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Food & Rural Affairs

The Role of Payments for Ecosystem Services in Climate Change Adaptation

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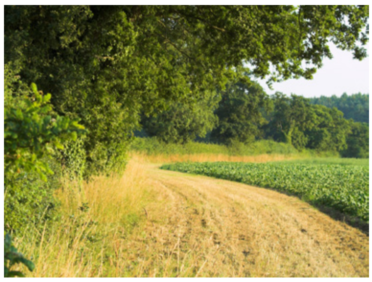

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1. EXECUTIVE SUMMARY

1.1 Context for the study

Payments for Ecosystems Services (PES) are market-based mechanisms that are designed to provide incentives to the owners of natural resources to increase the provision of ecosystem services upon which our society depends. The Natural Environment White Paper endorses the use of PES and, through this policy statement, commits the government to the delivery of a PES Action Plan in 2012.

At the same time, the government was committed, under the Climate Change Act 2008, to publish the National Adaptation Programme (NAP). The NAP addresses the priority risks set out in Defra's Climate Change Risk Assessment[1] (CCRA) and presents a range of time-bound actions and responsibilities to help UK businesses, local authorities and civil society to prepare for, and become more resilient to, climate change impacts. The NAP provides an opportunity to begin to consider how investing in natural environment solutions can increase resilience to climate change and specifically recognises the potential role that PES may play in encouraging land managers to deliver important services, including adaptation measures that benefit wider society.

Also, in July 2013, the Adaptation Sub-Committee (ASC) of the Committee on Climate Change published the second in a series of progress reports to assess how the country is preparing for the risks and opportunities from climate change. Together, the progress reports will provide the baseline evidence for the Committee's statutory report to Parliament in 2015 on the government's progress in implementing the NAP. The second report focuses specifically on assessing how climate change might affect the delivery of key ecosystem services provided by the land and explores the way that land is used in England and the extent to which decisions about the way in which land is managed are helping the country to prepare for climate change[2]. The report identifies PES as a mechanism to deliver additional adaptation benefits) by improving the incentive for land owners to invest in the creation and restoration of habitats in semi-natural, upland peat and coastal areas.

1.2 Objectives and approach

The overall purpose of this report is to provide a short evidence and analysis review that will inform UK adaptation policy. The key aim of the project is to increase the awareness of the potential role that PES mechanisms can play in facilitating adaptation to climate change through the delivery of natural environment solutions, which could include green infrastructure solutions.

More specifically, the objectives of this report are to:

- provide an overview of the potential use of PES mechanisms for delivery of natural environment solutions for climate change adaptation;
- identify specific barriers and challenges for PES that may exist in the context of climate change and propose specific actions both for government and other stakeholders as appropriate; and
- provide an overview of how the impacts of future climate change could be reflected in the design of PES to ensure the longer term sustainability of PES schemes through, amongst other things, 'adaptive management' and the way in which PES agreements are structured.

[1] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/69487/pb13698-climate-risk-assessment.pdf
[2] Adaptation Sub-Committee (2013) Managing the land in a changing climate. Progress report 2013 [online] available at http://www.theccc.org.uk/wp-content/uploads/2013/07/ASC-2013-Book-singles_2.pdf (last accessed 14/08/2013)

To achieve these objectives, this study was conducted as a largely desk-based review of the relevant literature to identify and characterise:

- key **climate change risks and opportunities** across a range of sectors and habitat types. The scope of the review of climate risks and opportunities covered all 11 sectors identified in the CCRA (including those not directly related to the natural environment). Generating a broad understanding of the nature and significance of climate risks and adaptation priorities across all sectors was considered a necessary precursor to identifying the broadest possible range of natural environment solutions particularly as these may cut across sectors and policy areas and may generate benefits beyond climate change adaptation;

- the **adaptation priorities** identified in the CCRA;

- **how the natural environment may facilitate adaptation** to a changing climate;

- the potential role for **PES** in stimulating investment in natural environment solutions to climate change.

This approach is depicted as a 'logic chain' in Figure 2.

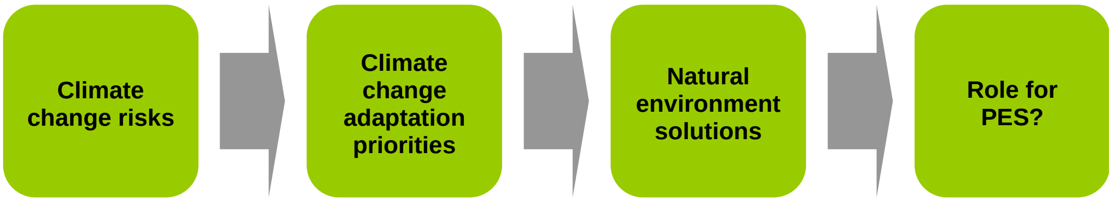

Figure 1 Project 'logic chain'

The opportunities for PES were shortlisted through a literature review and then prioritised through a workshop involving specialists from across each of the broad habitat types, held in London in April 2013.

Opportunities were prioritised in terms of PES potential using the following criteria:

- High – a PES scheme that is already operational or meets the majority of the key principles;

- Medium – a PES scheme that is not yet operational, but has the potential to meet the key principles; and

- Low – a PES scheme that meets few of the key principles, where the concept of PES in those circumstances is currently unproven and/ or where other policy tools may be more effective in delivering the desired outcome(s).

Following the workshop held in April 2013, the specific opportunities identified and the relative priority accorded to each were reviewed (and amended where necessary) in light of the evidence and recommendations presented in each of the PES Action Plan and the second ASC Progress Report.

1.3 Conclusions and further research

1.3.1 Conclusions

The research findings suggest that PES could potentially play an important role in stimulating investment in the natural environment to contribute towards efforts to adapt to a changing climate. Overall, the most promising opportunities are likely to be those PES schemes that generate multiple benefits, including climate change adaptation, and/or which confer immediate adaptation benefits, for example significantly reduced flood risk.

Scotland's ClimateXChange identifies three categories of climate change adaptations: no-regret actions', 'low-