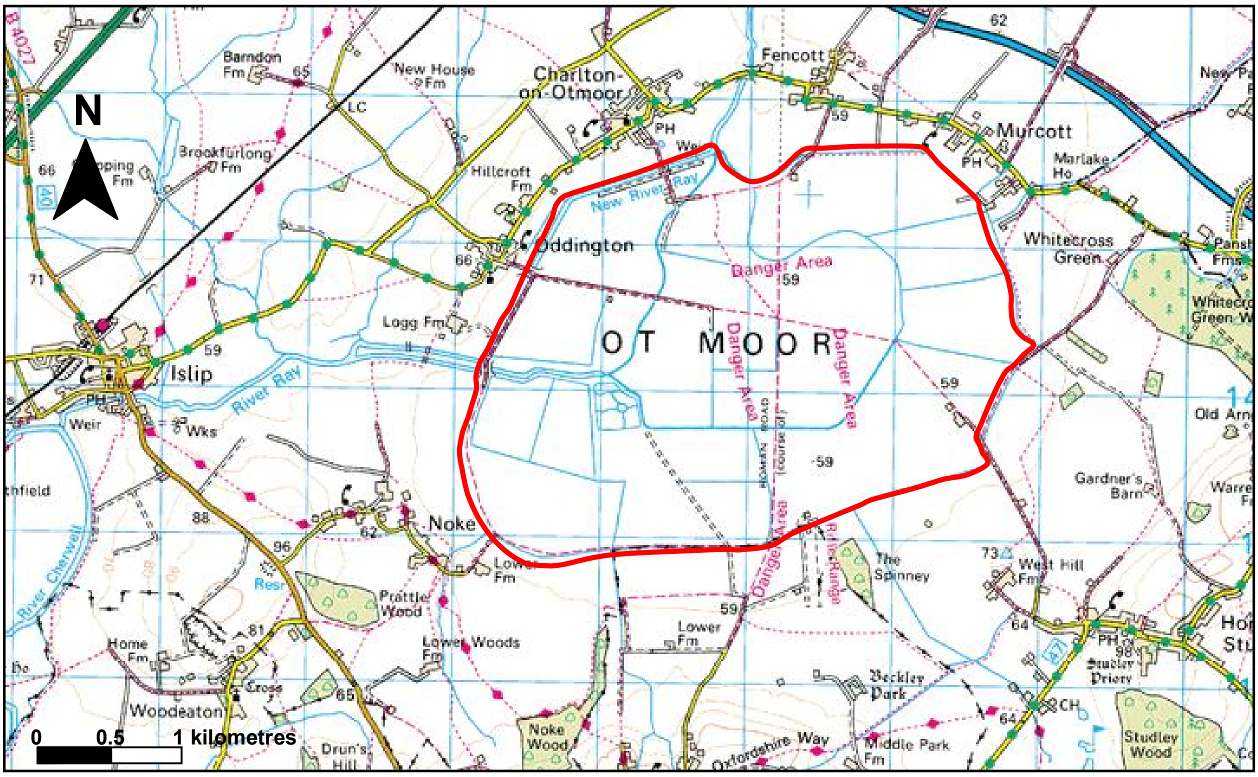


Figure 4. Otmoor limit of the study area (red line), topography, surface drainage and surrounding villages. (Reproduced with permission from the Ordnance Survey under licence No. 100031955).



Land use and designation

Archaeological evidence suggests that the moor and the surrounding area have supported human occupation for about 6,000 years. By the Doomsday Book of AD1086 the current pattern of human occupation is established in its modern locations (Tremayne and Lackie, 2001). Today, nine parishes touch on or are adjacent to the moor: Beckley, Elsfield, Woodeaton, Noke, Islip, Oddington, Charlton-on-Otmoor, Fencott and Murcott, and Horton-cum-Studley. The population of these parishes in 2001 was approximately 2,500. Human settlement is restricted to the slightly higher land above the central 'bowl' of the moor. The main part of the moor is virtually uninhabited. Other than agricultural practices the only influence of humans is the presence of footpaths, some of which date back to pre-Roman times.

Because of the limited influence of human settlement on the area, and despite being less than 10km from Oxford, the moor has retained the atmosphere of a wilderness. The land use within the low-lying land of Otmoor is dominated by agriculture and conservation management, which in turn depends on agricultural management practices. The study site focuses on the land within the Outer Ring Ditch (Figure 4) and can be assigned to one of four land categories based on designations and land management: the Upper Thames Tributaries Environmentally Sensitive Area (ESA); the Royal Society for the Protection of Birds (RSPB) Otmoor Reserve; the Otmoor Site of Special Scientific Interest (SSSI), which predominantly occupies land owned by the Ministry of Defence (MoD) Estates; and non-ESA land (Figure 6).

Figure 5. Flooding of the MOD land. Otmoor, January 2007.

The Upper Thames Tributaries Environmentally Sensitive Area (ESA)

The Upper Thames Tributaries ESA covers approximately 27,200 hectares of the Thames Valley and the lower reaches of five tributary rivers, the Windrush, Evenlode, Glyme, Cherwell and Ray. These six valleys radiate from Oxford, to the west, north and north-east, draining parts of the Cotswold dip slope, the upper Thames Valley, parts of the Vale of Aylesbury and parts of the Northamptonshire ironstone belt. The majority of the ESA lies within Oxfordshire, with areas extending into Gloucestershire, Northamptonshire and Buckinghamshire.

The ESA contains a rich and diverse mix of landscape features, wildlife and ecological value, as well as a wide range of historical features, that combine to form a strong riverine character. The river valleys incorporate elements of lowland river landscape, such as pasture and meadow hedgerows, pollarded riverside willows, parkland and copses, as well as stone river bridges. The Thames and the Ray contain the wide, flat and open areas, such as Otmoor.

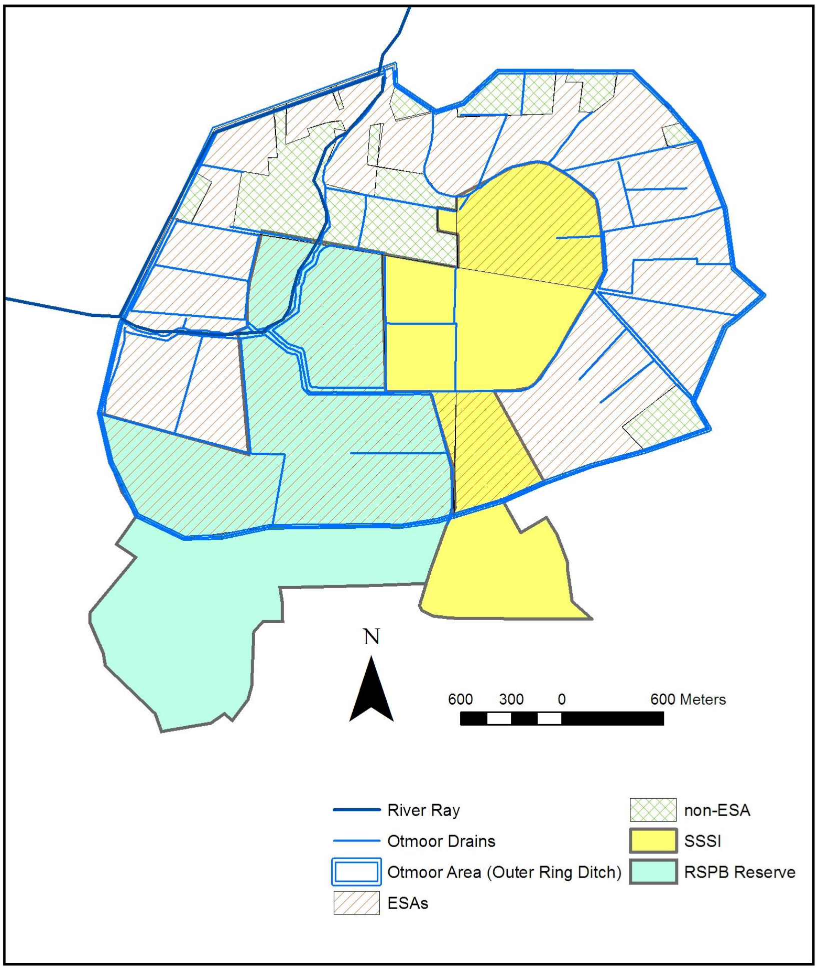
Much of the ecological interest of the ESA is associated with the wet grassland of the valley bottoms. Of particular importance are the remnants of semi-natural hay meadow and wet pasture. These support botanically diverse swards and several rare and scarce plant species, regionally important populations of breeding waders and a rich invertebrate fauna, including the marsh fritillary butterfly *Eurodyas aurinia*.

The management options for the different landscape types that have been entered into ESA agreements for the Upper Thames Tributaries were specified by the England Rural Development Programme (ERDP)[11]. This was a part-farm ESA with three main management options that land could be entered into:

1. All permanent grassland must be entered into option one. The grassland must be grazed (with limits on stocking rates), and restrictions are placed on fertiliser, and herbicide application. Agreement holders are also required to maintain ditches and other landscape features, such as pollarded willows, walls and hedgerows;
2. Option two relates to the management of wet grassland, the option one restrictions apply and, in addition, wetter conditions must be maintained by raising water levels in ditches during the spring and summer; and
3. Option three provides for the reversion of arable land to permanent grassland or wet grassland, and the enhancement of the nature conservation interest of ponds, ditches and rivers by establishing grass buffer strips on arable land.

Parts of the Otmoor SSSI and the RSPB reserve are also covered by the Upper Thames Tributaries ESA. Although the ESA scheme is now closed to new entrants, the current level of support will be maintained until the end of the life of the agreements. Defra introduced a new Environmental Stewardship Scheme in March 2005 which supersedes (with enhancements) the ESA and Countryside Stewardship Schemes.

Figure 6. Land designations and drainage on Otmoor.



[11] http://www.defra.gov.uk/erdp/docs/national/annexes/annexx/uttrex2.htm

RSPB Otmoor Reserve

The RSPB bought the Otmoor site in 1997 when it had been identified as one of the top potential wetland restoration sites in the country. Since 1997, the RSPB has been able to extend the site as additional land contiguous to the reserve has become available for purchase and subsequent restoration to wetland. The total amount of land now owned by the RSPB at this site is over 260 hectares.

In 1997 Otmoor was the most important single site within the Upper Thames Tributaries ESA for wetland birds as it was home to 41 pairs of breeding wading birds, including lapwings, redshanks, snipe and curlews. The RSPB began to restore the site in 1998 in partnership with the Environment Agency (EA) and with support from the Heritage Lottery Fund (HLF) and many others. A project team of RSPB and EA staff has overseen the work from concept to the present day. They designed the habitats, completed feasibility studies, and involved a variety of specialists from conservationists and ecologists to landscape architects, land agents and civil engineers.

Between 1982 and 2002 there were significant national declines in wading birds associated with wet grassland areas such as Otmoor. For instance, national populations declined by 38% for lapwing *Vanellus vanellus*, 61% for snipe *Gallinago gallinago*, 40% for curlew *Numenius arquata* and 29% for redshank *Tringa tetanus* (Wilson *et al*, 2005). Otmoor is now considered the most important site for breeding wading birds in Oxfordshire, the Upper Thames Tributaries ESA and Central England, and is also nationally important for wintering teal *Anas crecca*, shoveler *Anas clypeata* and pintail *Anas acuta*.

The RSPB management has ensured that Otmoor now has a greater number of birds and generally more wildlife. There are three times as many breeding wading birds and ten times as many wintering ducks such as wigeon *Anas penelope* and teal since the site has come under RSPB's management. New species have also been attracted to the RSPB reserve, including pochard *Aythya ferina*, bittern *Botaurus stellaris*, tufted duck *Aythya fuligula*, common tern *Sterna hirundo*, ringed plover *Charadrius hiaticula*, little ringed plover *Charadrius dubius* and great crested grebe *Podiceps cristatus*. Corncrake *Crex crex* are also believed to have bred. Hairy dragonfly *Brachytron pratense*, Roesel's bush cricket *Metrioptera roeselii* and black hairstreak butterfly *Satyrium pruni* have colonised.

The RSPB Otmoor reserve also provides a quiet, countryside experience close to Oxford with easy access from the M40, A34 and A40 attracting local birdwatchers and members from the local area and further afield. It is one of Oxfordshire's prime bird watching locations. The winter waterfowl create an impressive winter spectacle as does the starling roost in the reedbed. It is one of the best places to see hobby *Falco subbutea* in the area and attracts a range of wintering raptors including merlin *Falco columbarius*, peregrine *Falco peregrinus* and hen harrier *Circus cyaneus*. The site also attracts good numbers of passage waders for an inland site and this is also a key attraction especially in May. The dragonfly and butterfly populations offer an additional attraction for local people, notably brown hairstreak *Thecla betulae*, black hairstreak *Satyrium pruni* and hairy dragonfly *Brachytron pratense* (Otmoor is the only site in the county supporting the latter species).

The site is flat and provides easy walking with an extensive network of public rights of way and permissive paths on the reserve. The Oxfordshire Way passes along the edge of the reserve. In wet conditions, the public rights of way and part of the visitor trail can become boggy making the site less attractive at times. However, despite the good and relatively easy access, the RSPB does not intend to develop the site as a major visitor attraction.

The RSPB has considerable ambition for Otmoor. The reserve is one of the largest projects restoring arable land to wetland anywhere in the UK. Over the next 25 years the RSPB's vision is to see the full suite of lowland wetland habitats restored in a mosaic, enabling colonisation by species such as bittern, marsh harrier *Circus aeruginosus*, bearded tit *Panurus biarmicus*, black-tailed godwit *Limosa limosa*, spotted crake *Porzana porzana*, otter *Lutra lutra* and marsh fritillary *Euphydryas aurinia*. The intention is that Otmoor will continue to have a thriving population of breeding waders with numbers reaching national importance through further restoration and reserve extension. This should enable wading birds to re-colonise restored wetland habitats elsewhere within the Upper Thames. Numbers of wintering waterfowl should also continue to increase and achieve international importance. Management will enable the important invertebrate fauna and flora to flourish and facilitate the recovery or re-colonisation by key species.

The RSPB plans to conserve and manage the moor using a cattle-based farming system provided by the local farming community, supported by local contractors and the RSPB. Mechanical management will be minimised as the reserve matures and is able to support grazing for longer periods in the year. The viability of this farming system will be supported by environmental grants. Action will be taken to facilitate the restoration of a naturally functioning floodplain through policy advocacy and the removal of flood banks. Sensitive development of the reserve, which retains the wild character of the moor and provides access and facilities for all, is also planned.

The RSPB intends that the reserve will become a flagship demonstration site, being used regularly for advisory and education by a wide audience, particularly covering wetland restoration and management. The intention is that the local community will cherish Otmoor as a valuable resource for recreation, learning and a means to enhance their quality of life through developing further the strong links with the local community in order to foster understanding, appreciation and support for the work of the RSPB.

Otmoor SSSI

Otmoor SSSI covers 211.6 hectares of the central area of the moor (Figure 7). The site is designated for the wide range of habitats it supports, many with nationally uncommon plants and animals. Approximately half of the designated site is herb-rich damp grassland which grades into wet sedge and coarse grassland. Other habitats present include semi-improved grassland, a semi-natural woodland block, dense hedgerows and standing water pools and ditches. A full citation is provided in Appendix 6.

An unusual member of the herb-rich sward is the hybrid between the heath dog violet *Viola canina* and fen violet *V. persicifolia*. The Otmoor SSSI is one of only three sites in the UK, and the only one outside the East Anglian fens, known to support fen violet. Fen violet is regarded as Endangered in Britain (Cheffings and Farrell 2005) and is one of the plants included in English Nature's Species Recovery Programme (Palmer, 2006).

The wetter areas within the herb-rich meadows contain a diverse flora of sedges including the uncommon tawny sedge *Carex hostiana* and flea sedge *C. pulicaris* and the nationally rare downy-fruited sedge *C. tomentosa*. Other less common species present include meadow rue *Thalictrum flavum*, marsh valerian *Valeriana dioica*, tubular water-dropwort *Oenanthe fistulosa* and marsh stitchwort *Stellaria palustris*. Within the ditches the regionally uncommon fine-leaved water-dropwort *Oenanthe aquatica* occurs. The largest pool in the SSSI, known as the Pill, is rich in uncommon aquatic species including water violet *Hottonia palustris* and bladderwort *Utricularia vulgaris*.

The invertebrate fauna of the site is diverse and contains many nationally and regionally uncommon species, including several listed in the British Red Data Book of Invertebrates. There are several species whose foodplants are found largely in unimproved meadowland. These include the sawfly *Hartiga xanthosoma* on meadowsweet, the buprestid beetle *Trachys troglodytes* and the marsh fritillary butterfly *Euphydryas aurinia* on devil's-bit scabious *Succisa pratensis*, the longhorn beetle *Agapanthia villosoviridescens* on marsh thistle *Cirsium palustre* and the forester moth *Adscita statices* on sorrel *Rumex acetosa*. The blackthorn thickets contain large populations of the nationally restricted black hairstreak and brown hairstreak butterflies. This site has the only colony of marsh fritillary butterfly currently known in Oxfordshire, and represents the second most easterly station for this butterfly in Britain. Other regionally uncommon species present include the emperor moth *Saturnia pavonia*, the shield bug *Zicrona caerulea* and the longhorn beetle *Anaglyptus mysticus*. The ditches and pools contain several water beetles including *Agabus uliginosus, Enochrus isotae* and *Helophorus dorsalis*, while emergent vegetation and shallow water supports the reed-beetle *Donacia impressa*, and the hoverflies *Anasimyia transfuga* and *Parhelophilus frutetorum*. Other uncommon species recorded in recent years include the large soldier fly *Stratiomys potamida* and the dragonfly *Sympetrum sanguineum*.

For management and reporting purposes the site is divided into seven units (Figure 7). In the recent (October 2007) SSSI condition assessment[12], 20.78% of the site was considered to be in favourable condition (units 1 and 5), 42.08% in unfavourable recovering condition (units 3, 4, 6 and 7) and 37.15% in unfavourable no change condition (unit 2).

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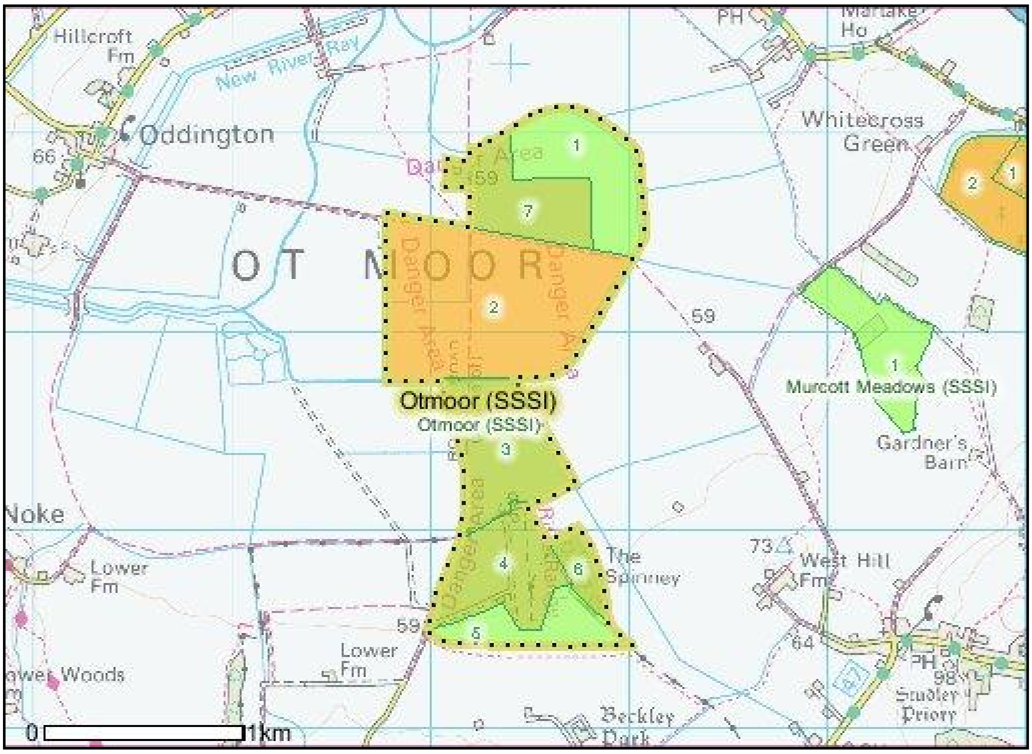
[12] http://www.english-nature.org.uk/Special/sssi/reportAction.cfm?report=sdrt18&category=S&reference=1002962

Figure 7. Otmoor SSSI and management units.



Non-ESA land

The remainder of the study area at Otmoor is farmland comprising ley and permanent pasture and arable. Grazing of pasture is by sheep and cattle. Some of these areas are improved considerably.

Table 2. Extent of land designation types at the Otmoor study site.

Land designation	Area (ha)
ESA	644.7
RSPB reserves	210.4
Otmoor SSSI	160.0
Non-ESA	100.3
Total	1115.4

Summary

The four land designations are of unequal size. The exact areas are shown in Table 2. It must be noted that these values do not represent the full extent of each of the designation types, only the areas within the boundary of the study area. For instance, the SSSI covers a total of 211.6 hectares of which only 160.0 hectares lies within the study area boundary (see Figure 7).

APPENDIX 2 – STAKEHOLDER RESPONSES

Local stakeholders

Introduction

In addition to the national and regional Government policies and objectives, the equitable approach to conservation and sustainable development, as advocated through an ecosystems approach, has as two key principles that management should be decentralised to the lowest appropriate level and that all relevant sectors of society should be involved.

In order to assess the relevance and importance of the policy objectives and drivers, the a total of 44 stakeholders were interviewed face-to-face or by telephone between December 2006 and March 2007. This represented a relatively comprehensive range of stakeholders but did not address every potential stakeholder.

Table 1. Stakeholders interviewed, with brief summary of the policy drivers that influence them and the implications of these for the management of Otmoor.

Stakeholder	Examples of policy drivers	Implications for management of Otmoor
RSPB staff, volunteers and visitors	Management plan for RSPB reserve and requirement to meet needs of financial sponsors; maintenance of rights of way.	A focus on conservation, with birds an obvious but not sole priority. A need to achieve biodiversity and access targets required by financial sponsors.
Natural England	Site of Special Scientific Interest (SSSI) notified under Section 28 of the Wildlife and Countryside Act 1981, and maintenance of this through Environmental Stewardship Agreements with farmers.	Grazing of wet meadows essential to maintain biodiversity and to control sedges.
District & parish councillors	None in particular: a desire to represent their electorate many of whom feel intimately bound to Otmoor.	A desire to return Otmoor to its condition before large scale drainage and arable agriculture in the 1960s.
Local government staff responsible for biodiversity	Biodiversity Action Plans.	A focus on conservation of rare and endangered species and the habitats that support them.
Environment Agency	Environment Act; Water Resources Act; Flood control; Wildlife & Countryside Act.	Management of water quantity and quality on Otmoor mainly to achieve conservation objectives and to prevent risk of damage to property or human life; secondary focus on preventing flooding of agricultural land.
Farmers	Environmental Stewardship Agreements entered into for economic and nature conservation motives; Common Agricultural Policy.	Focus on maximising productivity and profitability of agriculture, but with a desire to maintain the character of Otmoor.
Ministry of Defence	Maintenance of operational capabilities of Otmoor firing range whilst complying with the requirements of the Wildlife & Countryside Act 1981 to manage the SSSI.	Use of tenant farmers to maintain Otmoor SSSI so that MOD resources need not be spent.
Local residents	Wide range	Generally a desire to return Otmoor to its condition before large scale drainage and arable agriculture in the 1960s.

Stakeholders were asked the following questions:

1. What, if anything, do you understand by the term "ecosystem services"?
2. One simple definition of "ecosystem services" is that they are the benefits to people and wildlife provided by a natural area. What do you think are the main benefits of Otmoor to a) people and b) wildlife?
3. How would you rank these services in order of their importance to you?
4. What do you think is the main reason for visits to Otmoor by the general public?
5. What influence, if any, does farming on Otmoor have on the delivery of ecosystem services?
6. What influence, if any, does flooding on Otmoor have on the delivery of ecosystem services?
7. What influence, if any, does RSPB use of land on Otmoor have on the delivery of ecosystem services?
8. What influence, if any, does MoD use of land on Otmoor have on the delivery of ecosystem services?
9. Are there any other positive or negative interactions between the ecosystem services that you identified?
10. How might climate change affect any of the interactions that you have identified?

Stakeholder responses

The following is a summary of stakeholder responses, and identifies areas of agreement and disagreement.

What, if anything, do you understand by the term ñecosystem servicesò?

Most stakeholders had "…never heard of it before." However, when the concept of ecosystem services was explained to them in the subsequent question they understood what it meant.

One simple definition of ñecosystem servicesò is that they are the benefits to people and wildlife provided by a natural area. What do you think are the main benefits of Otmoor to a) people and b) wildlife?

Stakeholders identified the following benefits of Otmoor to people and wildlife:

People

- Livelihood
    - Farming (although much reduced in recent times. For example approximately 100 people in Horton-cum-Studley were involved in agriculture in 1901, but only four people are involved now (Timothy Hallchurch, local councillor, pers. com.).
    - RSPB staff
    - Ministry of Defence staff
    - Contractors (e.g., fencing and agricultural contractors)
    - Public houses serving visitors to Otmoor (although village shops and other services have declined in number in recent years (T. Hallchurch, pers. com.)).

- Housing: there is only one residence on Otmoor itself, which is occupied by a farming family. However, in Otmoor Ward there were 973 households with a population of 2455 in the 2001 census[13]. This ward covers the "Otmoor Towns" of Islip, Charlton-on-Otmoor, Fencott, Murcott, Horton-cum-Studley and Noke. There were no strong calls for housing to be allowed on Otmoor itself, but limited new housing in the Otmoor villages, probably focusing on infilling and social housing for local people, was suggested by some stakeholders.

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[13] http://www.neighbourhood.statistics.gov.uk

- Recreation for local people and visitors.
    - Bird watching: this includes more traditional "birding", but also appreciation of the aesthetics of tens of thousands of roosting starlings at certain times of year.
    - Walking and dog walking
    - Horse-riding
    - Volunteering on RSPB reserve ("a green gym")
    - "Escape" and a sense of well-being. This was a recurrent theme when speaking to local people, who also felt a strong sense of belonging to the area, summed up by the leader of an anthropological study of Otmoor people, who stated: *"We have been repeatedly amazed by the sense of belonging to an integrated society with a deep pervasive feeling for local heritage both in human and environmental terms, which one finds in the Otmoor villages, and particularly those centring on Charlton-on-Otmoor"* (Bixby 2001) and *"…we were impressed by what seemed to be a strong sense of community and a high level of personal well-being in Otmoor…'Otmoor folk' on the whole appeared to be remarkably happy"* (Harrison 2001). The Otmoor villages are built on the rim of low hills surrounding Otmoor and local residents have ready access to the moor.
    - Views: it may not be necessary to set foot on the moor to appreciate it – the views across it can engender a sense of well-being, and South Oxfordshire District Council regard the view to be worthy of conservation. For example, children in the local school have stated: *"I like to see the clouds coming in, I can see a lot of sky and can see a long way"* (Anne Purse, local councillor, pers.com).
- Purification
    - Otmoor may assist in removing nutrients from the River Ray during flood episodes. Much of Otmoor is under environmental stewardship, so the use of fertilisers is considerably reduced. Water quality in the River Ray remains poor because of nutrient inputs throughout the catchment, although fish diversity and abundance is improving (Graham Scholey, Environment Agency, pers.comm.)
- Flood control
    - Otmoor is capable of storing water during flood episodes and this may help to protect residences and land both upstream and downstream.

Wildlife

- Habitat
    - Otmoor is unique for this part of England in its size, lack of roads and villages, and the low visitor numbers, which means that habitats are relatively undisturbed and provide a refuge for many different species.
    - Otmoor also acts as a "staging post" for several bird species on migratory routes.
- Species
    - Several rare species, other than birds, are present on Otmoor (e.g., marsh fritillary and fen violet).
    - There is the potential for Otmoor to produce "an excess" of birds that will then move to adjacent areas and repopulate them (although there is also a danger that the RSPB reserve will act as a "honeypot site" and attract an excess of predators).

How would you rank these services in order of their importance to you?

Different stakeholders naturally ranked different services provided by Otmoor in different ways, according to their own interests. As Lackie (2001) states: *"…there have frequently been several 'sides', depending on whether those involved in the debate want to concentrate on flowers, or butterflies, or birds, or just get on with farming."* However, there was a general consensus across most stakeholders that the ranking of services should be:

1. Supporting: Biodiversity: specifically, acting as a refuge for biodiversity.

2. Cultural: Recreational: specifically, provision of recreational opportunity. This was ranked equal second with Provisioning: Food: specifically, conversion of light, energy and nutrients into agricultural biomass.

3. Regulating: Pollution control and detoxification: specifically, the removal of phosphorus and nitrogen.

4. Regulating: Natural hazards: specifically, reducing the likelihood of extreme flood events.

5. Defence: MoD training on the Otmoor firing range (although most stakeholders recognised that the MoD presence on Otmoor has assisted with service 1 above by preserving the habitat and making access to it more difficult).

The spread between ranks 1 and 5 above was not wide, with most stakeholders agreeing that all of these services are important.

What do you think is the main reason for visits to Otmoor by the general public?

Recreation, by definition, is the reason for visits to Otmoor by the general public (as opposed to visits by contractors, farmers, RSPB staff and others employed on the moor).

Bird watching is one of the main reasons for recreational visits to Otmoor, particularly to the RSPB reserve, and especially if visitors have travelled from greater distances. The RSPB reserve also holds family days which can attract children with more of an interest in attractive insects, planting of reeds and other non-ornithological aspects of the reserve. Other visitors come simply to walk (Otmoor features in some books on walking in Oxfordshire) or to experience the "magic" of Otmoor and its skyscape. This magic is described by most stakeholders as a sense of space, timelessness, isolation and wilderness in an otherwise crowded part of the UK, and can best be summarised by a series of published quotes:

"One of the last open wildernesses in Britain; an empty territory possessing a remarkable feeling of remoteness. There is a loneliness on the moor that can't be described. It is a remote and lonely place with a haunting atmosphere; a strange, half-wild, half-forgotten place, its sedgy depths awash in winter, its green lanes choked with weeds in summer" (Scargill undated).

"…to ride or walk there in an Autumn twilight is to find oneself in a place as remote from man as Barra or Knoydart" (Buchan 1940).

"[Otmoor] has grown on people's imaginations; its wildness, its inaccessibility to motor transport, its resulting peacefulness and sweet air and the unspoilt geographical unity of this old fen surrounded by low hills" (Treglown 1983).

"When I first visited the area I did not see that Otmoor was very different from other flat areas but I have to say that its qualities have gradually made me change my mind with successive visits…I accept that the area is rather unique…" (Emery 1983).

"[Otmoor has]… a special character as its attraction to artists and writers bears witness. While the fact that it is the subject of so many studies of one sort or another… reinforces its special nature both in its geography, land ownership and its population" (Emery 1983).

What influence, if any, does farming on Otmoor have on the delivery of ecosystem services?

Supporting Biodiversity

Farmers have helped to create the existing Otmoor, and agreements within the Environmentally Sensitive Areas scheme have encouraged farmers to help Otmoor become more natural, so helping to achieve wildlife objectives.

Recreational

Farmers are perceived by local stakeholders to be relaxed about access to land they own or lease, which supports the recreational use of Otmoor.

Provisioning: Food

The agricultural productivity of land farmed on Otmoor is low. There is a potential conflict in the desire of farmers to maximise their incomes through increased productivity, and the desire of Natural England and several other stakeholders to maximise biodiversity. Local farmers have been associated with Otmoor for a greater length of time than staff from the RSPB, Natural England and the Environment Agency, but the farmers do not have the scientific training of the latter. It is therefore difficult for both sides to reconcile different points of view when these are based on memory and experience on the part of farmers, and scientific theory and practice on the part of RSPB and regulatory agency staff. The specific and potentially conflicting interests of both sides also lead to some suspicion and mistrust over motives.

Regulating: Pollution control and detoxification
The use of fertilisers and pesticides by farmers on Otmoor may be restricted within land in current ESA agreements.

Regulating: Reducing the likelihood of extreme flood events.
Farming does not appear to have an influence on flooding on Otmoor. Indeed, farmers complain that poor management of flooding on the moor reduces their ability to farm.

Defence: MoD training
Tenant farmers on MoD land support defence training by entering MoD land only at appropriate times and by reducing the cost to the MoD of maintaining the SSSI.

What influence, if any, does flooding on Otmoor have on the delivery of ecosystem services?

Supporting Biodiversity
All stakeholders agree that flooding is both natural and desirable on Otmoor. The main point of disagreement is over the extent to which management of the distribution and duration of this flooding can and should be managed.

Artificial bunding of the RSPB reserve, which is a relic of earlier agricultural drainage engineering, means that the reserve is not in hydrological continuity with the floodplain and receives water from direct rainfall and influx from farmland and the aquifer to the south. The use of pumps means that the RSPB can control water levels within the reserve to favour particular species. The RSPB's long-term vision is to move towards a fully functioning flood plain, which they are prepared to achieve at the expense of a decline in bird abundance on the reserve, as long as this is compensated for by an increase in bird abundance across all of Otmoor.

Recreational
Flooding of land on Otmoor restricts access at certain times in certain places, but all stakeholders who expressed a view believe that this is worthwhile if it supports biodiversity. Flooding is also perceived as "natural" and of aesthetic value in its own right. Indeed, a contrast was drawn by some stakeholders between the flooded SSSI and the relatively dry RSPB reserve during winter 2006/7, with the view expressed that the former "…*looked much more like I would expect a wet meadow to look in winter.*"

Provisioning: Food
There is a perception by members of the farming community that the existence of the bunds and the practice of pumping may lead to inequitable flooding of their land, thus reducing agricultural productivity and reducing bird diversity (through destruction of nests) in non-RSPB parts of Otmoor.

Regulating: Pollution control and detoxification
There are differences in stakeholder perceptions of contamination of Otmoor via flood waters, with some stakeholders strongly of the view that oil and other pollutants from M40 runoff are responsible for polluting parts of Otmoor. The Environment Agency believes that their monitoring does not reveal any problems related to pollution.

Regulating: Reducing the likelihood of extreme flood events.
There are differences in perceptions of the causes of flooding in different parts of Otmoor. Some stakeholders consider that flooding frequency, duration and distribution are unaffected by the existence of bunds around the RSPB reserve, the frequency at which ditches are cleared by the Environment Agency, or the construction of the M40 motorway and its associated balancing ponds. Other stakeholders are strongly of the opinion that one or more of these are important factors in explaining flooding on Otmoor. Resolution of this issue is particularly important for the farming community, but may also be important for managing the delivery of other ecosystem services such as biodiversity, if ground-nesting birds are flooded out.

Defence: MoD training
Flooding of Otmoor is of little concern to the MoD as long as the position used for shooting by service men and women remains dry. Flooding of other areas on MoD land acts as a deterrent to other users and keeps them away during shooting practice, which benefits the MoD.

What influence, if any, does RSPB use of land on Otmoor have on the delivery of ecosystem services?

Supporting Biodiversity

Most stakeholders, with the exception of the farming community, see the RSPB's acquisition of land on Otmoor as very beneficial to wildlife and recreational services. However, the felling of mature trees to prevent crows and magpies perching and taking snipe and lapwing has been criticised, as these trees are regarded by many as an integral part of the Otmoor landscape (Tremayne 2001). There is also a fear by some, including those associated with the RSPB, that the reserve is too much of a "honeypot" for both avian and mammalian predators, and that more could be done to encourage wetland birds to spread out more widely across Otmoor and surrounding areas. This would mean working more closely with the farming community.

Recreational

There may be adverse effects on the well-being of local residents if visitor numbers to the reserve increase substantially. As Tremayne (2001) states: *"…a problem is likely to occur if rare species like the corncrake or bittern appear. Then the 'birding community' is likely to descend in droves. So far the discreet 30-place car park at the bottom of Beckley's Otmoor Lane has proved adequate, but the recent increase in unplanned parking in Oddington by visitors to the Reserve indicates the sort of pressures and conflicts that could build up in the future."*

For some stakeholders, the creation of artificial scrapes on the RSPB reserve has intruded on the attractiveness of views across the moor, although it was acknowledged that this may be because the scrapes are new, and this intrusion may diminish or disappear over time. Artificial reed beds are also visually intrusive to some stakeholders.

Provisioning: Food

As mentioned above, there is a perception on the part of the farming community that the bunds and pumps surrounding the RSPB reserve may be responsible for inequitable flooding of their land, which reduces production. In contrast, the RSPB are themselves farmers and use cattle to graze and maintain wet meadows in the reserve, so there is some additional production from this source.

A few local families apparently continue to go wildfowling on the RSPB reserve which provides additional food production from RSPB land.

Regulating: Pollution control and detoxification

The lack of hydrological connectivity between the RSPB reserve and the Ray floodplain means that the reserve contributes little to pollution control and detoxification.

One stakeholder expressed the view that the establishment of reedbeds had encouraged very large numbers of starlings, with consequent faecal contamination of the surrounding area.

Regulating: Reducing the likelihood of extreme flood events.

As mentioned above, some stakeholders believe that the bunds and pumps used by the RSPB actually contribute to an inequitable distribution of flooding on the rest of Otmoor.

Defence: MoD training

RSPB use of land on Otmoor has little direct influence on MoD training. However, there is a perception by some stakeholders that the RSPB has disproportionate influence over the Environment Agency, Natural England and other government bodies which may influence their attitude to other Otmoor land users. If this resulted in the abandonment of farming on the SSSI the MoD would be faced with the task of maintaining the SSSI themselves, which could impact on training resources.

What influence, if any, does MoD use of land on Otmoor have on the delivery of the ecosystem services?

Supporting Biodiversity

The existence of the MoD firing range on Otmoor is responsible for the preservation of certain habitats and species and its designation as a SSSI. Stakeholders felt that the MoD tried to understand ecological issues, but it was suggested by some that the MoD should take greater responsibility for funding maintenance of the SSSI.

Recreational

The MoD allows access to its land after 4pm and on certain days of the week. It was suggested by some stakeholders that the MoD should make further efforts to ensure that firing stops at the prescribed times to allow access to the site. It was also suggested that disturbance of local people could be reduced further through greater training of military personnel before they visit the site to ensure that transit through villages (e.g., Beckley) was effected as quietly as possible.

Provisioning: Food

The MoD encourages and supports tenant farmers on its land.

Regulating: Pollution control and detoxification

The MoD allows natural flooding to occur on its land, with any consequent pollution control and detoxification that this brings.

Regulating: Reducing the likelihood of extreme flood events.

The MoD allows natural flooding on its land., thus reducing the likelihood of flooding in other parts of the catchment.

Defence: MoD training

The primary purpose of MoD land is for training of service personnel.

Are there any other positive or negative interactions between the ecosystem services that you identified?

Supporting Biodiversity

Several stakeholders noted that removal of scrub on the SSSI to promote marsh fritillaries had a substantial adverse effect on nightingale populations, and questioned whether this management had been appropriate. This is an example of particular species being favoured over others, but there is no evidence that birds always receive favourable treatment – indeed this is an example when they did not.

Recreational

There has been some discussion by residents in Fencott and Murcott about the feasibility of setting up an Otmoor Visitor Centre to promote recreational activities on Otmoor (T. Hallchurch, pers. com). Views of other local stakeholders on this initiative are mixed, with some believing it to be a good idea, and others concerned that increased visitors will disturb them and the quiet of Otmoor.

Provisioning: Food

No other positive or negative interactions were identified by stakeholders.

Regulating: Pollution control and detoxification

No other positive or negative interactions were identified by stakeholders.

Regulating: Reducing the likelihood of extreme flood events.

No other positive or negative interactions were identified by stakeholders.

Defence: MoD training

No other positive or negative interactions were identified by stakeholders.

How might climate change affect any of the interactions that you have identified?

Supporting Biodiversity

Climate change is a major issue for management of the RSPB reserve as it is currently protected from at least some of the likely future influences of climate change by virtue of its isolation from the flood plain and the potential use of pumps to manage water.

Recreational

No views on this were expressed by stakeholders.

Provisioning: Food

More extensive flooding in winter and more cracking of clayey Otmoor soils in drier summers will make it more difficult to keep livestock on the moor.

Regulating: Pollution control and detoxification
No views on this were expressed by stakeholders.

Regulating: Reducing the likelihood of extreme flood events.
Climate change is likely to increase the likelihood of extreme flood events, as discussed elsewhere in this report.

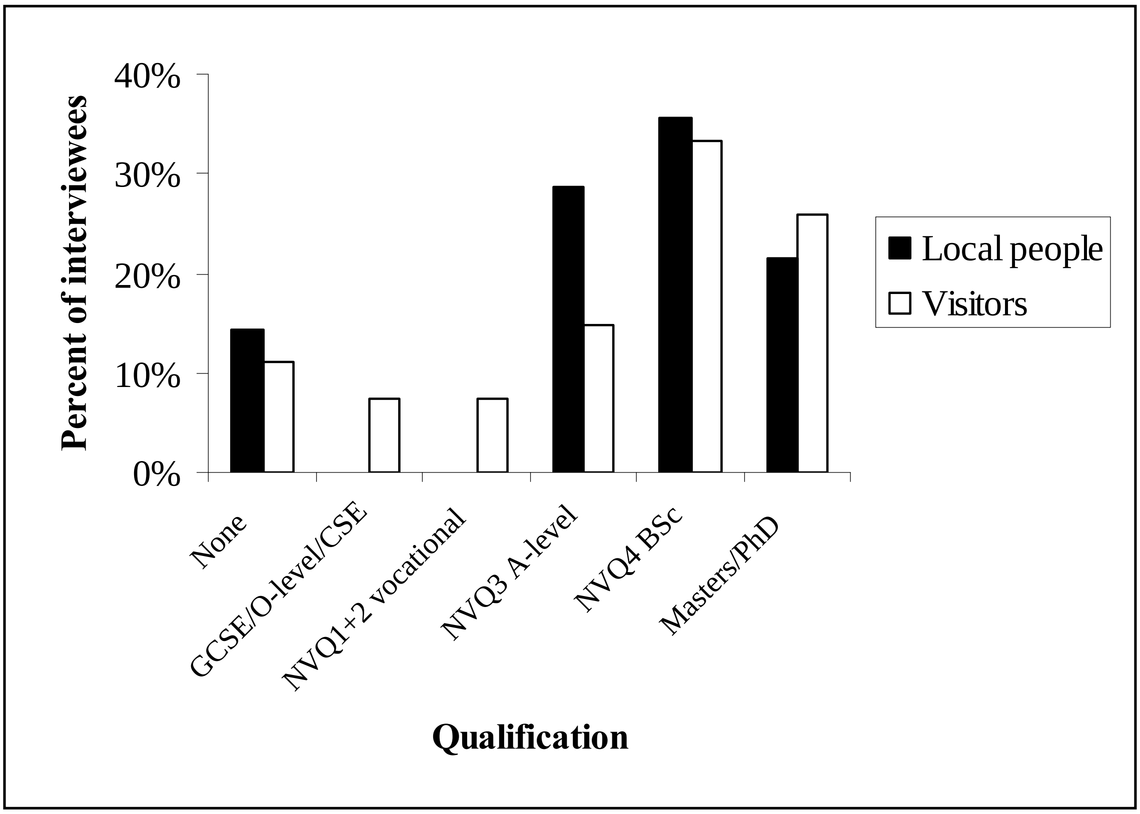
Defence: MoD training
No views on this were expressed by stakeholders.

Opinion Survey on the Value of Otmoor's Ecosystem Services
A total of 41 people were interviewed between 9th-13th February 2007 to determine their views on the ecosystem services provided by Otmoor. Twenty-seven visitors to the RSPB reserve on Otmoor were interviewed, and a further 13 local people were interviewed in the Otmoor villages of Bletchley and Noke. An additional resident of Bletchley was interviewed during a visit he made to the RSPB reserve. The gender balance of interviewees differed for local people and visitors, with men and women comprising 29% and 71% respectively of the local interviewees; visitors that were interviewed comprised 67% men and 33% women.

The purpose of these interviews was to obtain a range of views about Otmoor. The small sample size and limited duration of the survey mean that it should not be taken as entirely representative of the views of either local people or visitors to the RSPB reserve. It is for this reason that inferential statistics have not been used to determine the statistical significance of responses. However, the very similar views expressed about many of the issues, plus the generally low variance in responses, suggest that this small snapshot may be a reliable indicator of what people value on Otmoor.

Both local people and visitors tended to come from the A/B/C1 social classes, as shown by relatively high median minimum household incomes (locals = £30k [but note that n=5 because most refused to answer this question], visitors = £50k [n=22, with five refusing to answer]) and qualifications (Figure 1). Interviewees also tended to be middle-aged or older, with 50% of local people and 66% of visitors aged over 55, and few interviewees with children under 15 in their households (21% of local people and 7% of visitors).

Figure 1. Qualifications of local people (n=14) and visitors (n=27) to the Otmoor RSPB reserve.



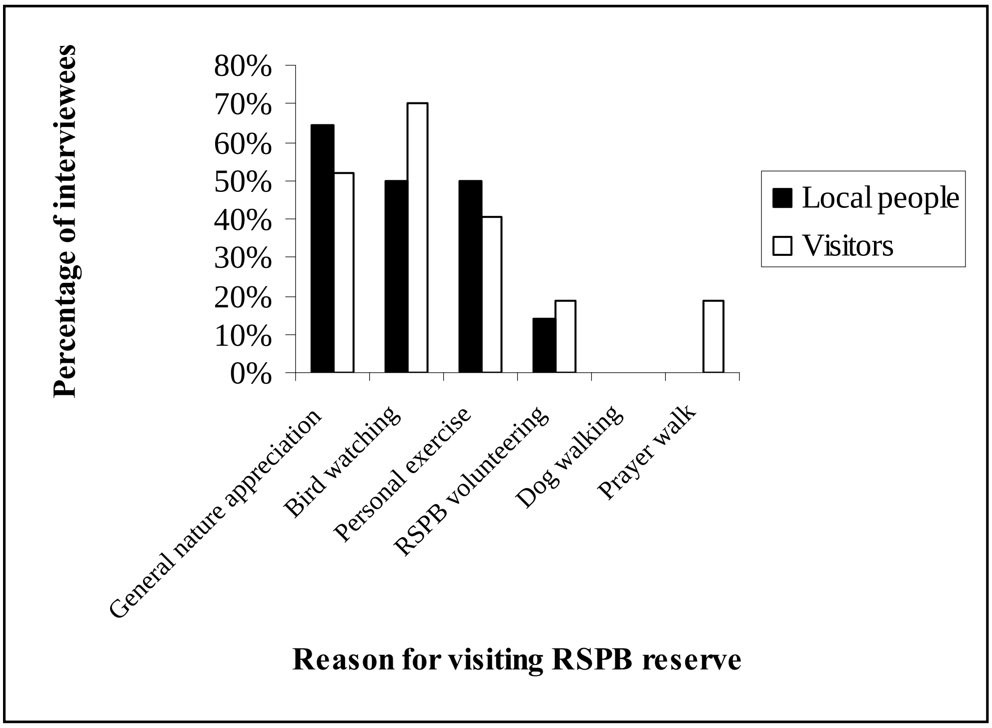
The local people who were interviewed had all visited Otmoor in the previous year, with a median time of 21 days since their last visit (range of 1 to 180 days). Most (78%) visitors to the RSPB reserve had visited Otmoor at least once previously and had come from locations as near as Oxford (5 miles) and as far as Rotherham (150 miles). The mean distance travelled by visitors to the RSPB reserve was 29.5 miles (standard deviation = 32 miles). Reasons for visiting the RSPB reserve were mostly similar for local people and visitors (Figure 2), with bird-watching, general appreciation of nature and personal exercise the most common reasons. A smaller number of local people and visitors engaged in voluntary work on the reserve. Several visitors interviewed on one day were involved in a "prayer walk", which is apparently "*praying 'on-site' for specific areas around you, and covering these areas with God's presence as you walk*"[14]. Most local people learnt about the presence of Otmoor by word of mouth (Figure 10), while most visitors learnt about it from RSPB information sources (70% of visitors who were interviewed were members of the RSPB).

Visitors also tended to be more likely than local people (78% versus 36%) to be members of other conservation organizations, including the National Trust, the Berkshire, Buckinghamshire and Oxfordshire Wildlife Trust, Oxfordshire Ornithological Society, the Woodland Trust, the British Trust for Ornithology, the Wildfowl & Wetlands Trust, and Birdlife International.

Local people and visitors had similar views on the importance of the six main ecosystem services provided by Otmoor. Interviewees were asked to rank the following services from 1 (least important) to 6 (most important):

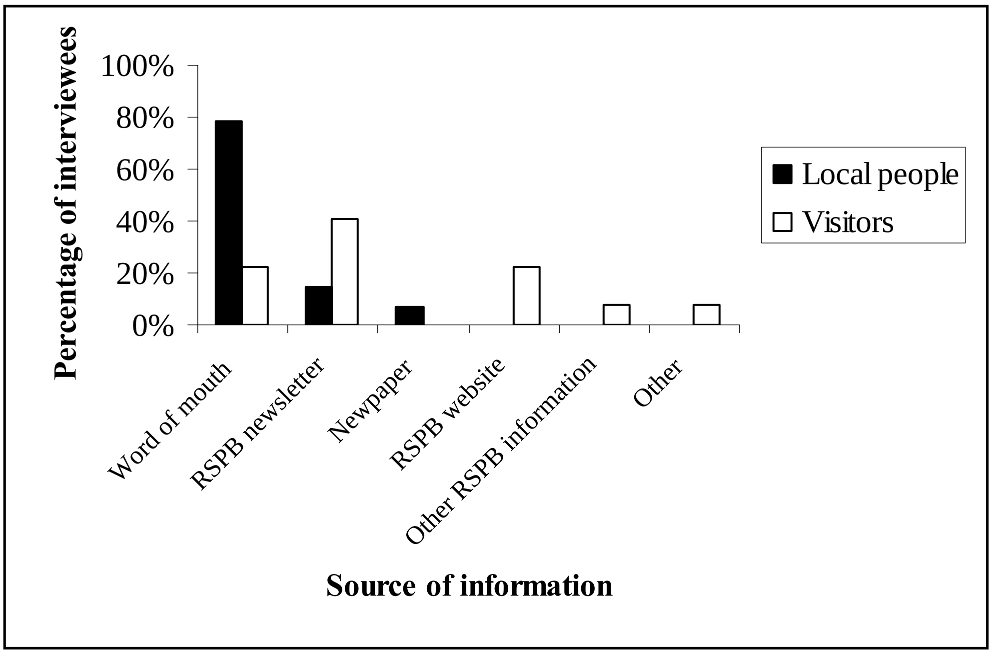
- reducing flooding in areas around Otmoor (e.g., Oxford);
- purifying water by removing toxicants and unnecessary nutrients;
- conservation of plants and animals;
- farming or forestry to produce food, fuel or timber;
- increasing opportunities for human recreation; and
- training for Ministry of Defence (MoD) personnel.

Figure 2. Reasons for local people and visitors to visit the RSPB reserve at Otmoor.



[14] http://www.speak.org.uk/node/73

Figure 3. Source of first information on Otmoor received by local people and visitors.



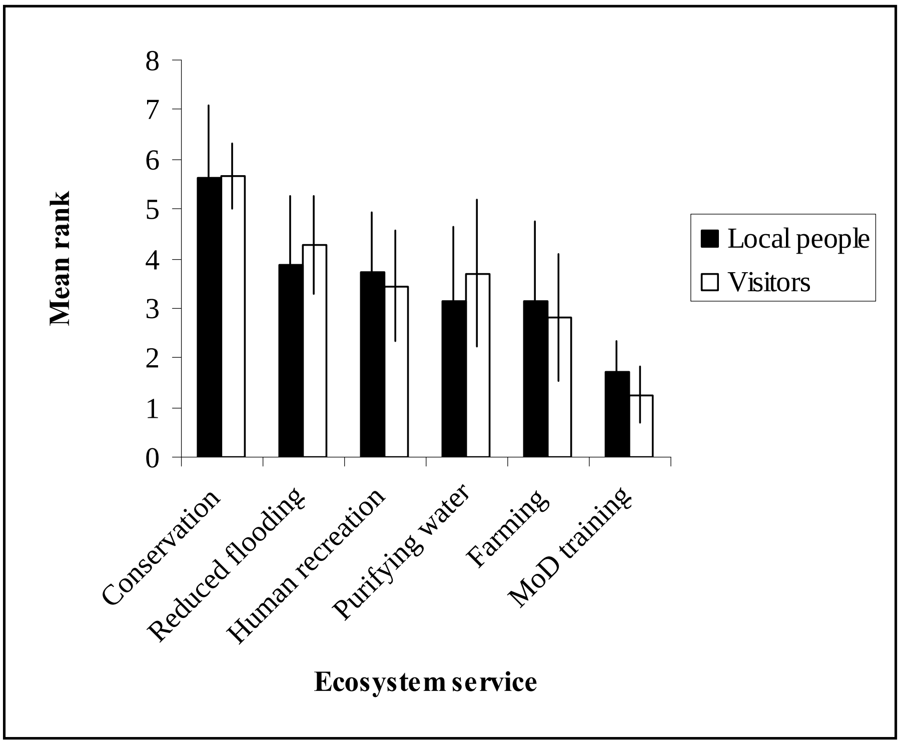
The responses to this question are shown in Figure 3. Local people and visitors valued the conservation of plants and animals on Otmoor most, and training for MoD personnel least, with other ecosystem services valued at a similar level between these two.

There was also little difference between local people and visitors in their strength of agreement about different questions on the use and management of Otmoor. Interviewees were asked to rank from 1 (strongly disagree) to 5 (strongly agree) their responses to the following statements:

- conservation of birds on Otmoor is more important than conservation of other wildlife plant and animal species;
- parts of Otmoor should be closed to the public at certain times of the year to protect wildlife (e.g., breeding birds);
- flooding should be allowed to occur naturally on all of Otmoor;
- housing development should be encouraged on Otmoor;
- more visitors should be encouraged to come to Otmoor for recreation;
- more crop farming should be encouraged on Otmoor;
- more livestock and dairy farming should be encouraged on Otmoor;
- more organic farming should be encouraged on Otmoor;
- the MoD should continue to use part of Otmoor for training; and
- Otmoor should be "left to nature" and not actively managed for conservation.

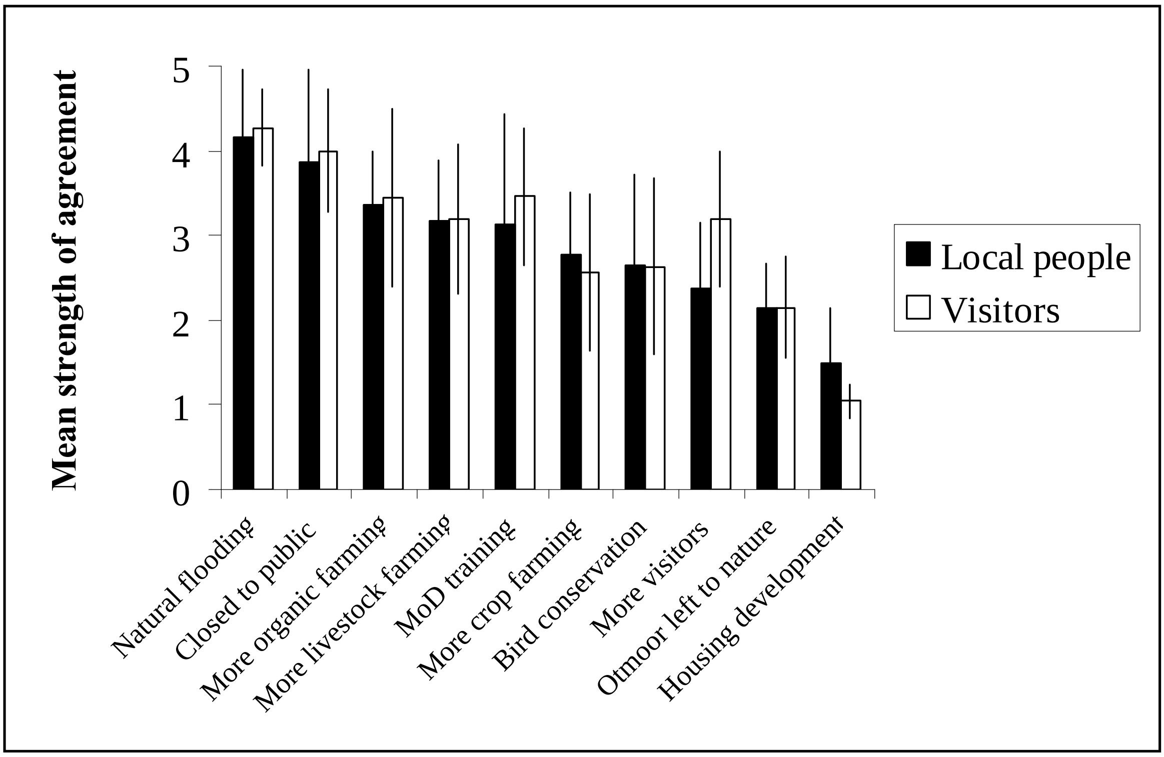
The responses to these statements are summarised in Figure 4. Most interviewees agreed or strongly agreed that flooding should be allowed to occur naturally on all of Otmoor, and that parts of Otmoor should be closed to the public at certain times of the year to protect wildlife, such as breeding birds. Interviewees also tended to agree that more organic, livestock and dairy farming should be encouraged on Otmoor, and that the MoD should continue to use part of Otmoor for training. In contrast, most interviewees disagreed or strongly disagreed that housing development should be encouraged on Otmoor. There was also a tendency for interviewees to disagree that more crop farming and visitors should be encouraged on Otmoor, that conservation of birds on Otmoor is more important than conservation of other wildlife plant and animal species, or that Otmoor should be "left to nature" and not actively managed for conservation. The greatest difference in opinion between local people and visitors, although still not large, was that the latter agreed slightly more with the statement that more visitors should be encouraged to come to Otmoor for recreation.

Figure 4. Ranking by local people and visitors of the ecosystem services provided by Otmoor. Error bars are one standard deviation.



What emerges from the answers summarised in Figures 4 and 5 is that both local people and visitors to Otmoor identify the conservation of all organisms as their top priority for Otmoor, and believe that this conservation should be actively managed, but with natural flooding allowed to occur.

Figure 5. Strength of agreement of local people and visitors about the use and management of Otmoor. Error bars are one standard deviation.



Most local people (71%) and a small majority of visitors (52%) did not wish to pay anything for access to the RSPB reserve. The visitors who were prepared to pay for access were willing to pay a mean sum of £2.38 (STD = 0.96, range = £2-£5, n = 13). The small number of locals (n=4) who expressed a willingness to pay identified a slightly higher sum (mean = £3.25, STD = 2.67, range = £2-£5, n=4). A small number of interviewees (n = 3) who were not prepared to pay an entry fee to the RSPB reserve were prepared to consider an annual subscription of £20 to £30.

Most local people (71%) and visitors (93%) stated that they would be able to visit another site that provided them with similar satisfaction if they were unable to visit Otmoor. Local people mentioned the following sites: Fencot, Mencot, Slimbridge, the Oxford University parks, Burnham Wood, Burnwood Forest, Brill Hill, White Horse Hill, Shabbington Wood, Shotover and Boundary Brook. Visitors mentioned Wittenham Clumps, Port Meadow, Shotover, Farmoor, College Lake (Tring), Fowlmere, Sandy Rye, Titchwell, Snettisham, areas in Suffolk, Warburg and Boundary Brook, and several stated that there were "many places" that they could visit.

Further comments made by local people were,

- The site should be maintained with no loss of service/value.
- I'm glad it's there and happy that it is reverting to its former state before farming, etc.
- I don't want the area to become overcrowded - the access road is not suitable for large volumes of traffic.
- Oak trees have been cut down on the RSPB reserve and there is a lack of information about this.
- I would like more information about the oak trees. Flooding sometimes blocks access. Roads and access are an issue, particularly condition of road.
- Although not fully aware of the situation the oak trees on the site should not be cut down.
- A toilet would be useful at the site.
- I really enjoy the site and use it a lot.
- I think there is talk of a large visitor centre at Otmoor - which would not be a good idea.
- The RSPB stopped helicopters flying over, which is good.

Further comments made by visitors to the RSPB reserve were,

- It's a unique environment that should be maintained.
- More access points for cars would be good and a circular walk around the reserve. Also, the oak trees should not be cut down and there should be more information about such issues.
- The path could be better (very muddy).
- A very nice area that should be protected for birds.
- The whole area has great conservation value.
- The speed of transition from farming to reserve is good.
- I'm happy with the way the site is going back to natural use and state.

Main areas of agreement and disagreement over the provision of ecosystem services, identified from stakeholder, resident and visitor interviews

The following was generally agreed by those interviewed in this project:

4. Conservation of all species should be a priority on Otmoor, with species or habitat rarity being the criterion used to rank conservation priorities.
5. Flooding should be allowed to occur naturally across all of Otmoor, at least in the long-term.
6. A large increase in visitors to Otmoor should not be encouraged.

The following are the main areas of disagreement between different stakeholders:

4. The appropriate balance between profitable farming and achievement of biodiversity goals.
5. The extent to which flooding can and should be managed across Otmoor for the benefit of farming and conservation.
6. The extent to which M40 runoff is responsible for pollution of parts of Otmoor.

Disagreement 1 above is policy-related and requires further collection of data. The question to be answered is what is the appropriate balance between farming and conservation on Otmoor? If small-scale commercial farming is a preferred mechanism for achieving conservation objectives then it must be economically viable. However, if the policy aim is for conservation objectives to be achieved through the purchase or leasing of land by conservation organisations such as the RSPB then this should be made explicit, and an exit route for existing farmers should be identified.

Resolution of disagreements 2 and 3 above depend upon the collection of appropriate empirical data to determine past, current and future water quantity and quality on Otmoor.

Summary

Local stakeholders and visitors value the landscape and wildlife aspects of Otmoor and are therefore in agreement with the main governmental policy drivers for the area. No-one interviewed during this project wanted to change the overall character of Otmoor, except to "change it back" to what some perceive to have been a more natural condition in the past. The main points of friction between some local stakeholders and government policy centre on the appropriate balance between farming and conservation. All parties agree that farming is essential to maintain the conservation and landscape value of Otmoor, but farmers believe that their reasonable economic interests are given insufficient priority by government departments and agencies. In particular, farmers would like more research on the quantity and quality of water on Otmoor and would like further evidence-based discussion of how the quantity of water should be distributed across Otmoor during floods.

APPENDIX 3 – CONCEPTUAL FRAMEWORK FOR PREDICTING AND VALUING ECOSYSTEM SERVICES

Introduction

Wetland ecosystems have long been recognised as providing a range of benefits for people and society (Maltby, 1986, Dugan, 1990, Turner and Jones, 1990, Davis, 1993). The Ramsar Convention on Wetlands[15] has promoted the wise use of wetlands as a means of maintaining their ecological character and the ecosystem processes and structure which underpin the delivery of ecosystem services. Increasingly the valuation of ecosystem services is seen as important in making more informed decisions regarding the use and management of wetlands and their benefit to society (Barbier *et al.*, 1997, Emerton and Bos, 2004, de Groot *et al.*, 2006). Because of the many services and multiple values of wetlands, many different stakeholders are involved in wetland use. This can lead to conflicting interests and the over-exploitation of some services (e.g., fisheries or waste disposal) at the expense of others (e.g., biodiversity conservation or nutrient removal (Hansson *et al*, 2005)). However, despite a wealth of clear evidence acknowledging that wetlands provide a range of benefits, there are still considerable challenges in developing this approach. This is particularly evident in the economic valuation of ecosystem services (Hartje *et al.*, 2003).

Ecosystem services are defined by the Millennium Ecosystem Assessment (MA) as:

> *The benefits people obtain from ecosystems. These include provisioning services such as food and water; regulating services such as regulation of floods, drought, land degradation, and disease; supporting services such as soil formation and nutrient cycling; and cultural services such as recreational, spiritual, religious, and other nonmaterial benefits* (Millennium Ecosystem Assessment, 2005).

The MA categorises ecosystem services into four broad areas: *provisioning, regulating, cultural* and *supporting* (Millennium Ecosystem Assessment, 2005). Each service possesses sub-categories. For instance *regulating* includes climate regulation, water regulation, water purification and waste treatment, erosion regulation and natural hazard regulation.

Conceptual approach

Ecosystems services, which are indispensable for both the natural environment and for human well-being, result from the interactions and processes within the ecosystem (de Groot *et al*, 2006). Wetlands are composed of a number of *biophysical structures* such as soils, water, plant and animal species. Within wetlands the interactions among and within the biophysical structures result in ecosystem *processes* such as denitrification, decomposition or primary production. The interactions among and within these different components allow the wetland to perform certain *functions* (de Groot, 1992; Maltby *et al*, 1996; McInnes *et al.*, 1998). The degree to which a wetland delivers ecosystem *services* depends on its functional properties (e.g., biotic and abiotic components) and relationship between and among ecological components and processes (Figure 1).

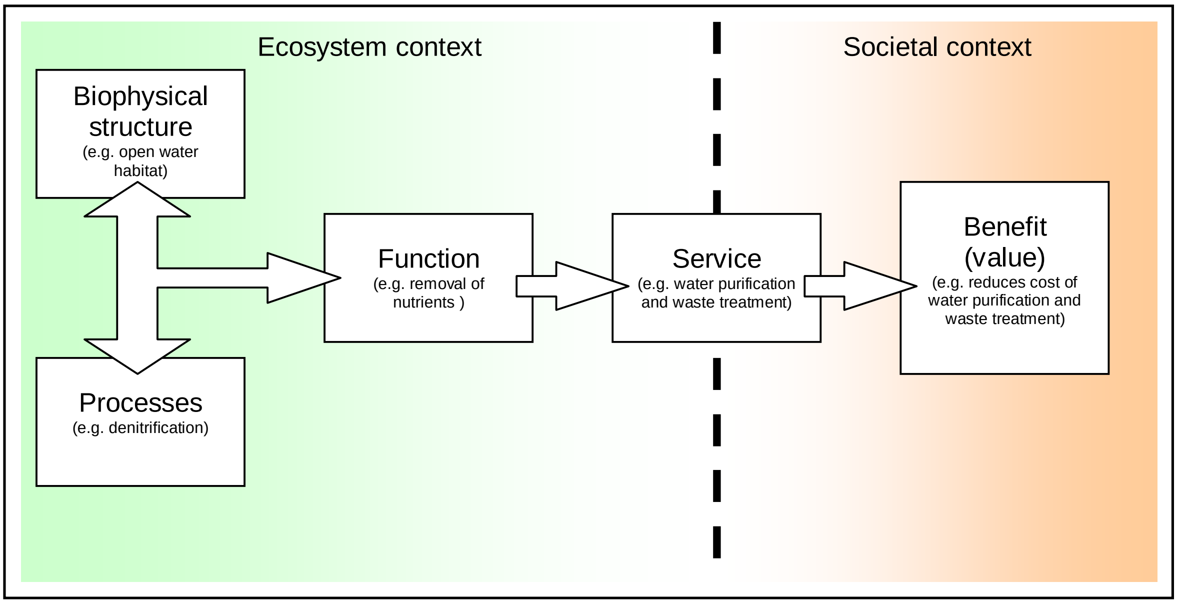
However, it is important to understand distinctions between the different components of the 'ecosystem services paradigm' (*sensu* Haines-Young *et al.*, 2006). It is also of paramount importance to understand the societal and spatial context. Figure 1 indicates that a wetland may have the capacity, i.e. it possesses the appropriate biophysical structure and supports the necessary processes which combine to produce a function, however it does not always follow that society perceives a benefit (value) for the delivery of the service, i.e. water purification and waste treatment. People and society will value function differently in different places at different times (Haines-Young and Potschin, 2007). Therefore in defining what constitutes an ecosystem service it is important to understand the societal, spatial and temporal context.

Figure 2 illustrates how an individual ecosystem service – Regulating – can comprise a variety of sub-categories which can be driven by a range of functions all of which are maintained by processes. Each process is in turn maintained by a range of controlling variables. For instance, in the case of regulating water quality through pollution control and detoxification, a range of functions operate to deliver on the overall ecosystem service. These functions include the removal and retention of a range of water-borne pollutants and

[15] http://www.ramsar.org/

contaminants. The processes supporting these functions result in removal of the pollutant from a wetland or the temporary or permanent retention of the pollutant within a wetland. For instance, wetlands can remove nitrogen from surface waters preventing eutrophication and water pollution issues (Paluden *et al.*, 2002). Wetlands can also retain and remove nitrogen from surface waters through a range of different processes including plant uptake (van Oorschot, 1994), denitrification (Blackwell *et al.*, 1999) or storage in organic matter (Craft, 1996) (Figure 2). All of these individual processes are controlled by a range of environmental variables including *inter alia* soil properties, climate, vegetation, hydrology, land use and type and rate of nitrogen input. This approach to breaking down an ecosystem service into its constituent functions, processes and controlling variables underpins a large body of research work undertaken to understand and predict the functions performed by wetland ecosystems (Maltby *et al.*, 1996, Maltby, in press).

Figure 1. The logic underlying the context of ecosystem services (adapted from Maltby *et al.,* 1996, de Groot *et al.,* 2006 and Haines-Young *et al.,* 2006).



It is possible to illustrate the relationships which exist among the ecosystem service → function → process → controlling variable concept by means of causal chain analysis. Causal chain analysis traces the cause-effect pathways from the socioeconomic and environmental impacts back to its root causes. This form of analysis has been used widely with wetland ecosystems including within the Global International Water Assessment (GIWA) undertaken by UNEP (UNEP, 2006a). For instance, in the Mekong River basin the GIWA conducted casual chain analysis on two of the prioritised issues which have caused wetland habitat modification, namely stream flow modification (and particularly resultant freshwater shortage) and elevated suspended solids (resulting from pollution) (UNEP, 2006b). The analysis involved a step-by-step process that identified the most important causal links between the environmental and socio-economic impacts, their immediate causes, the human activities and economic sectors responsible and, finally, the root causes that determine the behaviour of those sectors.

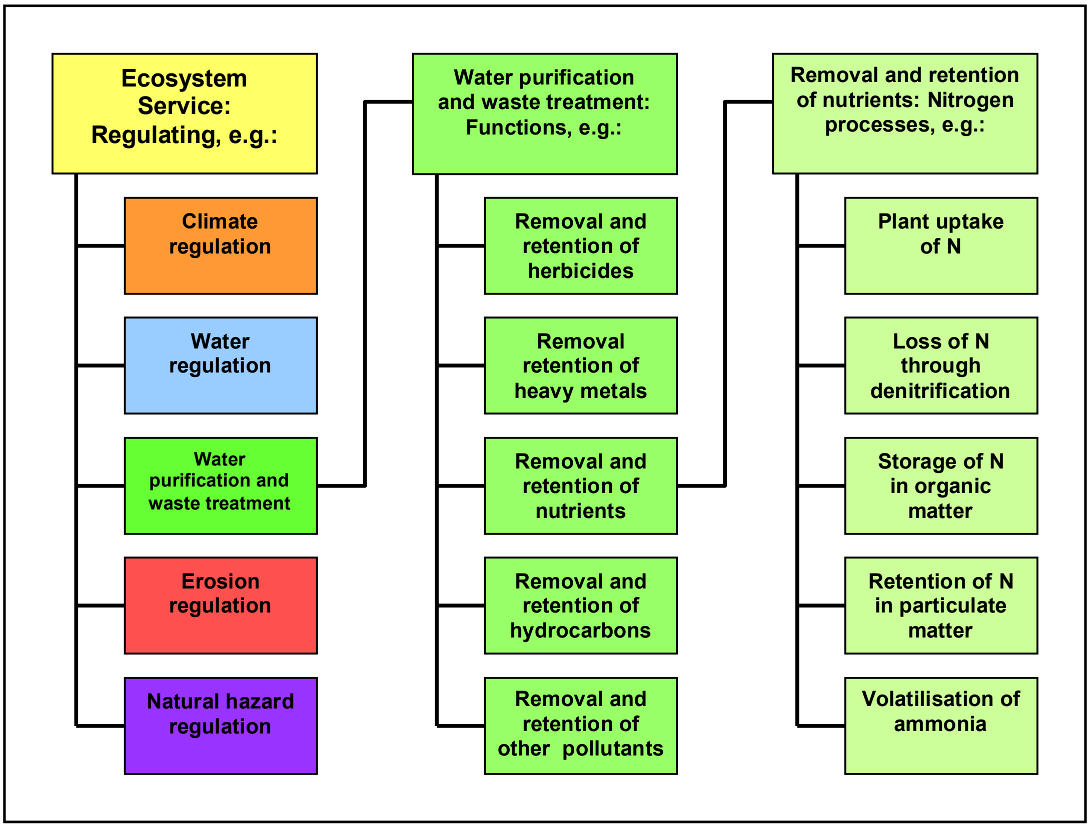
Ecosystem services at Otmoor

Otmoor, whilst undoubtedly important for wildlife, delivers a range of ecosystem services from which society derives benefit. It has not been the intention of this study to identify, quantify and evaluate every ecosystem service provided by the site but rather to demonstrate a method for identifying, predicting and valuing a selection of these services provided by the site, and to understand how this can assist in facilitating the application of the ecosystem approach within England. The work has focused on four of the ecosystem services defined by the MA (Millennium Ecosystem Assessment, 2005), each of which has been reduced to one component part in order to explore and demonstrate the approach. In consequence, the full ecosystem service has not been evaluated. The nomenclature adopted uses the language of the MA (Millennium Ecosystem Assessment, 2005). These ecosystem services considered are:

- **Regulating**: Water purification and waste treatment: specifically *the removal of phosphorus and nitrogen*.
- **Regulating**: Natural hazard regulation: specifically *reducing the likelihood of extreme flood events*.

- **Provisioning**: Food: specifically *conversion of light, energy and nutrients into agricultural biomass.*
- **Cultural**: Recreational: specifically *provision of recreational opportunity*.

Figure 2. Relationships among ecosystem services, functions and processes: example for removal and retention of nitrogen as a component of the *regulating* ecosystem service.



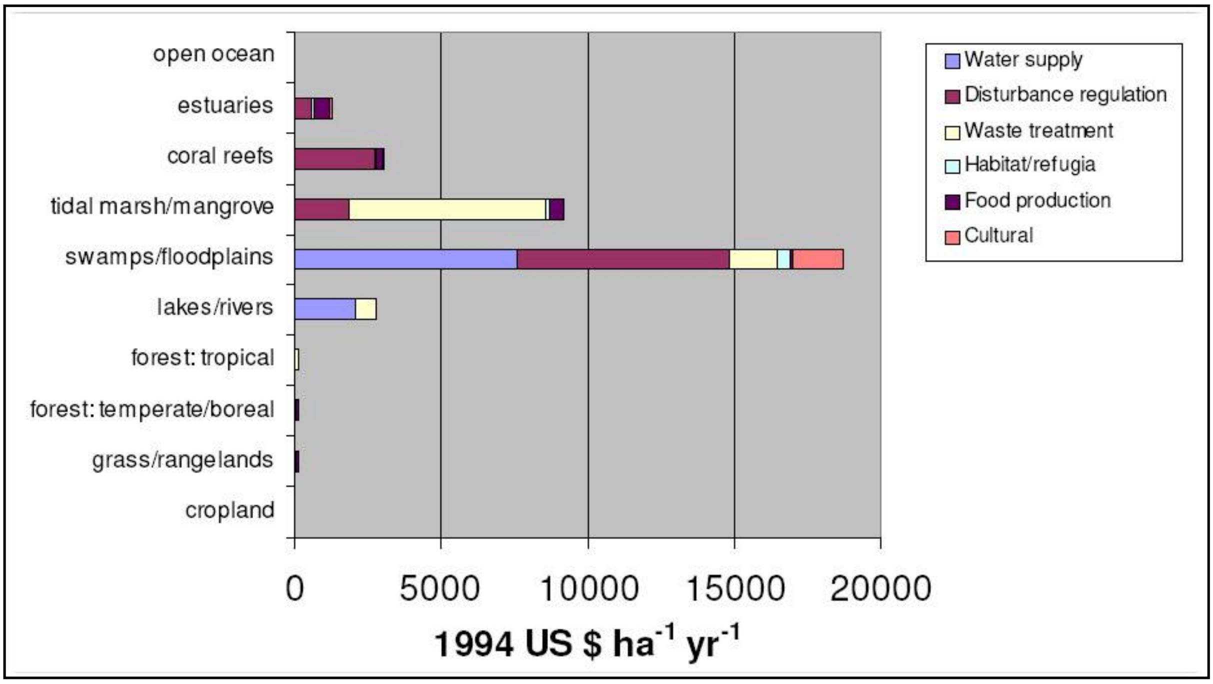
Each of the ecosystem services will have a variety of other component parts. For instance, regulating also considers climate regulation and how an area acts as a source or sink for greenhouse gases; provisioning also considers not just food production but also the generation of fuel wood, fodder or biochemical materials; and similarly, cultural services extend beyond the recreational to include educational and aesthetic benefits. However for the sake of simplicity the work at Otmoor does not attempt to identify or value these wider ecosystem services.

Economic valuation of ecosystem services

In order to make better decisions regarding the use and management of wetland ecosystems, such as Otmoor, their importance to human society must be assessed. Placing the benefits delivered by wetland ecosystems within an economic context forms one of the key principles underpinning the implementation of the ecosystem approach (Laffoley *et al.*, 2004). The concept of 'value' can be viewed and expressed in many ways depending on cultural, philosophical or other perspectives. 'Valuation' has been defined by the Millennium Ecosystem Assessment (2005) as "the process of expressing a value for a particular good or service . . . in terms of something that can be counted, often money, but also through methods and measures from other disciplines (sociological, ecology and so on)".

The ecosystem services provided by freshwater wetlands, especially floodplain areas such as Otmoor, represent a disproportionately high value in comparison to other types of ecosystem (Figure 3, Constanza *et al.*, 1997). Many studies have been conducted to demonstrate the economic value of freshwater wetlands. These are wide-ranging and address a diversity of ecosystem services including: the value of eco-tourism (Oumou *et al.*, 2006); the removal of diffuse agricultural pollution (Blackwell and Maltby, 2003); or the attenuation of flooding (Sather and Smith, 1984). To ensure that a more balanced approach to decision making is adopted it is crucial that these multi-functional values of wetlands are recognised and incorporated into policy creation and implementation.

Figure 3. Average global value of selected ecosystem services (after Costanza *et al.*, 1997).



Wetland values are often not taken into account properly or fully in decision making, or are only partially valued, often leading to degradation or even destruction of a wetland. The reasons for under-valuation are varied but include (based on de Groot *et al.*, 2006; Vorhies, 1999; and Stuip *et al*, 2002):

- **Market failure**: public goods. Many of the ecological services, biological resources and amenity values provided by wetlands have the qualities of a public good; i.e., many wetland services are seen as "free" and are thus not accounted for in the market (e.g., water-purification or flood-prevention).
- **Market failures**: externalities. Another type of market failure occurs when markets do not reflect the full social costs or benefits of a change in the availability of a good or service (so-called externalities). For example, the price of agricultural products obtained from drained wetlands does not fully reflect the costs, in terms of pollution and lost wetland services, which are imposed upon society by the production process.
- **Perverse incentives** (e.g., taxes/subsidies stimulating wetland over-use). Many policies and government decisions provide incentives for economic activity that often unintentionally work against the wise use of wetlands, leading to resource degradation and destruction rather than sustainable management (Vorhies, 1999). An example might be subsidies for shrimp farmers leading to mangrove destruction.
- **Unequal distribution of costs and benefits**. Usually, those stakeholders who benefit from an ecosystem service, or its over-use, are not the same as the stakeholders who bear the cost. For example, when a wetland is affected by pollution of the upper catchment by runoff from agricultural land, the people living downstream of the wetland could suffer. The resulting loss of value (e.g., health, income) is not accounted for and the downstream stakeholders are generally not compensated for the damages they suffer (Stuip *et al.,* 2002).
- **No clear ownership**. Ownership of wetlands can be difficult to establish. Wetland ecosystems often do not have clear natural boundaries and, even when natural boundaries can be defined, they may not correspond with an administrative boundary. Therefore, the bounds of responsibility of a government organization cannot be easily allocated and user values are not immediately apparent to decision-makers.
- **Devolution of decision-making away from local users and managers**. Failure of decision-makers and planners to recognize the importance of wetlands to those who rely on them, either directly or indirectly.

In assessing the variety of ecosystem services provided by Otmoor a range of valuation techniques have been adopted. The reporting of the derived value of the ecosystem services takes into account some of the common reasons for misrepresenting the real value of wetlands. These reasons for under or erroneous valuation are also considered later within a policy context.

The valuation of environmental or recreational assets for which there is no readily available market is likely to be problematic and controversial. In addition to the economic value derived from the direct use of the asset, such as agriculture produce, an asset will have other economic values. These include functional values (for example, the flood storage and wastewater treatment functions provided by wetlands), use values (such as recreational uses) and existence or non-use values (in which an asset is valued for its very existence even though those valuing it may not make any direct use of it).

MAFF (1999) considers that it is likely that the use and functional values of an asset will dominate the overall value of an environmental asset. However, the Guidance also advises that the use of existence values in practical contexts carries a considerable degree of uncertainty with the consequence that any estimates are likely to prove contentious (MAFF, 1999). Indeed, there remains a degree of hostility amongst some practitioners to the concept of valuing certain assets, such as prized landscapes or rare species. Consequently, the Guidance indicates that it may be preferable to attempt to quantify the relative impact of existence values for different options on a non-monetary basis, based on consultation with interest groups and the wider public as reported for this study in Section 2, rather than trying to include such values within an overall benefit-cost analysis. Otherwise, there is the danger that any decisions become sidetracked by arguments as to whether monetary values should be attached to environmental assets and which methodologies, if any, should be used to derive a value.

APPENDIX 4 – ASSESSMENT OF ECOSYSTEM SERVICES

Regulating: Water purification and waste treatment

Introduction

The regulating service 'water purification and waste treatment' considers the retention, recovery and removal of excess nutrients and a range of other waterborne contaminants such as pesticides and heavy metals. In the context of this study the focus is on the specific removal of nitrogen (N) and phosphorus (P).

Wetlands, such as Otmoor, can function to improve water quality by means of a variety of processes, by which nutrients (N and P), among other materials, can be either stored for varying periods of time within the wetland ecosystem or exported completely from it. The key processes responsible for delivering these and other wetland functions are regulated by factors (sometimes called controlling variables) which provide the drivers for causal chains, shown in flow diagrams below. The key functions, processes and controlling factors responsible for water purification are listed in Table 1.

Table 1. Functions, processes and controlling factors responsible for the removal of N and P.

Function	Process	Controlling factors
Nutrient (N and P) storage	Storage of N and P in vegetation by plant uptake Storage of N and P in soil organic matter	Vegetation type Degree of disturbance Soil organic matter status Soil wetness Vegetation Landform
	Adsorption in soil of N as ammonium	Hydrological flow path (opportunity) Soil type Soil profile wetness Soil pH
	Adsorption and precipitation of P in soil	Soil type Soil wetness Landform
	Retention of N and P as particulates	Flooding regime Particulate load Erosion and deposition
Nutrient (N and P) export	Denitrification	Opportunity for soil-water interaction Soil properties - temperature, carbon, oxygen and pH
	Ammonia volatilisation	Interaction between soil and water column Exposure
	Land management	Vegetation type Grazing and cutting regime Flooding regime
	Via wind and water	Soil wetness Landform Soil type Vegetation type Exposure Erosion

Causal chain

In order to optimise the potential for a particular function to be performed and consequent benefits delivered, it is important to understand the key processes operating within a particular ecosystem which deliver functioning, and the conditions (variables) controlling those processes. This understanding enables management options to be targeted towards optimising the performance of a particular function, and also allows judgement to be made about the likely affects of a range of both on- and off-site impacts. By way of illustration, causal chains have been produced for water quality functions (Figure 1) to illustrate relationships and dependencies of factors controlling the export and storage of N and P.

Evaluations of the potential of Otmoor for water quality improvement through N and P removal, are given elsewhere in Appendix 4. These figures make assumptions about the area functioning as a wetland in order that comparisons can be made with wetlands elsewhere, for which published data are available. Figure 1 indicates the central importance of on-site hydrological management to the performance of key processes.

In the case of processes which completely remove (export) nutrients from the ecosystem (Figure 1), if the site dries out, whether as a the result of land drainage or failure of measures put in place to retain water on the site, then soil water levels would fall resulting in the establishment of more aerobic conditions. With a rise in oxygen content in the soil, denitrification rates would fall and export of N be reduced. Similarly, the opportunities for ammonia volatilisation are reduced when wet conditions do not occur at the ground surface. These processes are also reduced when the source of N declines. This may result from lack of on-site additions (mainly from the excreta of grazing animals in areas of wildlife conservation, though fertilizers are likely to be a source on agricultural land). Nutrients in surface water are made available for the processes when flooding takes place. In this case most nutrients derive from catchment-wide farming activities, where losses of nutrients from fields depend on land management practices. Flows reach the River Ray and its tributaries via overland flow across fields and in ditches, and via sub-surface drains where soils are of low permeability, or lie wet due to their low-lying position. On more permeable land, water drains vertically to a water table at depth and then horizontally to the river channel. In these cases, nutrient contents are likely to be lower due to the opportunity for soil-based processes to take place.

Another effect of drying out of the site would be the wastage of organic material in the soil, a requirement for the process of denitrification.

With the exception of woody plants, much of the N and P taken up by vegetation is stored for only a short time and is recycled back into the soil on a seasonal basis when plants die back in the winter. However, when this cycle is interrupted by harvesting, the cut material is carted away and nutrients consequently removed from the site.

A similar inter-relationship among key factors also occurs in the processes leading to storage of nutrients within the ecosystem (Figure 1).

Data sources

The data required to estimate the effectiveness of wetlands at Otmoor in purifying water by removing N and P are summarised in Table 2. Soil type and hydrology together with climate and vegetation are the main factors responsible for controlling the key processes involved. Apart from soil information, most data derives from published sources as indicated. Soil information has been obtained from NSRI (National Soils Resources Institute) at the University of Cranfield. Information is held on the LANDIS (Land Information System) database, and was selected using the National Grid Reference for Otmoor and the soil association identified at that location on the National Soil Map (Soil Survey of England and Wales 1983).

Because of the small scale (1:250,000) of the National Soil Map, site-specific soil information was supplemented from auger borings undertaken during a number of field visits to Otmoor. Information was collected within the MoD (SSSI), RSPB and other areas. A range of information, including soil type, vegetation, surface condition and management, was recorded at over fifty locations across Otmoor. A summary of this information, and the location of information points, is provided in Appendix 7.

Climate

Information is provided from a number of sources (Table 2). Many long-term data are conveniently summarised in Soil Survey publications from around the Otmoor area of Oxfordshire.

Figure 1. Causal chain for N and P removal and storage.

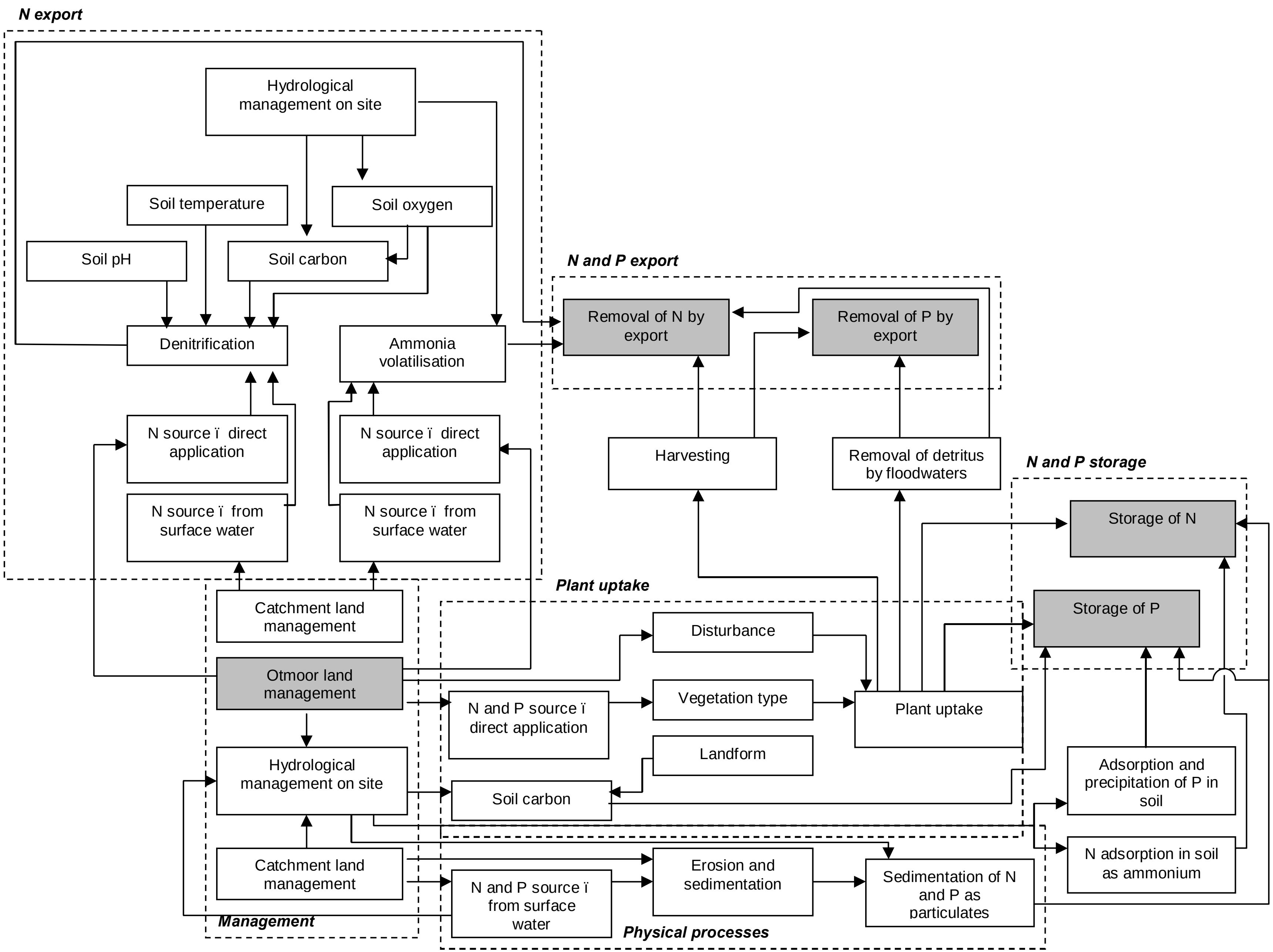


Table 2. Data sources for Otmoor.

Parameter	Values and comments	Source
Rainfall	Annual 635mm (Oxford); 50% of rainfall is in summer	Hazelden (1986)
	660mm (1931-60); monthly values	Jarvis and Hazelden, (1982)
Potential transpiration	460mm; max PSMD 152mm (Aug), deficit period Apr-Sept, (>140mm on map); excess winter rain 148mm;	Hazelden (1986)
	150-175 (map)	Bendelow and Hartnup (1980)
		Jones and Thomasson (1985)
Field capacity	125-150 days	Jones and Thomasson (1985)
Temp	Monthly air temperatures for Oxford (1931-60); also frost and grass temps	Jarvis and Hazelden, (1982)
	Accumulated day degrees above 0 degrees C (Jan-June) 1400-1450, and >1925 above 5.6	Jarvis and Hazelden (1982)
	degrees C (whole year), also sunshine and wind	Bendelow and Hartnup (1980)
	Growing season (Thame Valley) 265 days	Jarvis and Hazelden, (1982)
	Monthly ground temps at 30 and 122cm depths	Jarvis and Hazelden, (1982)
Exposure	Moderately exposed (map, average annual windspeed 3-4.8 m/sec)	Bendelow and Hartnup (1980)
Bioclimate	E4m/03 (moderately warm, slightly moist, unexposed, hemioceanic)	Bendelow and Hartnup (1980)
Vegetation	MG5 in SSSI; condition and management issues	Natural England website
Total N deposition	20kg/ha/y (medium rate)	DOE 1994 (Blackwell 1997)
Soils	Fladbury series and thin peat	1:250,000 soil map and survey NSRI LandIS data and report
HOST	Class 9; seasonally waterlogged by fluctuating groundwater and relatively slow lateral saturated conductivity	
Risk of corrosion	Highly aggressive	
Nitrate risk	Low risk of leaching to groundwater	
Pesticide leaching risk	Class H1vi; high risk, groundwater at shallow depth	
Pesticide run-off risk	Class S3m; moderate risk and moderate adsorption potential	
Hydrogeological rock type	Class 15; river alluvium	
Groundwater protection policy leaching	Class H1; high leaching potential which readily transmit liquid discharges because they are susceptible to rapid bypass flow directly to (*in this case*) groundwater	
Fladbury 1 soil association (National Soil Map)	Stoneless clay soils, in places calcareous, variably affected by groundwater; flat land, risk of flooding; stock rearing with arable where low flood risk	
Fladbury soil series		
Organic C	6.55; permanent grass 6.5 (3-13.8)	Mean and range of NSI samples
pH	5.8; permanent grass 5.6 (4.5-7)	
Total P	913 ((408-1594) mg/kg	
Olsen P (dissolved)	22 (7-68) mg/l	
Wetness class	IV/V (undrained), III/IV (drained); Otmoor probably IV in ESA and V on SSSI and RSPB land	Jarvis *et al* (1984)

Soils

Soils of Otmoor are mapped as Fladbury 1 association (Soil Survey, 1983) which is dominated by naturally wet clayey soils of the Fladbury series developed in river alluvium (Ragg *et al.*, 1984). The subsidiary component soils of this map unit, on a national basis though not necessarily specifically at Otmoor, indicate the possible occurrence of calcareous versions of Fladbury soils. This would be possible at Otmoor due to the presence of calcareous rock formations underlying the catchment of the River ray upstream from Otmoor, though no pH measurements were taken.

A number of exploratory auger borings were made over parts of Otmoor to give some indication of soil occurrence (Appendix 7). Soil texture (particle-size class) of individual horizons (layers) was identified by hand assessment texture, with colour and mottling also recorded. Particular emphasis was given to depth below the surface of mottling and to organic matter status (i.e., thickness and degree of decomposition of organic material). The auger borings confirmed the predominance of Fladbury soils. The main variation was found to be in the local development of peaty topsoils, especially in the farmed fields in the north-east part of the inner ring. Elsewhere some dark-coloured (possibly humose) topsoils were found which are evidence for the former occurrence of peat which has subsequently been lost through wastage (drying out and oxidation) as a result of agricultural activities, particularly drainage and cultivation.

A summary of NSRI analytical data on soils of the Fladbury series is shown (Table 2) for a number of important properties controlling key processes and functions responsible for water purification – pH, organic carbon and P content in topsoils, and wetness class for the profile.

Landform

Otmoor is located on a floodplain and consequently comprises predominantly flat land. However the ground surfaces of floodplains are often characterised by micro-relief, comprising small variations in ground surface elevation and configuration representing features such as former drainage channels and levees, formed during the history of floodplain development. In addition, many man-made features are found including drainage ditches and grips, excavated during phases of agricultural reclamation and improvement, and more recent scrapes, ponds and channels, constructed for the purposes of wetland restoration. Landform and hydrology are the key characteristics used to identify and delineate areas of land considered to function in a uniform way. These have been described as hydrogeomorphic units (Maltby *et al.*, 1996; Maltby, in press) and are based on a hydrogeomorphic approach to wetland classification and assessment developed by Brinson (1993) and others. During field visits, notes were made on the kinds and extent of natural and man-made depressions and elevations occurring in the landscape in order to identify and characterise potential wetland functional units, as summarised in Table 3.

Quantitative evaluation

No specific process studies or data are available for Otmoor, which means that any quantitative evaluation of water purification functioning will require extrapolation of data from studies elsewhere. Some processes, such as denitrification, are known to be extremely variable both spatially and temporarily, and require substantial research and/or monitoring resources in order to predict confidently how well the function is being performed in a specific location. So, the precautionary principle is applied in the Otmoor study; where published data are available from apparently similar wetland systems elsewhere, mean values are rounded down, or the lower end of a range of values is quoted. Where processes have been little-studied and/or results are not quantifiable, the contribution of the process is acknowledged but no figures are given. A summary of the processes likely to be involved, published values and references is given in Table 4.

In general, different processes are responsible for the removal of N and P from ground- and surface waters, either by temporary storage within the wetland or by permanent export from it. Some indication is given below of what might be considered a conservative value for functions where research evidence is available.

N-storage processes

Plant uptake: 50 kg ha^{-1} a^{-1}

Explanation: This process is confined to the growing season with losses recycled back into the system as plants die back, unless management intervenes to remove biomass through grazing or cutting. Some longer-term storage takes place in the timber of trees, though woodland is not a target habitat for Otmoor. Klopatek (1978) gives data for N removal from marshes in Wisconsin, USA: 20.8 g N m^{-2} a^{-1} (208 kg N ha^{-1} a^{-1}). But only 26% of this is considered to be retained in the vegetation, giving uptake of 54 kg N ha^{-1} a^{-1}. A conservative value of 50 kg ha^{-1} a^{-1} is given for Otmoor.

Table 3. Wetland functional units at Otmoor.

No	Description	Vegetation	Characteristic surface features	Comment
1	Undulating land with clayey alluvial soils and some minor depressions	Wet grassland and tall herb fen, rush pasture and improved grasslandï depends on management, especially grazing and cutting regimes	Natural depressions including old channel features, and defunct grips	Vegetation and tonal patterns on air photos reflect management; soil survey required to identify organic soils; need to estimate proportion of depression features by field observation ï too small to appear clearly on air photos, LIDAR a possibility
2	Flat land with clayey alluvial soils, but including artificial scrapes and ditches, with spoil forming low elevations (scrapes may occupy the site of former channels)	Rush pasture with open water in scrapes and ditches	Scrapes, ditches and banks; depressions usually contain standing water	Especially in RSPB reserve; needs management plan and/or air photo (or LIDAR) of current conditions to identify proportion and location of features
3	Old channels of former stream systems; can contain shallow standing water or give splashy surface conditions, wetter than adjacent land	Sedge and rush-dominant; usually in contrast and evidently wetter than adjacent higher level ground surface	Depressions (often sinuous) of varying depth and extent	Large enough to be evident on air photos ï preferably delineated using stereo pairs (or LIDAR)
4	More or less permanent standing water bodies ï natural or artificial	Some emergent vegetation or none, depending on water depth and duration	Standing water	Usually evident on air photos and/or OS maps; readily observed in the field

N-fixation in soil organic matter: positive but not quantifiable.
Explanation: The wet conditions of Otmoor are conducive to the accumulation of organic matter in soil, and indeed some thin peaty topsoils are found within the ESA land. However rates are likely to be slow and interspersed with seasonal phases of organic matter degradation and loss during dry periods when some draw-down of the water table is expected to occur.

Adsorption of N as ammonium: positive but not quantifiable.
Explanation: The process is poorly understood and process data are generally not available. The process is optimised in clay soils below pH 7 and where organic matter is well decomposed (characteristics of the Fladbury series), though N retention in this form can be short term, and where environmental conditions change, N can be released from soil colloids.

N-export processes
Denitrification: 70 or 105 kg N ha^{-1} a^{-1} on level ground; 105 kg N ha^{-1} a^{-1} in depressions (containing temporary or permanent surface water).

Explanation: It is possible to identify broad denitrification rate categories based on values of atmospheric deposition of N (Groffman *et al.*, 1987). Using N deposition values given by the DOE (1994), Blackwell identified denitrification rate classes of low (<10), medium (10-35), and high >35 kg N ha^{-1} a^{-1}. The high class is further subdivided into categories 1 (35-70), 2 (70-105) and 3 (>105 kg N ha^{-1} a^{-1}) based on the results of detailed site measurements recorded in South West England by Blackwell (1997). Category 3 is equivalent to a 'zone of enhanced denitrification' (ZED), where none of the factors controlling the operation of the process (controlling variables) are limiting.

Table 4. References for N and P removal and storage rates and values.

Process/function	Values	References	Comments
Plant uptake of nutrients	20.8 g N m^{-2} a^{-1} 5.3 g P m^{-2} a^{-1}	Klopatek (1978)	Rates measured in riverine marshes in Wisconsin. But limited retention of 26% of N and 38% of P; the rest is returned by leaching and litterfall.
Fixation in soil OM	-	Childers *et al* (2003)	Slow rates of peat accumulation
Denitrification	29.3 mg N m^{-2} a^{-1}	Blackwell (1997)	In ZED with overland flow from grazed land.
	<1 to 1428 mg N m^{-2} a^{-1}	Johnston *et al.* (1997)	Considerable temporal and spatial variation reported
	2.9 - 4.8 g N $m^{-2}a^{-1}$ 31.5 g N $m^{-2}a^{-1}$ 156 g N $m^{-2}a^{-1}$	Struwe and Kjoller (1989) Lowrance *et al.* (1984) Kirkham and Wilkins (1993)	All quoted in Blackwell *et al* (2002)
Overall N-removal (by buffer strips); many examples reported	Reductions in run-off: nitrate (79% of 4.45 mg L^{-1}), ammonium (78% of 0.4 mg L^{-1}), particulate organic N (86% of 19.5 mg L^{-1})	Peterjohn and Correll (1985)	Does not differentiate processes; compares values entering and leaving a 50m wide buffer; most nitrate removed from shallow groundwater ï other forms of N increase (groundwater / subsoil flow unlikely in clayey soils of Otmoor).
	Reduction from 9.0 to 0.5 mg NO_3^- L^{-1}	Haycock and Pinay (1993)	Within first 5 m of entering buffer zone
	-	Pinay and Burt (2001)	No significant difference between forested and meadow riparian areas for N-removal
Phosphine emission	1.7 g P $m^{-2}y^{-1}$	Devai *et al.* (1988)	The only process for gaseous removal of P
Sedimentation	Up to 98% P retained	Jensson *et al.* (1993)	In artificial wetland; but flows are usually more concentrated and less efficient, and can become a source if erosion initiated
		Wenger (1999)	Review recommends 30m wide buffer zone to trap sediment in most cases.
		Sorrano *et al.* (1996)	Prediction that P loading could be reduced by 55% by afforesting riparian areas (100m wide)
	Greater retention of P than N	Venterink *et al.* (2003)	2-3% of N adsorbed on particles compared with 50-70% of P; increasing discharge reduces efficiency of retention.
Land management			Harvesting of biomass only removes small amounts (e.g. Herskowitz (1986) reported only 2.5% of total P)

The following are key controlling variables in the process of denitrification, and any failing to provide optimal conditions are likely to reduce the process rate: N (nitrate) input, carbon supply, oxygen supply, pH, temperature, residence time and interaction of nitrate.

- Nitrate inputs are supplied from the excreta of grazing animals and wetland birds, together with periodic flooding over parts of Otmoor.
- Carbon supply is required to be at least 2% easily oxidisable soil carbon, a value exceeded in the topsoils of the Fladbury series, the main soil found at Otmoor; the values for peaty and humose topsoils would be even larger.
- Oxygen supply in the soil requires a wetness class of V or VI. Undrained Fladbury soils are Class V (or VI where water is penned within the system or excavations created). Drier conditions would exist only where artificial land drainage exists, perhaps locally reducing the process rates on ground which does not occupy depressions in the landscape.
- Optimal pH conditions are greater than 6. The mean value for Fladbury soils is 5.8, though some higher values may be present on Otmoor, either where land was limed for cereal crops in the past, or where soil water derives from calcareous bedrock in the catchment. Where standing water occurs, pH will be close to neutral at the soil/water interface. In most cases pH is likely to be about 6, causing no significant reduction in denitrification rate.
- The temperature regime is classes as temperate (mesic), enabling the bacterial-driven process of denitrification to take place to some degree throughout the year, though at a faster rate in summer than winter, given other factors being optimal. The average monthly air temperatures at Oxford (1931-60) vary from 3.8^{o}C in January to 17.1^{o}C in July (Jarvis and Hazelden 1982). Similarly for Oxford, earth temperatures at 30 cm depth range from 3.8^{o}C in January to 17.8^{o}C in July.
- There is generally significant residence time of water in association with soil at Otmoor. Fladbury soils are described as being seasonally waterlogged by fluctuating groundwater and with relatively slow lateral saturated conductivity (NSRI report on Fladbury soils at Otmoor using 1:250,000 National Soil Map (1983)). The land surface is either some form of depression, in which surface water is detained, or comprises the original floodplain surface with little or no gradient to encourage surface flows to take place. Additionally, wetness is artificially maintained over parts of the area by the penning of water in drains during dry periods of the year.

Ammonia volatilisation: positive but not quantifiable
Explanation: The process characteristically takes place on land receiving excreta from livestock or birds, and from shallow water bodies, both conditions commonly found on Otmoor. Optimal pH in the water is >7 with temperature >8^{o}C, conditions likely to be met on Otmoor. There is little information on process rates from wetlands.

P-storage processes
P storage by plant uptake: 20 kg P ha^{-1} a^{-1}
Explanation: This process is confined to the growing season with losses recycled back into the system as plants die back, unless management intervenes to remove biomass through grazing or cutting. Some longer-term storage takes place in the timber of trees, though woodland is not a target habitat for Otmoor. Klopatek (1978) gives data for P-removal from marshes in Wisconsin, USA: 5.3 g P m^{-2} a^{-1} (53 kg P ha^{-1} a^{-1}). But only 38% of this is considered to be retained in the vegetation, giving effective uptake of 20 kg P ha^{-1} a^{-1}

P storage by adsorption and precipitation in the soil: positive or negative effect but not quantifiable.
Explanation: Phosphate-P can be adsorbed on to soil particles, optimised by the presence of iron, aluminium and calcium, clay and organic soils; clay is a key feature of Fladbury soils, while organic material and calcium-rich soils can also be present within the Fladbury 1 map unit (Soil Survey 1983). However the adsorption capacity is finite, beyond which further adsorption is not possible. Also waterlogged anaerobic conditions can lead to the desorption of P and its loss from the system. P may also be precipitated in the soil and in the water column in the presence of ions of the above elements. The processes are highly dynamic and variable in both temporal and spatial terms, making it difficult to predict their overall contribution to P content and water quality.

P storage by retention of particulates: highly variable and probably positive though not quantifiable.
Explanation: P bound to particulate matter can be transported to the site suspended in floodwater, where it can be deposited on the surface of soil and vegetation. However it can be susceptible to subsequent

mobilisation if drainage flow paths are concentrated and erosion takes place, though no evidence for this was noted during the field survey. In addition, the process of sedimentation can be highly variable, precluding any quantification without detailed field studies.

P-export processes:
Phosphine emission: 2 kg P ha^{-1} a^{-1}
Dèvai *et al* (1988) report a small amount of P (1.7 g P m^{-2} a^{-1}) exported from wetlands as the gas phosphine is generated and emitted, though further research is required to quantify the process under a range of conditions. A small element is included here to account for this form of P loss.

N and P export by land management: 15 kg N ha^{-1} a^{-1} and 3 kg P ha^{-1} a^{-1}
Explanation: a small proportion of the amount of N and P stored in plant biomass but subsequently recycled through die-back at the end of the growing season would be exported from the site either as liveweight gain of livestock, or as a hay or silage crop cut for stock feeding. A conservative figure of 10% of the N (7.4% of 208 kg N ha^{-1} a^{-1}) and P (6.2% of 53 kg P ha^{-1} a^{-1}) calculated above (storage by plant uptake) as recycled from end-of-season die-back is taken for this estimate, assuming either cutting or grazing has taken place during the growing season.

Summary of N and P storage and export
Total N removed by storage and export: 170 kg N ha^{-1} a^{-1} on flat land, 190 kg N ha^{-1} a^{-1} in depressions.
Total P removed by storage and export: 25 kg P ha^{-1} a^{-1}.

The potential of land for the removal of N and P is calculated by multiplying these storage and export values by the areas of land concerned. In the case of P, this includes all of the land, while for N, separate calculations are made for depressions and flat land, the rates being slightly higher in depressions. The areas occupied by depressions are those calculated for 0.5m out of bank flood depth (see Natural Hazard Regulation). Flat land is calculated by difference from the total area for each land designation type. The values calculated for N and P removal are given in Table 6, and are used in economic evaluations.

Table 5. Areas (ha) of land designation types at Otmoor.

Land designation	Total area	Depressions	Flat land
ESA	357.0	71.0	286.0
SSSI	160.0	21.9	138.1
RSPB	210.0	28.2	181.8
Non-ESA	100.0	15.7	84.3

Table 6. Potential annual N and P removal (kg) from land designation types at Otmoor.

Land designation	Depression (N)	Flat land (N)	Total N	Total P
ESA	13,490	48,620	62,110	8,925
SSSI	4,165	23,474	27,638	4,000
RSPB	5,352	30,911	36,263	5,250
Non-ESA	2,974	14,339	17,313	2,500

Economic evaluation

Water companies are legally obliged to supply drinking water with nitrate concentration levels of under 50mgl^{-1} and comply with these standards by constructing and operating nitrate reduction plants and/or sourcing low nitrate water to dilute high nitrate supplies.

Defra calculated that the annual capital expenditure by water companies on nitrate removal between 1992 and 1997 was £18.7m with operating costs of £1.7m. ERM (2005) estimated that the annual capital costs borne by water company customers for the removal of nitrates was £14.4m in 2002-03 prices. Pretty *et al.* (2000) has estimated that there is an annual cost of £16.4m to the water industry for the removal of nitrate pollution from agriculture on the basis that 80% of nitrate is generated from agricultural activities. Available Ofwat data allows identification of capital expenditure for water treatment relating to nitrate and phosphate removal and the associated operating expenditure. None of these estimates, however, provides unit costs of removal and all costs are after the effects of N and P storage and removal from wetlands and other land.

The potential of wetlands to remove nitrates and phosphates may have an economic value equivalent to the costs of removal at treatment plants or dilution but only if there is a need to remove nitrates and phosphates from the particular supply (i.e., if levels are above the legal thresholds). If quality standards are already met by water supplies before the processes of temporary storage and export from the wetlands, there would not be any saved costs although there would be additional human health benefits.

It has proved difficult to locate reliable, up-to-date unit costs for nitrate removal although Blackwell and Maltby (2003) quote a nitrate removal cost of £6.78kg $^{-1}$ at 1999 prices. This would equate to £8.32kg^{-1} in 2007 prices using the Retail Price Index. It also has to be recognised that unit costs are likely to vary considerably with the scale of treatment plants.

On the basis that approximately half of the SSSI at Otmoor falls within the ESA, the potential removal of N by the processes outlined above could amount to approximately 140,000 kg per annum. Assuming also that the equivalent amount of N would otherwise need to be removed from water supplies, this suggests that the value of this service could equate to £1.1m per annum at a unit cost of £8kg^{-1} of nitrate removed or an equivalent value of £1,360ha^{-1}. Such values appear disproportionately high to the national annual costs of nitrate removal actually incurred by the water companies, although such costs are incurred after the effects of N storage and removal from wetlands and other land. For a true comparison, it would be necessary to identify water quality standards prior to these effects taking effect.

Arup (2005) set out estimates of the costs of phosphate removal based on unit cost models produced by Ofwat for chemical dosing and ASP (activated sludge plant) processes. These models were in turn based on information provided by water companies on a regulatory basis and voluntarily as part of the study and on information provided by the EA.

The model estimated the cost (at 2004 prices) per unit weight of phosphorus removed (£kgP^{-1}) for a range of plant types and sizes. Unit costs were estimated under a number of scenarios, depending on the standard of phosphate consent (stringent, medium and less stringent), the size of the treatment works (very small, small/medium, medium/large and large works) and whether or not there is an agreed 'metal consent' in place (a 'metal consent' is a limit on the concentration or mass of metals (iron, aluminium) that may be discharged from a wastewater treatment works).

The mean cost for a medium/large works (population equivalent of 10,000 – 80,000) using chemical dosing varies from £6kg^{-1} under a less stringent consent of 2mgl^{-1} to £11kg^{-1} under a medium consent (1 mgl^{-1}) and £15kg^{-1} under a stringent standard of less than 1mgl^{-1}. These increase to £9kg^{-1}, £17kg^{-1} and £24kg^{-1} when a metal consent is implemented due to additional costs arising from tertiary treatment.

A figure of £11kg^{-1} under a medium consent in 2004 prices would equate to £12kg^{-1} in 2007 prices and £17kg^{-1} (where a metal consent is implemented) to £18kg^{-1} in 2007 prices.

The mean unit cost of load removed in works that employ biological solutions to treat sewage was found to be £11kgP^{-1} for a medium/large plant (£12kg^{-1} in 2007 prices).

On the basis that approximately half of the SSSI at Otmoor falls within the ESA, the potential removal of P could amount to approximately 20,000 kg per annum. At a unit cost of £12kg^{-1} of phosphorus removed, the value of this service could equate to £240,000 per annum or the equivalent of about £290ha^{-1}.

This value could range from £140,000 (equivalent to £170ha^{-1}) for a medium/large plant using chemical dosing under a less stringent consent (in 2007 prices) to £520,000 (equivalent to £630ha^{-1}) for a similar plant operating under a stringent standard and implementing a metal consent.

Summary

The different land designation types all possess the potential to remove nutrients and thus improve water quality in the River Ray catchment. However, it should be borne in mind that these values represent the potential of Otmoor to remove N and P from water supplies but that this will only have an economic value if water supplies exceed the legal concentration limits and would otherwise have to be treated or diluted in order to comply with these limits. Notwithstanding this, the removal of N and P will have a role to play, both physically and economically, under the Water Framework Directive in contributing to the improved ecological status of the river. The potential value of each of the areas is summarised in Table 7.

Table 7. Areas (ha) of land designation types at Otmoor.

Land designation	Total area (ha)	Potential value N removal (£,000 a^{-1})	Potential value P removal (£,000 a^{-1})	Total potential value (£,000 a^{-1})
ESA	357	516	107	624
SSSI	160	229	48	278
RSPB	210	301	63	365
Non-ESA	100	14	30	174

Regulating: Natural hazard regulation

Background

The regulating service 'natural hazard regulation' considers the control of flooding (both fluvial and coastal) and protection from storms. In the context of this study the focus is on the alleviation of, and protection from, low frequency, high magnitude flood events (Figure 2).

As described previously, the amount of water flowing through the Otmoor network of drains is heavily controlled. Levels in the inner and outer ring ditches are kept high to act as a barrier to enclose livestock. On the RSPB reserve a series of flexi-pipe drains are in use to replenish the surface water using water from the ditches during dry periods. The extent of the drainage and the different land designations are shown in Appendix 1.

Flooding on Otmoor is common both directly from rainfall (surface water flooding) or following high flows on the River Ray. The flooding is partly due to the low-lying nature of Otmoor but also to the controlling of water levels. To ensure that the RSPB land is not widely inundated, which can be detrimental to nesting bird species, the levels in the ring ditches are kept below bank. This has caused large areas of the neighbouring SSSI to flood.

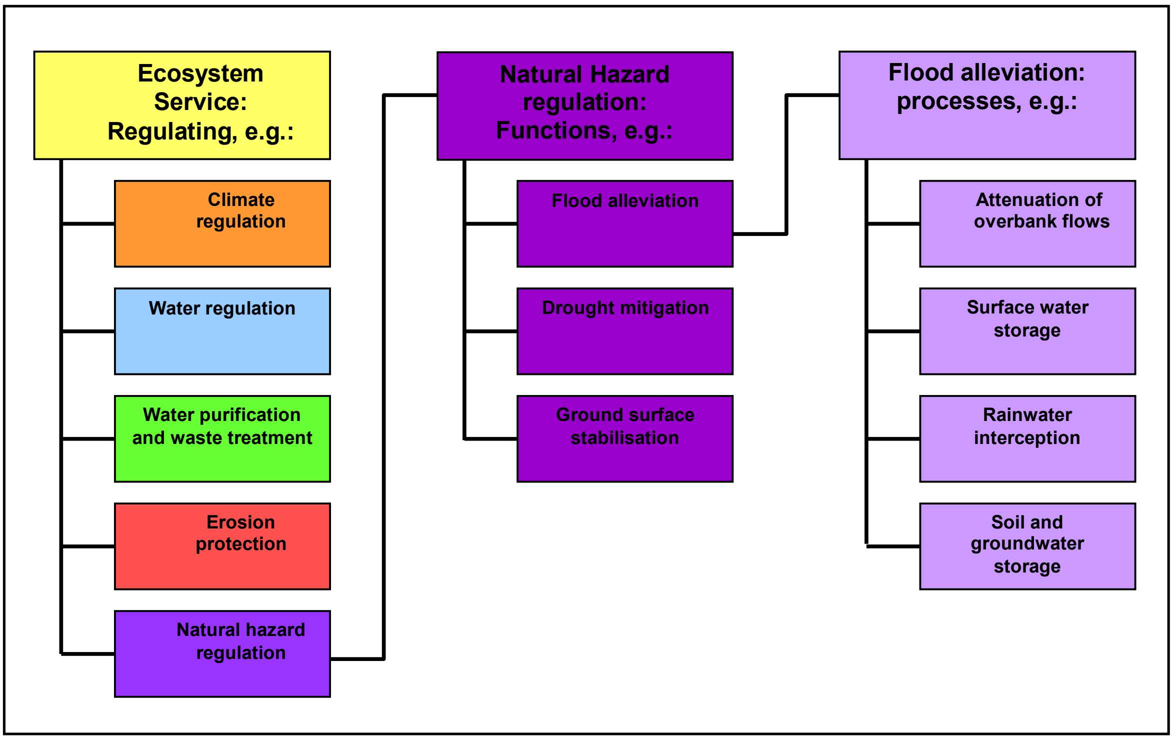
Causal chain

A wetland area such as Otmoor plays an important role in reducing the effects of flooding both locally and for the catchment as a whole. In simple terms the wetland can be seen as having a dual role in that it does not generate floods and, when floods have been generated elsewhere in the catchment, it can reduce the impacts of these floods further downstream.

On a catchment scale, the presence of wetlands can affect the severity of the flood peak experienced at a point downstream. A wetland can moderate flooding through the interception of rainfall by wetland vegetation and the storage of water in surface, soil and groundwater compartments before it is returned to the river. Where the residence time of water in a wetland is relatively long this would allow a gradual return of rainwater into the river system. The contribution of water from a wetland to the flood flows of a river would be minimal compared to an impermeable urban surface where rainfall would find its way into the surface water drainage and river system more or less instantaneously hence greatly increasing the contribution to the flood hydrograph.

At a more localised level, when a river is already in flood a wetland can also have a notable influence on the severity of the flooding. Otmoor, like many wetlands is low-lying, below much of the surrounding land so out-of-bank flood waters will in preference flow into the wetland as opposed to other areas. The dense network of drainage channels in a wetland provides a significant volume of storage and this will reduce the flood flows and levels at points further downstream. Similarly, the on-site management of water will impact upon the flood attenuation function at Otmoor (Figure 3).

Figure 2. Relationships among ecosystem services, functions and processes for flood alleviation.



Quantitative evaluation

The most effective way to quantify and evaluate the role of the Otmoor wetland in reducing the impact of severe flooding on a catchment scale is to use hydrological modelling. This approach can compare standard hydrological observations such as the peak river flow for different land use scenarios which enhance or reduce the role of the wetland area.

The Flood Estimation Handbook or FEH (Institute of Hydrology, 1999) is the recognised standard methodology for the prediction of extreme flood flows in UK rivers. The FEH includes software packages to calculate flood flows at given return periods – called design flows. The flows are calculated based on a number of parameters known as catchment descriptors which are derived for any catchment area identified to the nearest 0.5km^2. The catchment descriptors are automatically downloaded into a file using part of the FEH software and a flood hydrograph is then generated using a unit hydrograph rainfall-runoff model (Kjeldsen *et al.*, 2005). This procedure was undertaken for the Ray catchment using a point downstream of Otmoor as the catchment outlet. The catchment descriptors are listed in Appendix 8.

Since the catchment descriptors reflect the properties of a catchment as a whole it was difficult to assess the role of Otmoor in terms of its location without conducting empirical studies beyond the scope of this work. However, in terms of estimating an economic value at risk from flooding it is common practice to predict a depth of flood water through the use of hydrodynamic modelling. For the current study this was done by using a surveyed cross section downstream of Otmoor (Figure 4) and the Manning's equation, which is a standard equation used for deriving flows for different channel characteristics:

$$Q = (A\ R^{2/3}\ S^{1/2})\ /\ n$$

Where:
Q is the flow; A the cross-sectional area of the channel (m^2); R the hydraulic radius of the channel – the ratio of the cross sectional area to the wetted perimeter (m); S the channel bed slope (m/m) and n Manning's Roughness Coefficient. By applying this equation at a number of water depths, a rating curve (Figure 5) was derived from which a flood level could be calculated for the FEH design flows.

Figure 3. Causal chain for flood attenuation at Otmoor.

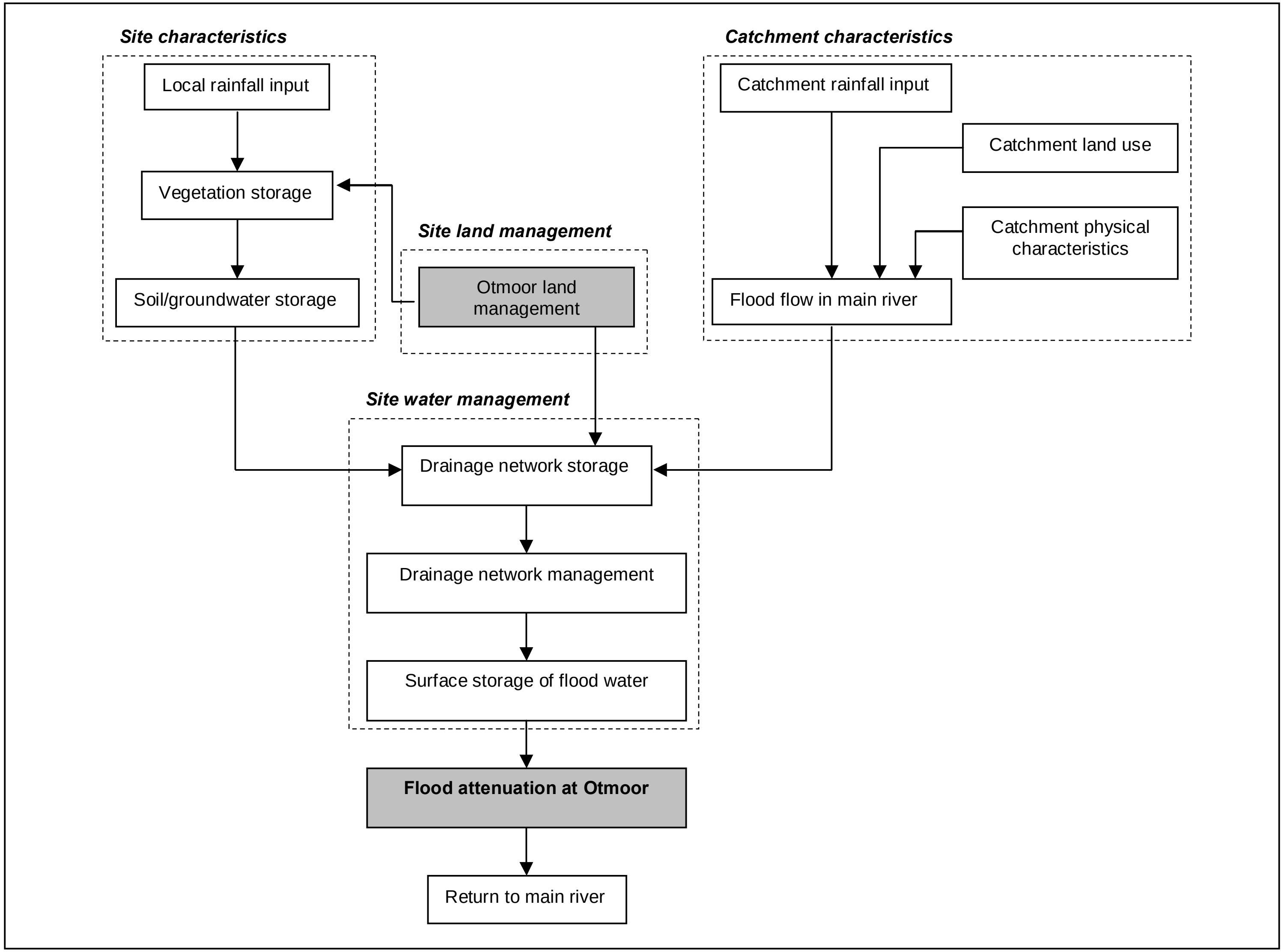


Figure 4. Surveyed cross section of the Ray downstream of Otmoor. (Data provided by David Mould, CEH Wallingford).

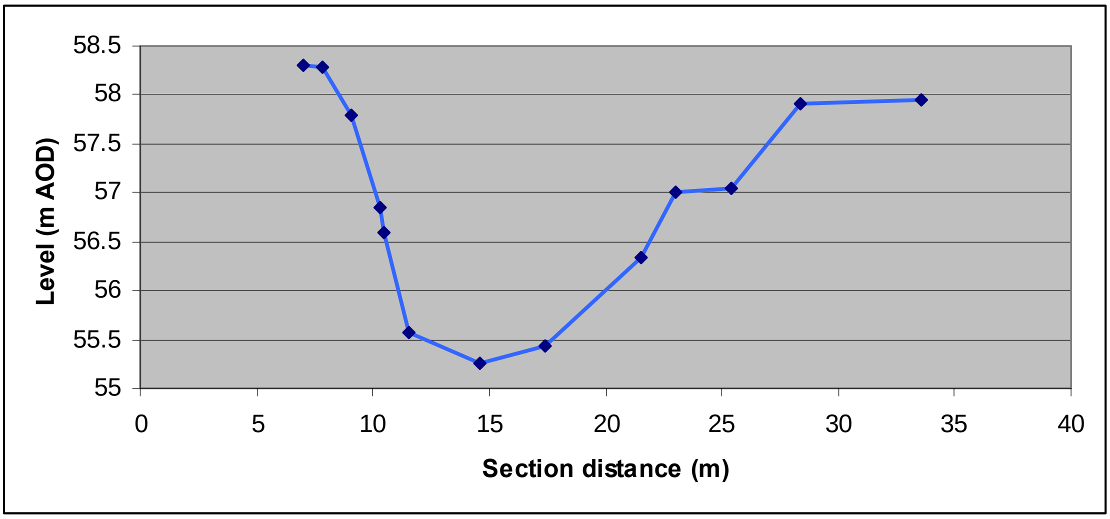
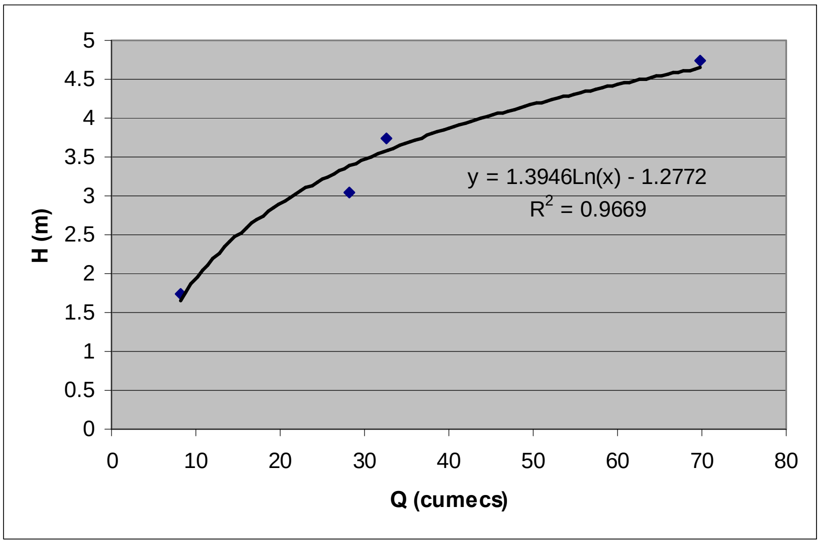


Figure 5. River Ray flow /level rating curve.



The results of the modelling demonstrate a range of depths and flows across Otmoor depending on the return event frequency (Table 8). For instance, for a 100-year flood event a depth of 1.56m and a flow of $67.7 m^3 s^{-1}$ is predicted. Similarly for a more frequent 2-year flood event values of 0.45m and 30.5 $m^3 s^{-1}$ are predicted for depth and flow respectively.

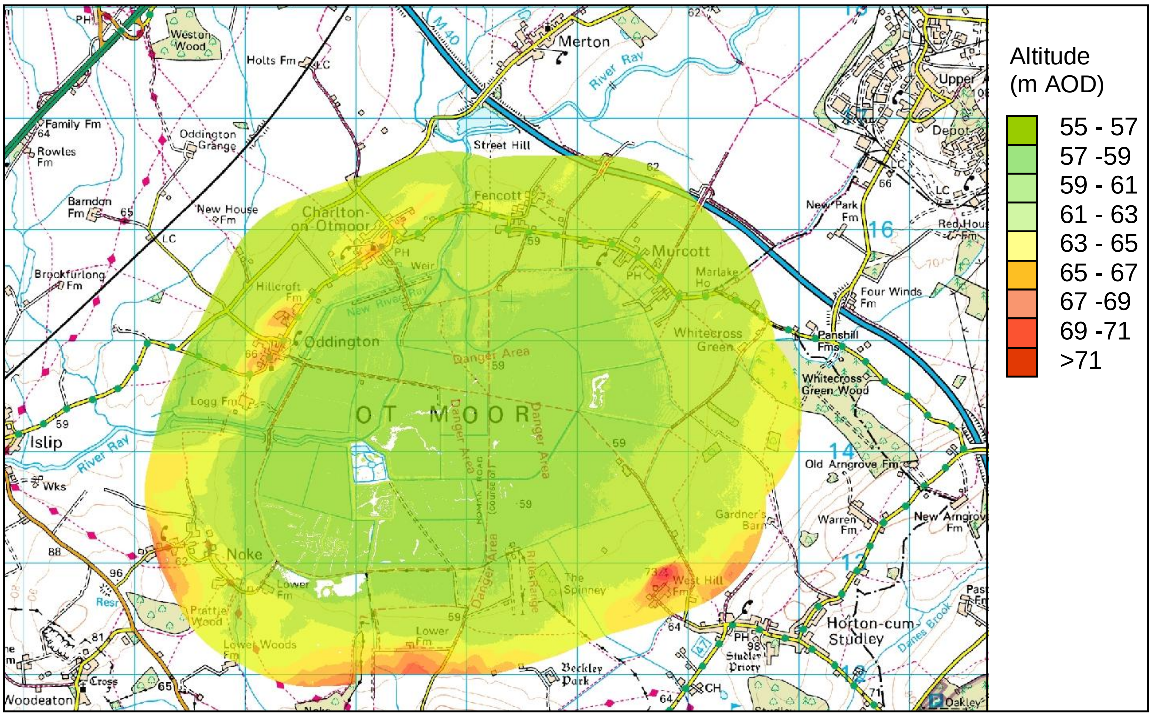
Table 8. Flood flows and out-of-bank flood depths at Otmoor.

Return Period (years)	Baseline conditions Depth (m)	Flow ($m^3 s^{-1}$)
2	0.45	30.5
5	0.77	38.4
10	0.98	44.6
25	1.2	52.3
50	1.37	59.3
100	1.56	67.7
100 + 20%	1.8	80.2

The levels in m AOD can also be considered as out-of-bank flood level, based on the assumption that at bankfull the river would be at a 2-year return period flow. This is a reasonable assumption based on research into channel morphology and has been previously used for flood models. The out-of-bank flood levels are simply derived by subtracting the 2-year flood level from the other design flood levels. The resulting levels could be used to estimate the potential cost of damage.

A further approach can be developed by considering the amount of water which can be stored within the different land designations at Otmoor when the Ray is in flood. This assessment of water storage was undertaken using a GIS cell based modelling technique (Rodda, 2005) and a digital terrain model (DTM) of the area derived from Environment Agency LiDAR (light detection and ranging) data. The DTM has a horizontal resolution of 2m and a vertical accuracy of +/- 0.3m and was provided to cover the full extent of Otmoor (Figure 6).

Figure 6. Ground levels from the LiDAR DTM for the Otmoor area.



The DTM gave a variation in altitude of the Otmoor area of between 55 and 63 m AOD. Some cells of the DTM had no data values as these were areas of surface water which cannot give a signal for a LiDAR survey. The GIS cell based modelling required definition of areas where flood waters would originate as source cells. These were taken as the channels of the New Ray and Old Ray as they pass through Otmoor. Any of the DTM cells outside of the source cells were then considered as destination cells. The flood extents were defined for the DTM area using four out-of-bank flood depths of 0.5, 1.0, 1.5 and 2.0 m. The following tasks were undertaken to produce the flood extents:

1. The selected river reaches (source cells) were gridded to the same size as the DTM (i.e. 2m).
2. For each cell in the DTM area (destination cells), the corresponding source cell in the river was determined by the path of the lowest cumulative altitude taken from the DTM cell to the water body.
3. The DTM cell was then given the corresponding source cell altitude.
4. The depth of flooding was then added to all the DTM cells.
5. The cell values form step 4 were then subtracted from the original elevation values to give an altitude based flood extent map. Any cells where the value was negative were flooded.

These operations in were then repeated for the range of flood depths. The flooded areas and volumes for different land uses within the Otmoor area were calculated from totaling the numbers of cells flooded and in the case of volume multiplying by the cell flood depth.

This method is represented graphically in Figure 7. It is somewhat approximate however, and shows the *potential* flooded area as it does not consider the surface roughness and dynamics of the flow. Also it can not simulate the controlling of water levels on the inner and outer ring drains by the hydraulic structures. However it has the advantage over detailed hydrodynamic models such as ISIS that it requires few parameters and can be easily set up and simulated for a range of scenarios in a relatively short time frame. Due to the approximate nature of this approach the actual design flood levels given in Table 8 were not used; also these levels were calculated for a specific cross section on the Ray and there would be a notable variation in these over a longer reach.

Figure 7. A simplified illustration of the grid cell based operations used to produce a flood extent map: (a) River (grey) and land cells with altitude; (b) Determining the lowest altitude path (yellow) from a buffer cell (46) to the nearest river cell (2); (c) Allocation of river cell altitude to all corresponding buffer cells; (d) Flood depth of 2 m added to each cell; (e) Grid from (d) subtracted from DTM grid (a) with all negative values representing flooded cells.

a)

34	36	37	38	39
36	35	36	38	39
37	36	37	37	39
39	44	40	39	38
48	46	46	41	39

b)

1	36	37	38	39
36	2	3	38	39
37	36	37	4	39
39	44	40	39	5
48	46	46	41	6

c)

34	34	36	36	36
34	35	36	38	36
34	35	36	37	38
34	35	36	37	38
34	35	36	39	39

d)

36	36	38	38	38
36	37	38	40	38
36	37	38	39	40
36	37	38	39	40
36	37	38	41	41

e)

-2	0	-1	0	1
0	-2	-2	-2	1
1	-1	-1	-2	-1
3	7	2	0	-2
12	9	8	0	-2

The potential flooded area and volume results are shown in Table 9. When the controls on the flow of water through the ring drains are imposed however the areas and volumes flooded are quite different. During times of high flows the RSPB reserve is prevented from flooding and the excess water extends over the area of the SSSI.

Economic evaluation

The Flood and Coastal Defence Project Appraisal Guidance (FCDPAG3) (MAFF, 1999) sets out the principles that should be used in undertaking economic evaluations for publicly-funded projects for river and coastal flood alleviation and other similar projects. The Guide interprets the requirements of the Treasury's Green Book in respect of such projects.

Table 9. The potential areas and volumes of land flooded for different out-of-bank flood depths. The ESA area includes ESA land also within the SSSI and RSPB reserve. Non ESA land is outside of RSPB reserve and the SSSI.

Land designation	Total Area (km^2)	Area of flooding (km^2)				Volume of flooding (m^3)			
		0.5m	1.0m	1.5m	2.0m	0.5m	1.0m	1.5m	2.0m
SSSI	1.6	0.22	0.45	0.77	0.79	50,512	232,571	540,340	934,840
RSPB	2.1	0.28	0.79	0.93	0.94	87,195	372,088	812,149	1,283,020
ESA	3.57	0.71	1.36	1.52	1.76	52,508	194,015	401,146	627,330
Non ESA	1.0	0.16	0.38	0.43	0.47	224,128	773,995	1,648,808	2,381,214
All Otmoor	8.24	1.36	2.97	3.77	3.96	414,049	1,570,649	3,264,235	5,213,850

Increased frequency and duration of flood inundation on Otmoor could potentially lead to benefits both downstream and upstream, principally in the reduction of damage to property and the potential avoidance of new or replacement flood alleviation schemes or measures. Damage caused by flooding is a function of the depth, duration and velocity of flooding, together with the effects of sediment and pollutants carried by the floodwater.

The principal measurable costs of increased flood events on Otmoor would be a reduction in agricultural productivity from that land and hence its agricultural value. There would also be ecological losses, particularly associated with ground-nesting birds.

It is beyond the scope of this Study to undertake a full benefit-cost analysis of the different flooded areas and volumes calculated above. This would require a separate study of itself, with the benefits calculated as the expected value of annual flood losses averted. In particular, it would be necessary to define and survey the areas of residential and commercial property which would be subject to reduced damage from flooding as a result of the different areas of land assumed to be flooded on Otmoor. Nevertheless, a brief outline of the approach to be taken can be provided here.

The Flood Hazard Research Centre (FHRC) produces standard data on the losses to be expected for different types of residential property, according to the type and age of dwelling, and also the social class of its occupants, as a result of flooding of different depths and duration (Flood Hazard Research Centre, 2005).

The social class of the property's occupants is relevant where it is considered necessary to consider the distributional impacts of alleviation proposals. Such proposals could have differential impacts on individuals depending, among other things, on their income groups and social class (the loss or gain of one £ will be a greater loss or gain to someone with a lower than a higher income). The Treasury Green Book suggest that earners in the lowest and highest income bands respectively value £1 as the equivalent of £2.45 and 45p.

Damage to residential properties should be based on the economic rather than the financial costs of the effects of flood waters on the fabric and contents of a building. Direct and indirect taxes should be excluded and depreciating goods valued at their depreciated value rather than their replacement cost.

Defra has also produced guidance on the appraisal of the intangible impacts of flooding such as increased stress, health effects and loss of memorabilia which may be as important to householders as the direct material damage to their homes and their contents.

FCDPAG3 advises that permanent buildings which are at risk of total loss from flooding should be valued at their current market value, excluding any adjustment in value for the flooding risk (MAFF, 1999). For strategic and preliminary studies, the Guide advises that it is appropriate to assume that the value of properties will fall within the mid-range of Council tax bands, suitably adjusted from their 1993 price datum, and that residential properties will be assumed to be written off if the mean maximum water level exceeds the floor level.

For large industrial and commercial properties, the Guide advises that it will often be necessary to carry out a site survey of the likely losses.

The loss of agricultural output would be valued either as occasional losses of output as a result of flooding events or, with increased incidence of flooding or a rise in the soil water level, an overall fall in the agricultural output per unit area.

The loss of a single year's agricultural output can usually be estimated by calculating the gross margin foregone (gross output less variable costs) using standard farm management data (e.g., the Farm Management Pocketbook) as fixed or overhead costs will be unchanged. Where a standing crop is lost to flooding, variable costs that have already been incurred, such as seeds and fertilisers, would need to be added back. Where the losses are more than occasional, there are likely to be some savings in fixed costs as farmers adjust to the changed circumstances.

Provisioning: Food

Background

There are three distinctive Environmentally Sensitive Areas (ESA) of grassland management at Otmoor:

1. An area of Wet Grassland managed by the RSPB;
2. An area of Extensive Permanent Grassland that includes MOD land;
3. An area of Permanent Grassland.

An area of arable land, farmed conventionally and not under any ESA management agreement, is also included in the study area. It is possible to investigate these different land management practices and evaluate differences in terms of food production and income.

Data sources

Information on the ESA objectives, scheme prescriptions and associated agronomic issues and incentives are taken from the Defra website.[16]

Defra's ESA agreements are limited to ten years and all will expire over the next seven years. The scheme has been replaced by the Higher Level Scheme (HLS), part of Defra's Environmental Stewardship Scheme, which is a new overarching agri-environment scheme that provides funding to farmers and other land managers in England who deliver effective environmental management on their land. HLS funding is used to support exceptional environmental land management practices. The funding is competitive and discretionary so applicants may not be successful with their applications, even in priority areas such as Otmoor.

HLS funding has been targeted to support scarce and declining bird species, including breeding waders such as snipe, redshank and lapwing. It is also used to conserve important wildlife habitats, such as ancient hay meadows, wetlands and heathlands, and boost the condition of England's most sensitive landscapes.

Because of restricted budgets Natural England is facing a great deal of pressure in setting priorities for HLS funding in those areas which produce the highest environmental benefits and areas currently being farmed with the benefit of an ESA agreement may not receive continuing funding in favour of other land being put into arable reversion.

Causal chain

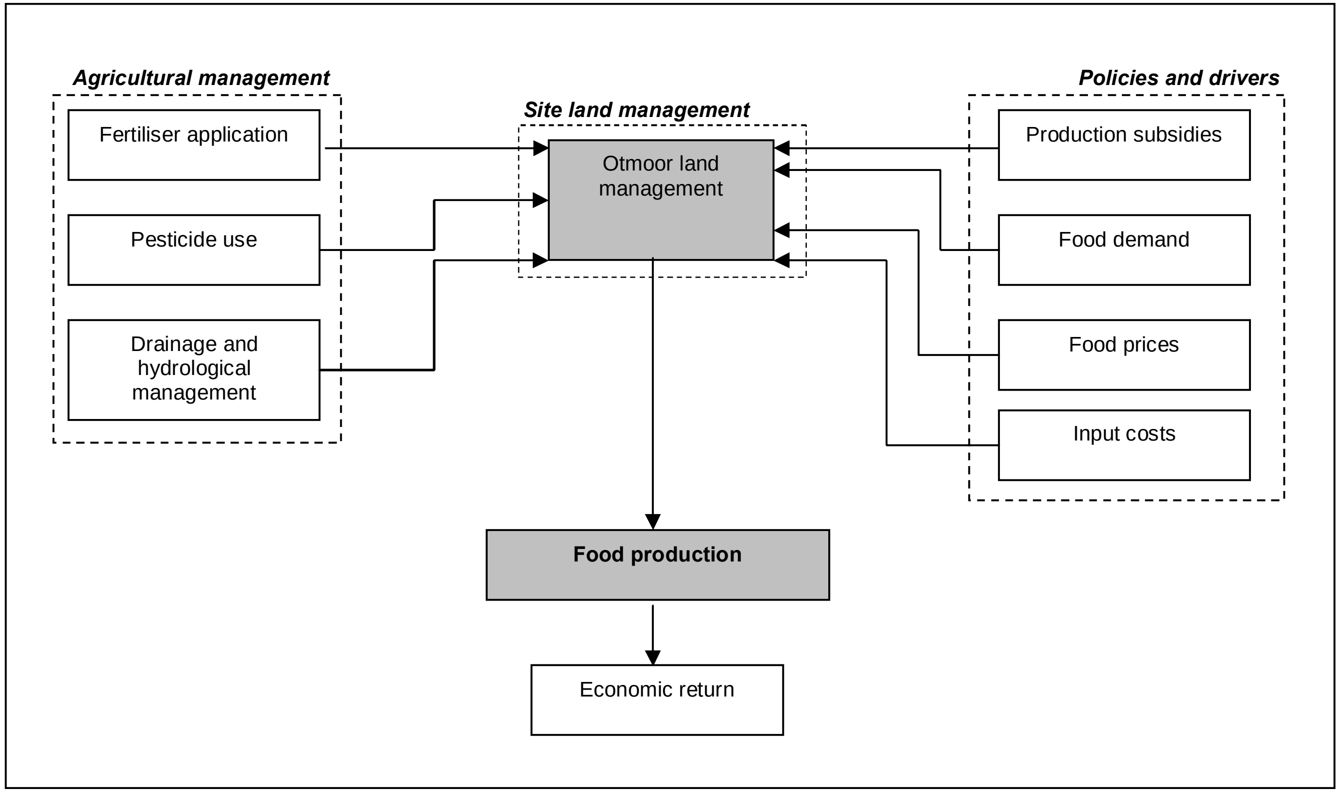
The causal chain for food production is presented in Figure 8. As described above, changes in funding, especially in terms of agri-environment schemes demonstrates the potential fluidity of the components.

Quantitative evaluation

Laid out below is a theoretical valuation of what might be achieved under each management regime on Otmoor. The value is calculated by estimating the theoretical live-weight gain achievable by beef cattle during the grazing season and placing a value on the total kilograms of gain from each hectare according to stocking rates permissible within the scheme. Current ESA payment rates for management tiers are shown with each managed grassland unit within Otmoor. The values are summarised in Table 10.

[16] http://www.defra.gov.uk/erdp/docs/national/annexes/annexx/uttrex2.htm

Figure 8. Causal chain for agricultural food production.



Wet Grassland (Tier 2) – RSPB Otmoor Reserve

Under the ESA, livestock grazing is not permitted between 15th March and 31st May but, due to access difficulties, grazing livestock will only be possible from 1st June to 30th September. These areas will only support approximately 0.5 strong store beef animals per hectare since stocking density is restricted to 0.55 Grazing Livestock Unit per hectare ($GLUha^{-1}$) (a beef animal being the equivalent of 0.8 livestock units). In this example the animal is a weaned calf from an autumn-calving suckler cow. Standard data from the Farm Management Pocket Book (37th Edition) shows the average weaning weight of an autumn-born calf to be 335 kg when turned out at about 10.25 months old.

This type of grassland is likely to support very low daily live-weight gains for the period; it is noteworthy that farmers responding to the questionnaire indicate a weight loss on this type of pasture. A theoretical estimate of 0.25kg live-weight per day may be achievable with a mowing regime during the period that encourages new grass growth (no supplementary feeding is allowed). The resulting total live-weight gain for the period will be 30kg per beast (120 days x 0.25kg) or 15kg per hectare (30kg x 0.5 stocking rate). Given an average annual market sale price of £1.00kg^{-1} for store cattle, the grazing value of Wet Grassland is £15ha^{-1}. Input costs will be minimal since no fertilizer or seed can be applied under the ESA management agreement.

The current ESA payment for this type of land is £270ha^{-1}, against an estimated income foregone of £255ha^{-1}, making the estimated net income from such land £285ha^{-1}.

Extensive Permanent Pasture (Tier 1b) – Otmoor SSSI

Under the ESA agreement, management of this type of pasture is restricted, in that no chain harrowing or rolling can take place between 1st April and 30th June (to protect ground nesting birds). A supplementary payment can be paid if livestock are excluded between 15th March and 31st May. If a forage crop is taken, hay can only be cut after 30th June. Stocking rates for these pastures are again reduced to 0.55 $GLUha^{-1}$ which are only likely to support an average of 0.5 strong store beef animals per hectare.

Theoretically this extensive system (incorporating slightly better grassland species) is likely to support a marginally higher average daily live-weight gain for the period. It is estimated that a daily live-weight gain of 0.5kg per day may be achievable. Where stock is initially excluded (March to May) the total live-weight gain for the period (June to October) is estimated at 75kg per beast (150 days x 0.5kg) or 37.5kg per hectare (75kg x 0.5 stocking rate) which produces a grazing valuation of £37.50/ha using a sale price of £1.00 per kg for store cattle. Where stock are not excluded and grazing occurs from turnout (potentially 1st April) to housing (at the end of October), the overall growth rates are likely to be the same, but there is the potential that during the early part of the grazing season they could be slightly higher.

The total live-weight gain for the period (April to October) is estimated at 105kg per beast (210 days x 0.5kg) or 105kg per hectare (210g x 0.5 stocking rate) which produces a grazing valuation of £105ha^{-1}.

Potentially a single hay crop could be the only forage grown with limited grazing of aftermath by cattle. The hay crop is cut after 30th June and yield and quality are likely to be low. Fresh grass yield is estimated at 10 to 15 tonnes per hectare with no application of fertilizer but with a single addition of farmyard manure (FYM). Hay yields are then based on 25% of the fresh grass weight which would produce a hay crop of between 2.75 and 3.75 tonnes per hectare.

In addition to income from farming, the ESA payment for this regime is £105ha^{-1} against an estimated income foregone of £125ha^{-1}; £175ha^{-1} for limited grazing; and £197ha^{-1} for haymaking. Where grazing is limited, the net income from this area will be £212.50ha^{-1}, including a stock exclusion supplement. Where the land is grazed from April to October, the net income would be £210ha^{-1} and, taking a net valuation hay crop at £40^{-1} tonne, between £307ha^{-1} and £347ha^{-1}.

Permanent Grassland (Tier 1a) – ESA land

Under ESA management, this grassland is not ploughed or re-seeded and any existing fertilizer application rates, whether organic or inorganic, cannot be increased. Stocking rates permitted are 1.6 GLUha^{-1} on heavier land and 1.85 GLUha^{-1} on lighter land. Cattle or sheep can be grazed on these pastures.

Beef cattle grazing the heavier land would be stocked through the grazing season at approximately 2 cattle per hectare (1.6 GLU ÷ 0.80 LU) and sheep at 14 ewes per hectare (1.6 GLU÷ 0.11 LU). On lighter land beef would be stocked at 2.25 cattle per hectare and sheep at 16 ewes per hectare. Theoretically the beef cattle grazing these pastures could achieve an average live-weight gain of 0.75 kg per day for the grazing season (April to October). This represents an average total live-weight gain per beast of 157.5kg (210 days x 0.75) or a grazing valuation of £315ha^{-1} (157.5 x 2 stocking rate) on the heavy land or £354ha^{-1} (157.5 x 2.25 stocking rate) on light land.

In addition to the farming income, an ESA payment of £35ha^{-1} is available, making net incomes £350ha^{-1} for heavy land and £389ha^{-1} on light land.

Table 10. Summary of income values for different land management practices.

	Wet Grassland	Extensive Permanent Pasture			Permanent Grassland		Arable	
					Heavy Land	Light Land	Wheat	Spring Barley
Live-weight gain kg/day	0.25 kg		0.5 kg		0.75 kg			
Stocking rate	0.55GLU		0.55GLU		1.6 GLU	1.85GLU		
Beef animals/ha	0.5		0.5		2	2.25		
Live-weight gain kg/day	0.25		0.5		0.75			
Value /hectare	£15		Grazing restricted £37.50	No restriction £105	Heavy land £315	Light land £354		
Hay		2.75tha^{-1} - 3.75 tha^{-1}						
Net Income	**£285**	**£327**	**£212**	**£210**	**£350**	**£389**	**£359**	**£235**

Arable land not under ESA

On the arable land there is the potential to grow either a winter wheat crop if land cultivations can take place immediately after harvest or a spring crop of barley if land conditions determine that autumn cultivations cannot take place. The Farm Management Pocket Book gives average yields for feed winter wheat of 8.25 tonnes per hectare and for feed spring barley of 6.0 tonnes per hectare. Costs of production for both crops would have to be taken into consideration.

The Farm Management Pocket Book quotes a gross margin of £359ha^{-1} for winter wheat and £235ha^{-1} for spring barley; no allowance is made for any possible future payments for or restrictions on cropping regimes.

Summary

There are clear differences between the economic value associated with agricultural food production for the different land designations (Table 11). The range of incomes available from land at Otmoor is between £210ha^{-1} and £389ha^{-1}, although the area of light land available is limited, and for most of the ESA a maximum of £350ha^{-1} is most likely, making wheat growing the economically most attractive option for land use, outside the ESA scheme. Recent increases in grain prices have further improved the margins available from cereals and future funding from the HLS will have to reflect this in order to avoid parts of the study area returning to arable agriculture.

Where individual farmers' preference is for livestock-based agriculture, it is very likely that the retention of existing levels of funding will be sufficient to sustain most of the environmental practices necessary to maintain and possibly improve the current state of the SSSI. However, individual farmer preference is not predictable and often does not reflect the best economic option, this is evidenced at Otmoor by the land management practices adopted by the RSPB, which are intended to provide habitat for a range of bird species rather than provide food for society.

Table 11. Potential income for the different land designation types at Otmoor.

Land designation	Total area (ha)	Range (£ha^{-1})	Range (£annum^{-1})
ESA	160.0	350 ï 389	56,000 - 62,240
SSSI	210.0	210 - 347	44,100 - 72,870
RSPB	357.0	285	101,745
Non-ESA	100.0	235 ï 359	23,500 - 35,900

Cultural: Recreational

Background

The stakeholder analysis indicated that Otmoor provided an important recreational resource. The access to areas of high conservation value facilitated by the RSPB has enforced this importance. A variety of recreational activities take place at Otmoor. The principle activities are dog walking, walking, horse riding, cycling or bird watching.

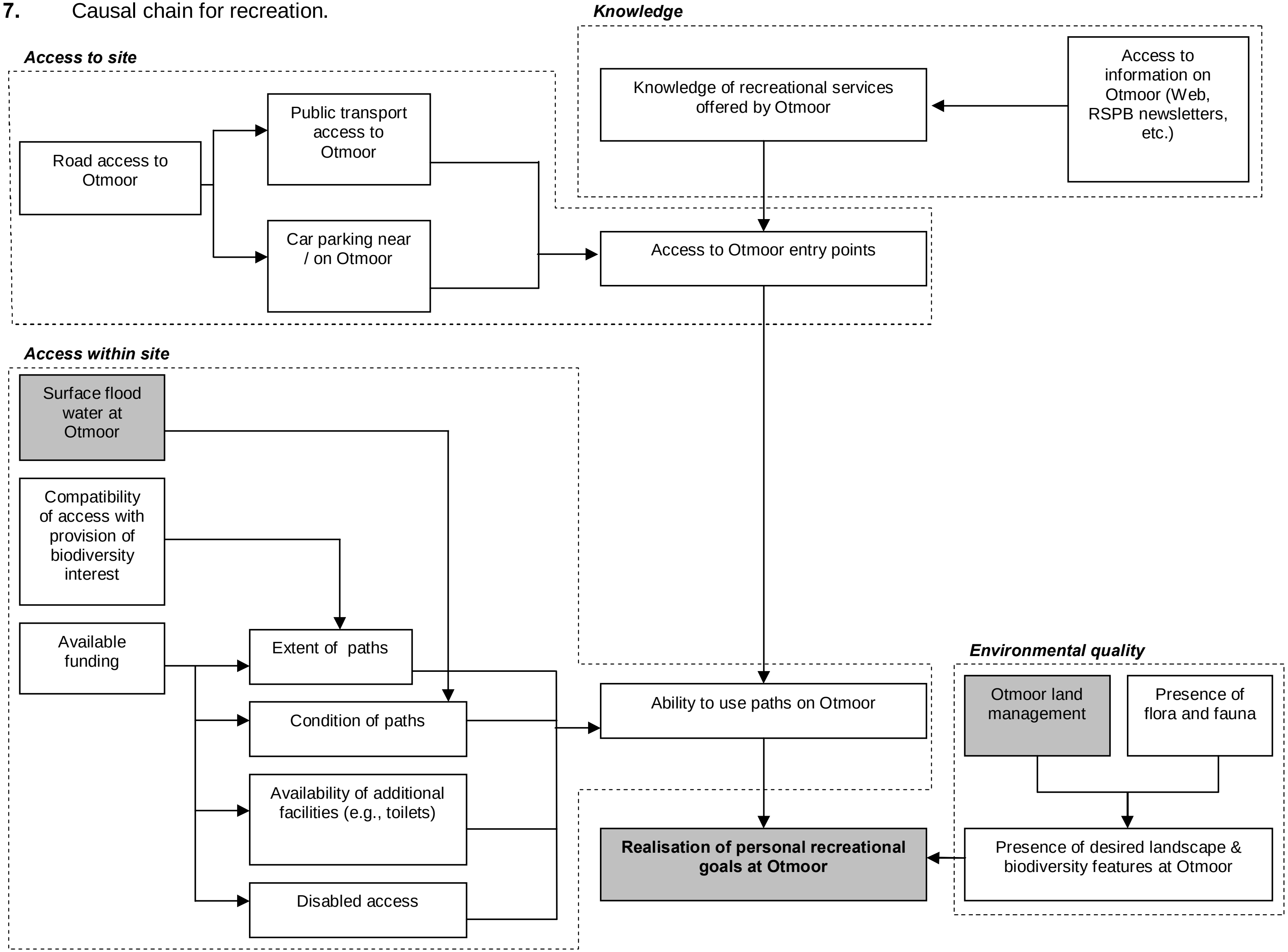
Causal chain

The realisations of individual recreational goals depend on a variety of factors (Figure 9). These factors can be grouped into the following categories: access, both to Otmoor and within the area, knowledge and environmental quality.

Data sources

The RSPB provided data on visitor numbers to their Otmoor reserve between April 1999 and April 2007. These data were collected by volunteer wardens located at either Beckley or Oddington and identify visitors as dog walkers, walkers, horse riders, cyclists or bird watchers. The reliability of these data will depend on how consistently the data were collected, which is likely mainly to be a function of the number of volunteers on-site during each month. However, without these data, or commissioning new studies, limited analysis of the recreational value of the site could be achieved.

Figure 17. Causal chain for recreation.



Quantitative evaluation

Crystal Ball Predictor software (Decisioneering Inc.) was used to analyse time series in these data and to project trends over the next five years. The results of this are shown in Figures 10-15. Visitor numbers to the reserve are just over an average of 300 per month (Figure 10), with just under an average of 300 per month of these visiting to bird watch (Figure 11). Projections over the next five years, based on the time series from 1999 to 2007, suggest that these numbers are quite stable and will neither increase nor decrease significantly unless there are major changes in reserve management. Numbers of dog walkers and walkers on the reserve are low and appear to be declining, while numbers of horse riders and cyclists, although also low, appear to be stable. In summary, the great majority of visitors to the RSPB reserve come to watch birds, and visitor numbers appear to have stabilised at just over 300 per month.

Figure 10. Total number of visitors to RSPB Otmoor reserve observed by wardens April 1999 ï April 2007, with projections to March 2012. Data fit a single exponential smoothing time series model.

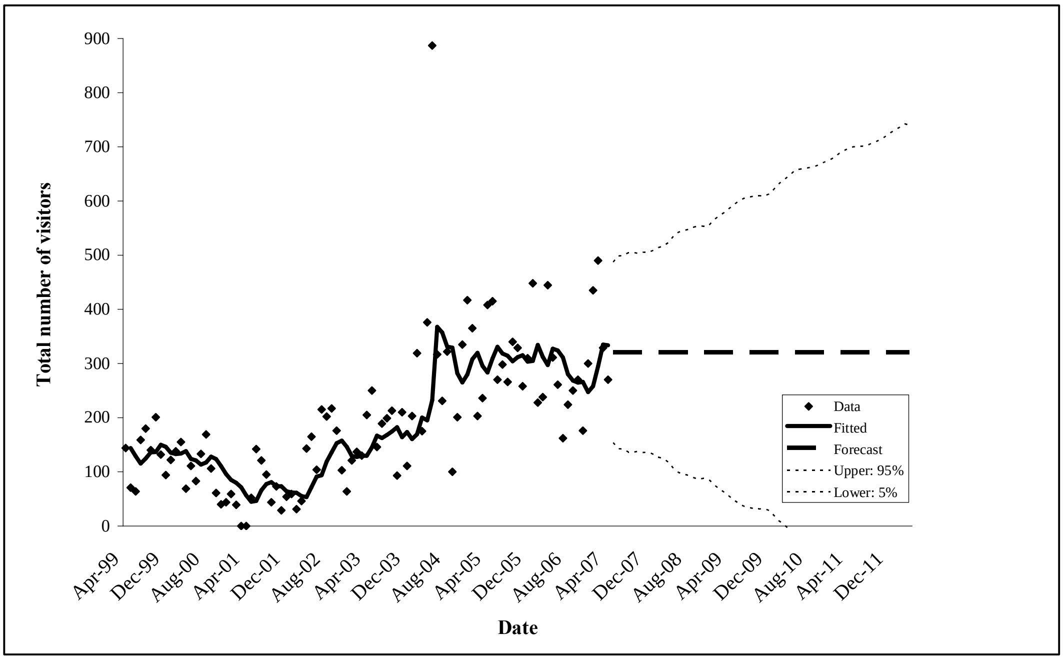


Figure 11. Total number of bird watchers visiting RSPB Otmoor reserve observed by wardens April 1999 ï April 2007, with projections to March 2012. Data fit a single exponential smoothing time series model.

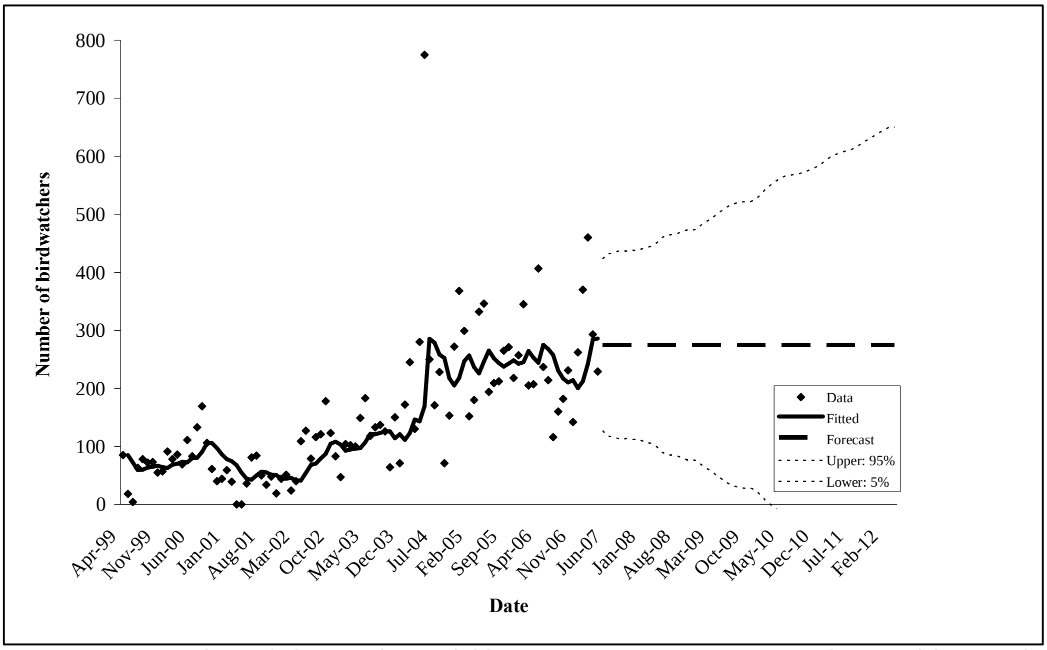


Figure 12. Total number of dog walkers visiting RSPB Otmoor reserve observed by wardens April 1999 ï April 2007, with projections to March 2012. Data fit a double moving average time series model.

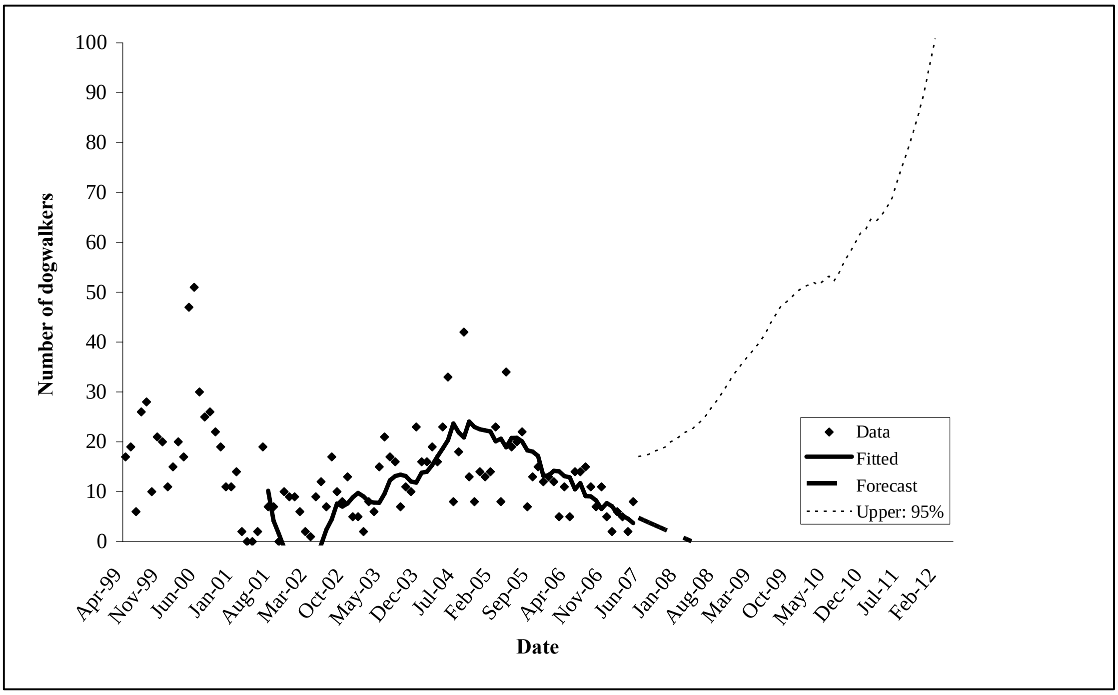


Figure 13. Total number of walkers visiting RSPB Otmoor reserve observed by wardens April 1999 ï April 2007, with projections to March 2012. Data fit a double moving average time series model.

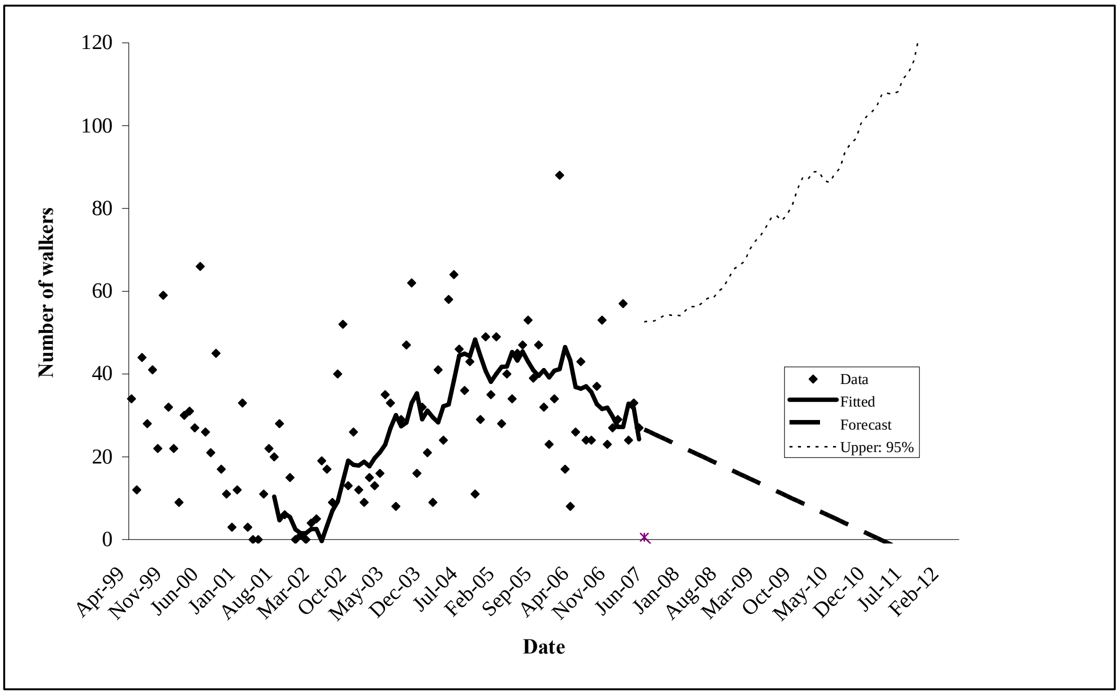


Figure 14. Total number of horse riders visiting RSPB Otmoor reserve observed by wardens April 1999 ï April 2007, with projections to March 2012. Data fit a double moving average time series model.

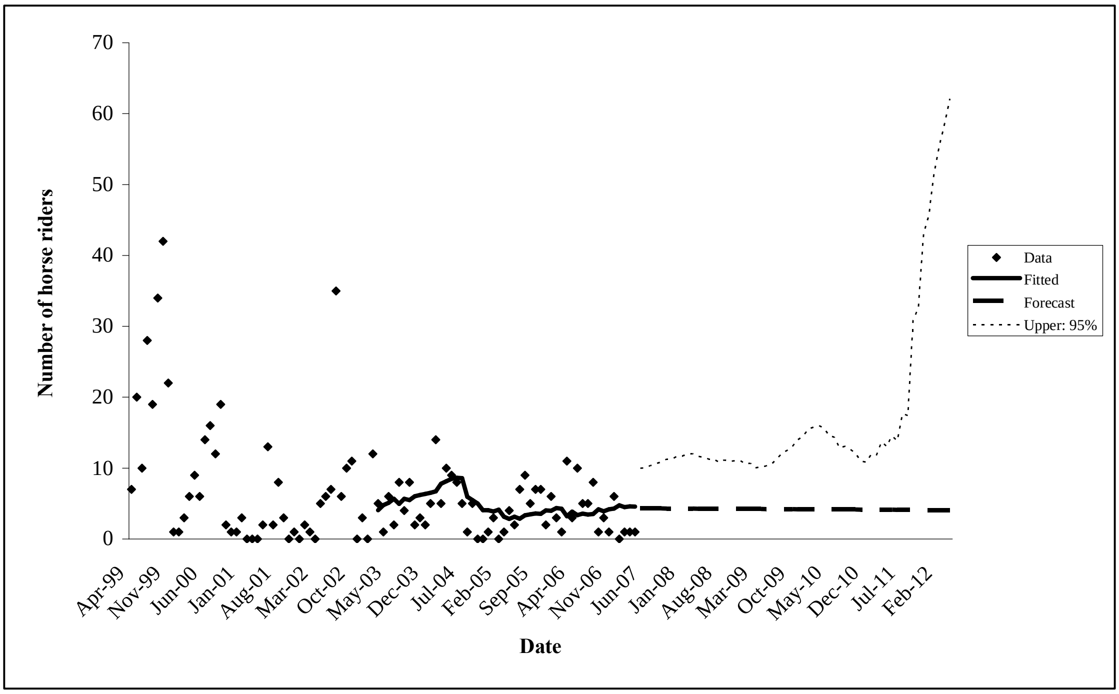
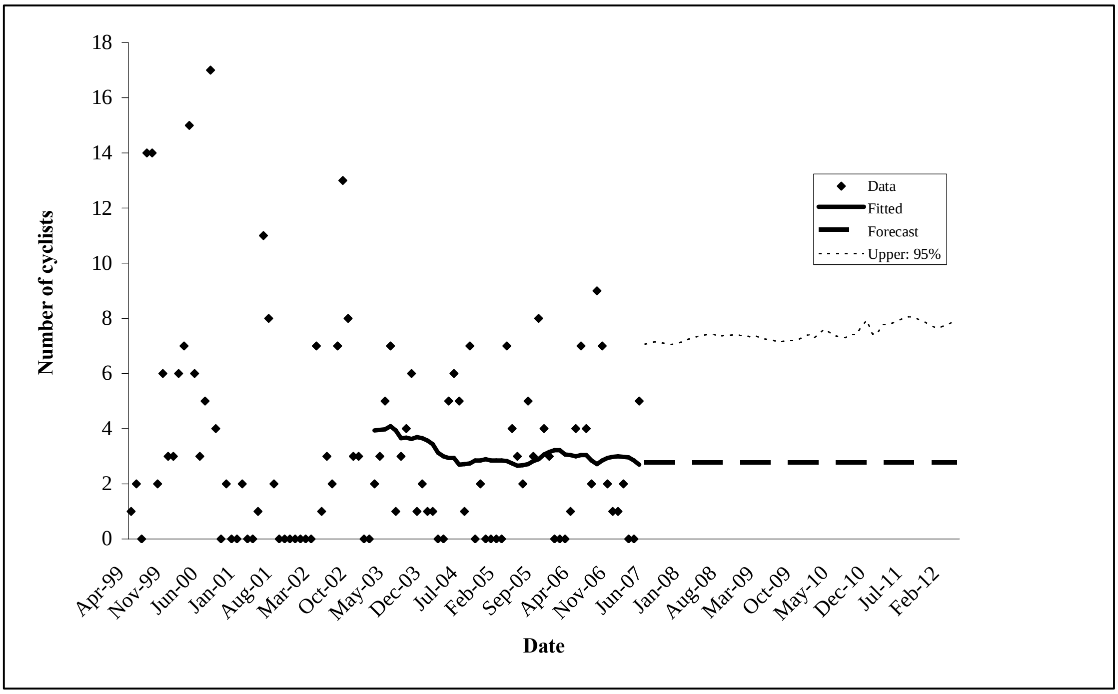


Figure 15. Total number of cyclists visiting RSPB Otmoor reserve observed by wardens April 1999 ï April 2007, with projections to March 2012. Data fit a single moving average time series model.



Economic evaluation

Otmoor, in common with other environmental assets, has both use value (as measured through bird watching and other recreational uses) and non-use existence value. It is not, however, always possible or desirable to express all use and non-use values in monetary terms or even to quantify them in meaningful ways.

FCDPAG3 (MAFF, 1999) advises that it may be acceptable to use standard values of benefit per visit from the Yellow Manual (now replaced by the Flood Hazard Research Centre's Multi-coloured Manual) but there are insufficient case studies to be certain of the differences between sites that produce differences in values of enjoyment. Where recreational value forms a significant fraction of total benefit using the estimated number of visits to the site, it will probably be necessary to undertake a contingent valuation study to derive a site-specific value of enjoyment. FCDPAG3 defines the contingent valuation method as a valuation methodology which uses questionnaire techniques to elicit valuations using respondents' willingness to pay for an environmental improvement.

However, the Guidance suggests that, in order to carry validity, such studies will inevitably be costly and time-consuming, with minimum sample sizes of 500 individuals and likely costs of over £50,000. It is beyond the scale and scope of this study to undertake a contingent valuation on the scale recommended in FCDPAG3.

Section 2 of this report sets outs the size and characteristics of the sample of local residents and visitors to Otmoor. The small size of the sample and limited duration of the survey means that the results obtained cannot be presented as representative of local people or visitors to the RSPB reserve. Rather, the survey sought to understand the likely range of views about Otmoor.

Similarly, the survey results cannot be used with any validity to assess the use or existence value that is placed on Otmoor. As no entry fee is charged to the RSPB reserve, there is no direct means of establishing the recreational value of at least this part of Otmoor (i.e., the RSPB reserve and its immediate surrounds). Most local people did not wish to pay anything for access to the RSPB reserve whilst about half the visitors expressed a willingness to pay (all within the range of £2 to £5 per visit) but the size of the sample and its age and social class bias would make extrapolation to a wider population meaningless. Furthermore, there are no data on the mean distances travelled by visitors to the RSPB reserve and hence their costs incurred in undertaking the visit.

Eftec (2007) summarises the findings of a number of studies which sought to value recreational visits to wetlands. Each of these studies was set in the context of proposals to improve or create recreational (and other) services and it is questionable whether their results can be transferred from their specific context to this study where there is no proposal to change people's ability to access Otmoor for recreational purposes or to charge for the provision of that service. For the sake of completeness, though, Eftec assumed that a visit (to the case study of the Wareham Managed Realignment) would be valued at £2 per person, within a range of £0.50 and £5, which is similar to the willingness to pay of those questioned.

The number of visits made to the site can be a good indicator of the likely magnitude of recreational benefits, placed within an appropriate context.

No information is available on the proportion of RSPB members within the 300 visitor numbers to the reserve per month so it is not possible to use their subscriptions as a proxy value for the recreational use of the reserve. Considerably more information would be required of visitors to make such an approach meaningful, such as the average number of repeat visits to Otmoor per month, the number of visits to other RSPB reserves and the value placed on other services offered by RSPB membership.

The remaining means by which to value the recreational use of Otmoor is set out in FCDPAG3 which advises that the least contentious and lowest cost method of deriving a proxy for the lower bound economic value of an environmental asset can be taken as the lowest of:

i) the cost of creating a similar site elsewhere of equivalent environmental value;
ii) the cost of relocating to another site; or
iii) the cost of local protection

FCDPAG5 stresses that calculating the habitat replacement cost does not imply that habitat replacement is the most appropriate option but rather that is simply a means of estimating the minimum monetary estimate of the benefit of a protected habitat or asset (MAFF, 2000). FCDPAG5 sets out guidance on estimating habitat replacement costs, particularly in respect of setting objectives, land acquisition, planning, assessment and design, implementation, monitoring and additional costs. Land acquisition usually dominates both financial costs and total economic costs.

Whilst there are conceptual difficulties to using such proxies to value the existing use and non-use values of a unique area such as Otmoor, they nevertheless could prove to be a useful estimate of the value that society has placed on the RSPB reserve both in terms of its nature conservation and recreational functions, particularly given that the reserve has itself been mostly restored from farmland. A similar-sized area of farmland in southern England would be likely to cost in order of £1m and considerable expenditure, including a £670,000 Heritage Lottery Grant, has been incurred in establishing and managing the reserve. These, discounted to net present values, would provide a minimum estimate of the economic cost of recreating an equivalent asset elsewhere, although they would not account for the 'uniqueness' of Otmoor which is unlikely to be replicated.

APPENDIX 5 – SOIL TYPES FOUND AT OTMOOR

Soil information is based on the 1:250,000 Soil Map of England and Wales (Soil Survey of England and Wales 1983).

Map symbol	Soil association	Description of main soil series
343c	Elmton 3	Freely draining, shallow, brashy, lime-rich, loamy soils over limestone
411a	Evesham 1	Lime-rich clayey soils with impeded drainage
411b	Evesham 2	Lime-rich clayey soils with impeded drainage
511a	Aberford	Freely draining, lime-rich, loamy soils over limestone
511b	Moreton	Freely draining, lime-rich, clayey soils over limestone
511h	Badsey 1	Freely draining, lime-rich, loamy soils over limestone gravel
544	Banbury	Freely draining, ferruginous loamy soils over ironstone
571i	Harwell	Freely draining loamy over clayey soils over inter-bedded loam and sandstone
711f	Wickham 2	Slowly permeable, seasonally wet, base-rich, loamy over clayey soils
711t	Beccles 3	Slowly permeable, seasonally wet, base-rich, loamy over clayey soils
712b	Denchworth	Slowly permeable, seasonally wet, base-rich, clayey soils
712g	Ragdale	Slowly permeable, seasonally wet, base-rich, clayey soils
813b	Fladbury 1	Naturally wet, clayey floodplain soils
841d	Shabbington	Naturally wet, loamy soils affected by groundwater

APPENDIX 6 – OTMOOR SSSI CITATION

COUNTY: OXFORDSHIRE **SITE NAME:** OTMOOR

Status: Site of Special Scientific Interest (SSSI) notified under Section 28 of the Wildlife and Countryside Act 1981

Local Planning Authorities: Oxfordshire County Council,
South Oxon District Council,
Cherwell District Council

National Grid Reference: SP575130

Ordnance Survey Sheet 1:50,000: 164 **1:10,000:** SP51

Date Notified (Under 1949 Act): 1952 **Date of Last Revision:** 1972

Date Notified (Under 1981 Act): 1988 **Date of Last Revision:**

Area: 211.6 ha 522.86 ac

Other information: Much of the site is an MOD firing range.

Description and Reasons for Notification

Otmoor is a large bowl-shaped area of land on the flood-plain of the River Ray to the east of Oxford. The area of special scientific interest represents the core of what was, until recent times, an extensive area of wetland which was flooded in winter and was traditionally managed as rough grazing marsh. Much of the land outside the special area has been drained and converted to arable or improved pasture. The site contains a wide range of habitats with many species of nationally uncommon plants and animals. Approximately half of the site is herb-rich damp grassland which grades into wet sedge and coarse grassland.

The whole site is underlain by Oxford clay; the soils are derived from river alluvium and are predominantly stoneless, and occasionally calcareous clays of the Fladbury 1 Series. On the southern edges of the site are fine loams of the Shabbington series. Wetter areas of the site have a peat layer developed over the alluvium.

A series of grassland types are represented on Otmoor, ranging from coarse tussocky grassland dominated by tufted hair-grass *Deschampsia caespitosa* to a herb-rich sward. Most of the site supports neutral grassland, with local differences attributable to variation in soil type, peat cover and water levels. The more acidic soils contain plants such as purple moor grass *Molinia caerulea* while the calcareous influence is shown by the presence of upright brome *Bromus erectus*, dropwort *Filipendula vulgaris* and dyer's greenweed *Genista tinctoria*.

Herb-rich swards in the southern half of the site are largely of crested dog's-tail *Cynosurus cristatus*-black knapweed *Centaurea nigra* grassland. One field with a ridge and furrow topography is on the south-east corner of the site. The more freely draining soils have a rich flora with a local abundance of species indicative of unimproved neutral meadow, including betony *Stachys officinalis*, lady's bedstraw *Galium verum*, devil's-bit scabious *Succisa pratensis*, sneezewort *Achillea ptarmica*, saw-wort *Serratula tinctoria* and great burnet *Sanguisorba officinalis*. An unusual member of these swards is believed to be a hybrid between the heath dog violet *Viola canina* and fen violet *V. persicifolia*. The wetter areas within the herb-rich meadows contain a diverse flora of sedges including the uncommon tawny sedge *Carex hostiana* and flea sedge *C. pulicaris* and the nationally rare downy-fruited sedge *C. tomentosa*. Patches of sedgedominated sward follow the flow of surface runnels with areas of greater pond sedge *C. riparia* swamp merging into canary reed-grass *Phalaris arundinacea* and meadowsweet *Filipendula ulmaria*. Other less common species present include meadow rue *Thalictrum flavum*, marsh valerian *Valeriana dioica*, tubular water-dropwort *Oenanthe fistulosa* and marsh stitchwort *Stellaria palustris*. The grasslands of the northern half of the site contain a mosaic of coarse, tussocky tufted hair-grass grassland and patches of more diverse grassland on drier soils. The former includes false fox-sedge *Carex otrubae*, hard rush *Juncus inflexus*, lesser spearwort *Ranunculus flammula* and skullcap *Scutellaria galericulata*, whilst drier areas have a sward which includes crested dog's-tail, sweet vernal-grass *Anthoxanthum odoratum*, marsh foxtail *Alopecurus geniculatus*, sneezewort, black knapweed and self-heal *Prunella vulgaris*. The northern-most fields consist of semi-improved grassland with red fescue *Festuca rubra*, tufted hair-grass, marsh foxtail and tufted forget-me-not *Myosotis laxa*, together with oval sedge *Carex ovalis*, compact rush *Juncus conglomeratus*, soft rush *J. effusus* and tubular waterdropwort in wetter areas.

A woodland block forms part of the eastern boundary of the site. This is semi-natural pedunculate oak wood which has been established since 1840 on an old ridge and furrow system. It has a dense understorey of blackthorn which forms a substantial thicket along the western edge. A ride on the western side contains a mainly ruderal flora amongst which a number of meadow species survive including the nationally rare true fox-sedge *Carex vulpina* and greater burnet saxifrage *Pimpinella major,* on the edge of its range in Britain.

Several dense hedges are present throughout the site and most date back to the enclosure of Otmoor in the mid-nineteenth century. These consist predominantly of hawthorn and blackthorn together with mature pedunculate oak and crack willow.

Standing water habitats are well represented. The central area of the site regularly floods in winter and two shallow pools remain in most years. The pools and ditches are rich in submerged and emergent aquatic plants. Most contain stands of branched bur-reed *Sparganium erectum*, reed sweet-grass *Glyceria maxima*, bulrush *Typha latifolia*, water plantain *Alisma plantago-aquatica* and flowering rush *Butomus umbellatus*. Many of the ditches contain arrowhead *Sagittaria sagittifolia* swamp, with frogbit *Hydrocharis morsus-ranae*, fat duckweed *Lemna gibba*, ivy-leaved duckweed *L. trisulca* and the regionally uncommon fine-leaved water-dropwort *Oenanthe aquatica*. The largest pool, known as the Pill, is rich in uncommon aquatic species including water violet *Hottonia palustris* and bladderwort *Utricularia vulgaris*.

The invertebrate fauna of the site is diverse and contains many nationally and regionally uncommon species, including several listed in the British Red Data Book of Invertebrates. There are several species whose foodplants are found largely in unimproved meadowland. These include the sawfly *Hartiga xanthosoma* on meadowsweet, the buprestid beetle *Trachys troglodytes* and marsh fritillary butterfly on devil's-bit scabious, the longhorn beetle *Agapanthia villosoviridescens* on marsh thistle *Cirsium palustre* and the forester moth *Adscita statices* on sorrel *Rumex acetosa*. The blackthorn thickets contain large populations of the nationally restricted black hairstreak and brown hairstreak butterflies. This site has the only colony of marsh fritillary butterfly currently known in Oxfordshire, and represents the second most easterly station for this butterfly in Britain. Other regionally uncommon species present include the emperor moth *Saturnia pavonia*, the shield bug *Zicrona caerulea* and the longhorn beetle *Anaglyptus mysticus*. The ditches and pools contain several water beetles including *Agabus uliginosus, Enochrus isotae* and *Helophorus dorsalis*, while emergent vegetation and shallow water supports the reed-beetle *Donacia impressa*, and the hoverflies *Anasimyia transfuga* and *Parhelophilus frutetorum*. Other uncommon species recorded in recent years include the large soldier fly *Stratiomys potamida* and the dragonfly *Sympetrum sanguineum*.

Otmoor was once renowned as an outstanding site for overwintering wildfowl and waders. Although much of this interest has been lost due to drainage and agricultural improvement, the site is still of high regional value for birds with over sixty breeding species recorded in recent years. The wet grasslands in the northern half of the site are still regularly used by many species of overwintering and breeding waders and wildfowl. The wintering birds regularly include teal, wigeon, snipe, lapwing, golden plover and short-eared owl and, less frequently, merlin, hen harrier, marsh harrier, green sandpiper, jack snipe and stonechat. The scrub and grassland habitat provides nesting sites for many species of summer visitors with nightingale, grasshopper warbler and lesser whitethroat common in certain areas. Breeding waders include regionally important numbers of snipe, and there is also regular breeding by curlew and lapwing, and occasional use by redshank. Other vertebrates recorded include water shrew, badger and grass snake.

APPENDIX 7 – NOTES FROM FIELD VISIT, NOVEMBER 2006

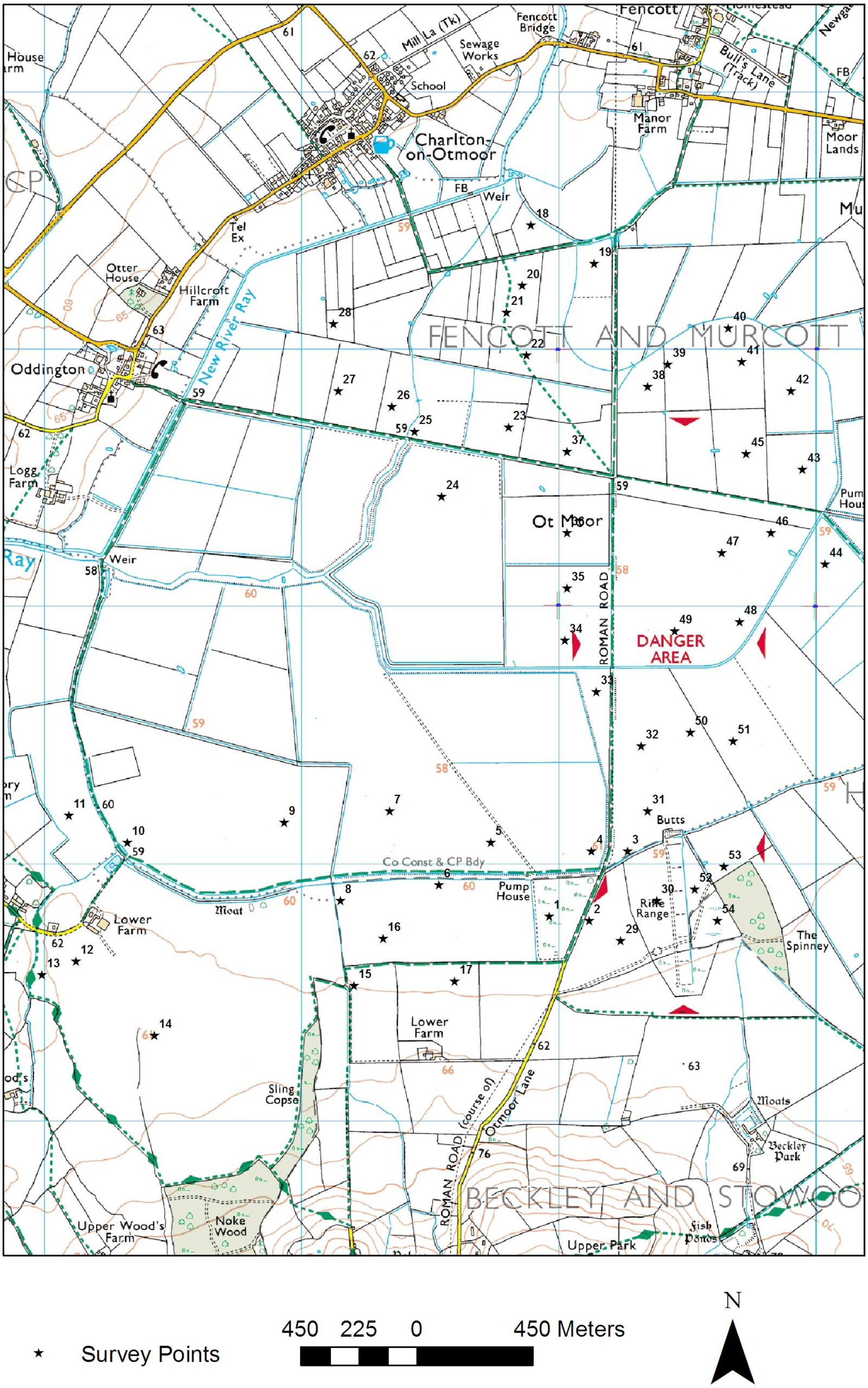
Note	RSPB Compartment	Comments
		Notes from visit to RSPB reserve (south-eastern sector)
1	1	Sheep grazing scrub and sedge beds
2	1/20a	Wide corridor of willow. High level of standing water in shallow ditch on east side of track. Stacks of willow logs and chips.
3	18	Brown topsoil in poached gateway (range firing day ï no access)
4	2	Outer ring ditch is 10m wide with deep water and flanked with reed, Typha and sedge. New scrapes and ditches in field with dark excavated material exposed
5	2	Pile of composted material for spreading in field to raise OM in topsoils; track running NW has wide ditches on either side; stock access points to fields
6	2/22	Water level in outer ring ditch is about 1m higher than that in parallel ditch to south of track, demonstrating water retention on site.
7	2	Rush pasture and new scrapes (say 25% disturbed)
8	21	New scrapes, bridge and ditch enlargement; peaty topsoil over clay in ditch section
9	6	Rush pasture with new scrapes (say 25-50% disturbed); water table at 20-30 cm depth; weather station present; clay soils rutted by machines, some black topsoils evident
10	6	Met contractor who recalled draining the land in 1972. drained to about 4 feet, water pumped to ditches and corn crops grown moderately well though old root mat took several years to decompose. Peat only encountered in topsoils.
11	outside	Ley grassland grazed with sheep
12	21	Gentle slopes, coarse grass, brown soil in spoil from scrapes
13	outside	Ditch clogged with sedge; small flow to east
14	21	A series of small scrapes including rectangular depressions about 50 cm deep; water at 40 cm depth; spoil has brown clay loam topsoil and mottled brownish sandy clay
15	outside	Ditches flowing; young ley with dark (humose?) topsoil; gentle slope
16	outside	Rough cultivated with dark (humose?) topsoil; level field
17	outside	E-W ditch with deep water but very little flow evident; containing Phragmites and Typha; fields under ley with patches of maize (for game cover)
		Notes from visit to north-western sector
-	11	Small fields have permanent pasture with and without rush, some leys
18	12	Depression in field has Juncus and Phalaris
19	12	Grazed permanent pasture; field has slight fall towards ditch and track; topsoil is 10 cm ZCL over grey mottled ZC
20	12	Footpath field, permanent pasture grazed by heifers; about 5% is depression ï old channel course? containing coarser vegetation (Deschampsia?); heavy clay loam topsoil contains calcareous particles derived from footpath route over wet spot; shallow defunct grip runs N-S across field
21	12	Southern part of field has much Deschampsia and rush tussocks; soils are 10 cm humose ZCL over ZC.
22	12	Wetter part of field in slight depression with splashy conditions and Phalaris; 10 cm humose ZCL over ZC
23	10	Level field with permanent grass (lightly improved with buttercup); 10 cm ZCL over ZC
24	4	RSPB; large field of ley grass with bare patches being altered for conservation; compost has been spread to improve OM status; some scrapes begun though more to be done ï see management plan
25	10	River Ray (old course) with no obvious flow evident; stage board by bridge
26	9	Herbage grazed off by cattle (recently removed, fresh dung pats); filed generally level but some slight undulations, which could include R Ray channel works; 10 cm humose ZCL over 10 cm ZCL over ZC
27	9	Level field of permanent grass with 5 m wide old grips, splashy and about 30 cm deep; 20 cm grey mottled ZCL over ZC
28	11	Lightly improved grass with patches of rush and Deschampsia; 10 cm humose

		ZCL over 10 cm grey mottled ZCL over ZC

		Notes from visit to SSSI (MOD range, central/southern sector); following overnight rain
29	20a	Generally level field with slight undulations; species-rich wet grassland with sedge and rush; 10 cm humose ZCL over 30 cm grey mottled ZCL over mottled SC; water table at 20 cm depth
30	20a	Land beside firing range; ground surface and vegetation as 29; 15 cm humose ZCL over 5 cm mottled ZCL over ZC
31	18	Level field of rush pasture with very little sedge; grazed by cattle (recently removed); 10 cm humose ZCL over 40 cm ZC over C containing some sand particles; water table at 20 cm depth
32	18	Level field with defunct grips; rush pasture with greater concentration of rush and sedge in depressions; some standing water; 20 cm humose ZCL over 40 cm dark grey ZCL to ZC over grey mottled ZC
33	18	Level field flooded to about 5 cm depth (from the inner ring drain?); grass-sedge community; 15 cm humose ZCL over 15 cm grey mottled ZCL over silty clay, ZC is generally blue/grey in colour but with some very dark bands
34	16	Area of rank ungrazed vegetation including large tussocks of sedge and Deschampsia, occasional rush and scattered hawthorn bushes and dog rose; indications of larger hawthorn bushes having been cut; splashy surface, snipe seen; 5 cm humose ZCL over 15 cm mottled ZCL over mottled ZC
35	16	Vegetation as 35 and also with blackthorn bushes and some creeping thistle; splashy surface; 2 cm humose ZCL over 38 cm mottled ZCL over grey mottled ZC; note: cattle have access from 36 but have grazed only a little way into the rougher vegetation here; standing water in scrapes
36	15	Rush pasture with some sedge, grazed with cattle; splashy surface, flock of snipe; 15 cm humose ZCL over 25 cm blue-grey ZC over grey mottled ZC
37	13	Field of grass with creeping thistle, sloping gently down to area of standing water in old channels (?) containing prominent rush; 10 cm humose ZCL over wet grey mottled ZC
38	14a	Level field of permanent grass with creeping thistle and scattered clumps of rush; grazed by cattle; no water table encountered within 80 cm depth (drains working?); 15 cm humified peat over 15 cm grey mottled ZC over 30 cm blue-grey ZC over grey mottled C
39	14a	Permanent grass containing large surface water body in depression; water level here is about 1 m higher than that in the adjacent inner ring drain, into which it is discharging
40	14b	Fenced-off area with pond and island (and swans), where water level is about 0.5 m below field surface and 0.5 m above inner ring drain
	28a	Not visited ï by observation across inner ring drain; improved grass with clumps of rush, grazed with cattle
41	14b	Level field of permanent grass with scattered rush, grazed with cattle; cattle have access points to inner ring drain for drinking water; 10 cm black humified peat over 10 cm grey mottled ZCL over grey mottled ZC
	27a	Not visited ï by observation across inner ring drain; large rushy depression with standing water
42	14b	More or less level permanent grass with occasional rush, grazed with cattle; splashy surface; 10 cm loamy peat over 15 cm grey mottled ZCL over grey mottled ZC
	27a	Improved grass with occasion thistle
43	14b	Lightly grazed semi-improved grass with Deschampsia; splashy conditions in depression and swans on deeper depression/pond; 5 cm loamy peat over 25 cm grey mottled ZCL over 20 cm blue-grey ZC over grey mottled ZC
44	24b	Rough grazing dominated by Deschampsia, lightly grazed with cattle, and small patch of large sedge community; splashy conditions; 20 cm loamy peat over 10 cm grey mottled ZCL over 30 cm blue-grey ZC over grey mottled ZC
45	14a	Most of field is rush pasture with creeping thistle, soil described in wetter community of Deschampsia and large sedge; 10 cm loamy peat over 10 cm humose ZCL over 20 cm blue-grey ZC over grey mottled ZC

46	17	Mostly more or less level field of rush pasture grazed with cattle and splashy surface; rush more prominent on margins of scrapes, scattered elsewhere, sedge concentrated in slight depressions with deeper standing water; 10 cm humose ZCL over 10 cm grey mottled ZCL over 30 cm grey mottled ZC over grey mottled C
47	17	Permanent grass with occasional rush, scrape nearby, grazed with cattle; 10 cm humose ZCL over 30 cm blue-grey ZC over grey mottled C
48	17	Rush pasture grazed with cattle; nearby vegetation boundary indicates cutting (for hay?) in grass-Descampsia-sedge-rush community; some splashy surface conditions; 15 cm loamy peat over 15 cm grey ZCL over 10 cm blue-grey ZC over grey mottled ZC
49	17	Deschampsia-dominant community, grazed (elsewhere) by cattle; damp surface; 10 cm loamy peat over 10 cm grey ZCL over blue-grey ZC over grey mottled ZC to C
50	18	Grass-sedge-rush community grazed by cattle (removed), and with FYM applied; damp/splashy surface; topsoil of 10 cm loamy peat to humose ZCL
51	19	Level filed of improved grass, no rush apparent, occasional patches of creeping thistle, ground conditions moist, grazed by cattle; 10 cm humified peat over 15 cm grey ZCL over 45 cm blue-grey ZC over grey mottled C
52	20a	Adjacent to firing range; cultivated patch, dry sirface conditions; 5 cm humified peat over 10 cm grey ZCL over grey mottled ZC
53	20b	Grass-sedge-rush community, cut in summer?; 10 cm loamy peat over grey ZCL (no depth specified, probably shallow boring)
54	20a	Ungrazed level field with prominent sedge and meadowsweet; 60% of field cut (for hay?); thin humose topsoil over silty clay; adjacent to oakwood

Location map for field notes.



APPENDIX 8 – FLOOD ESTIMATION HANDBOOK CATCHMENT DESCRIPTORS

456500,215550,"SP,57000,16200"
AREA,210.59,
FARL,0.988,
PROPWET,0.32,
ALTBAR,80,
ASPBAR,183,
ASPVAR,0.18,
BFIHOST,0.446,
DPLBAR,15.02,
DPSBAR,18.2,
LDP,27.78,
RMED-1H,10,
RMED-1D,31.4,
RMED-2D,38.7,
SAAR,628,
SAAR4170,653,
SPRHOST,39.5
URBCONC,0.659
URBEXT1990,0.015
URBLOC,0.754
C,-0.024
D1,0.329
D2,0.312
D3,0.253
E,0.294
F,2.474
C(1km),-0.023
D1(1km),0.31
D2(1km),0.343
D3(1km),0.248
E(1km),0.288
F(1km),2.461

APPENDIX 9 – CLIMATE CHANGE SCENARIO

Introduction

The full impact of a warmer atmosphere on the climate of the UK is difficult to assess. The latest simulation results from a number of global circulation models do not present clear cut projections of UK climate over the full range of seasons. However one aspect where the models are in strong agreement is that the winter rainfall would increase with a warmer mean annual temperature (Maraun *et al.*, 2008). The impact of a wetter winter on Otmoor will be more flooding both in terms of its severity and duration. An increased severity of flooding was represented by assuming the levels associated with a 1 in 10 year flood (1 m). The increase in the duration of flooding was assumed from river flow analysis. Using flow records on the Ray at Islip, the number of days above the current estimated 2 year return period (30.1 cumecs) were listed for each winter (October to March) as shown in Table A1.

Table 1. The number of winter days above Q2 from 1995-2006.

Winter	Days above Q2
1995/6	12
1996/7	0
1997/8	8
1998/9	29
1999/2000	9
2000/1	54
2001/2	7
2002/3	38
2003/4	3
2004/5	0
2005/6	1

Although the exact number of days when Otmoor was flooded may differ from these durations due to the management of the wetland and the time taken for the flood waters to dissipate, they were considered an appropriate of the actual duration of flooding. The current average (mean) value of 14 days was taken to represent normal conditions, whereas the maximum duration of 54 days (2000/1) was considered as a likely scenario for increased winter flooding.

In terms of recreational, the effect of climate change can be demonstrated by the length of footpaths that would be underwater given more severe flooding. This was demonstrated by comparing the length of footpaths flooded under 2 year and 10 year out-of-bank flood depths (Table 2, Figures 1 and 2). Under dry conditions the total length of footpaths in the Otmoor area is 15.8 km.

Table 2. The impact of climate change on winter visitor access at Otmoor.

Scenario	Depth of flooding	Duration	Length of flooded footpaths
Present	0.5	14	5.4
Climate Change	1.0	54	11.1

Figure 1. The potential extent of flooding (blue) with 0.5m (2 year) flood depth over the Otmoor area (black line). Recreational access (footpaths, by-ways and bridleways) are shown by the red dashed lines.

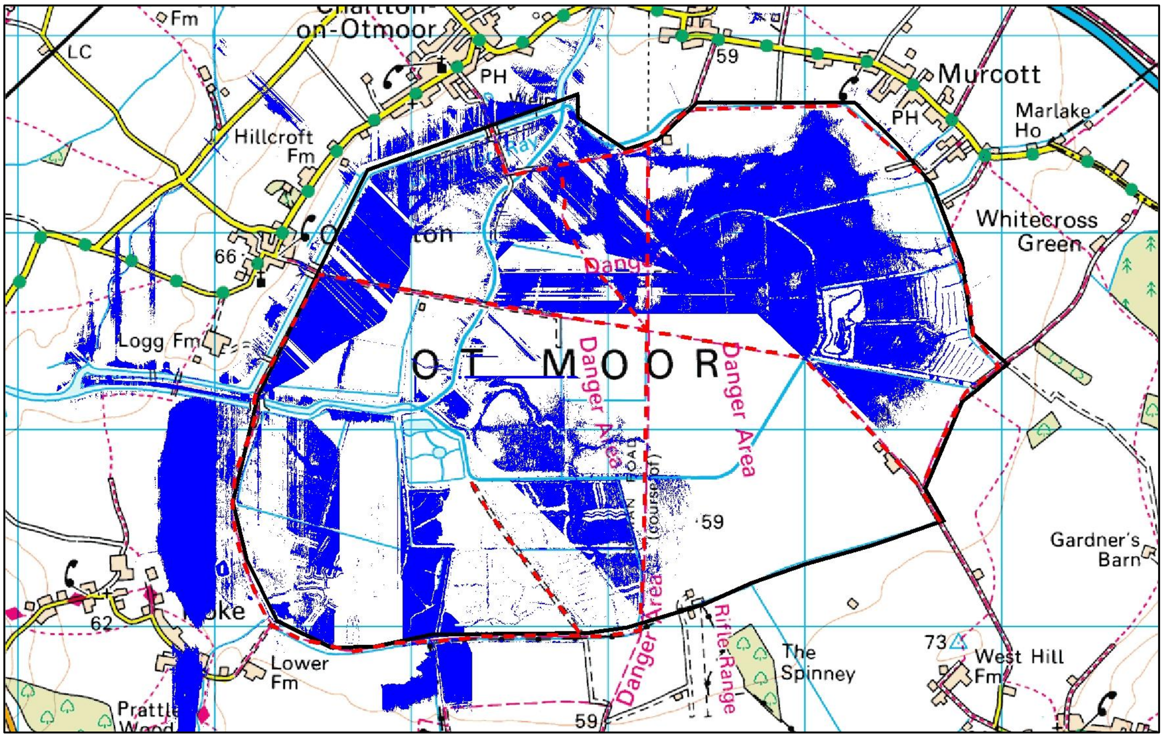


Figure 2. The potential extent of flooding (blue) with 1.0m (10 year) flood depth over the Otmoor area (black line). Recreational access (footpaths, by-ways and bridleways) are shown by the red dashed lines.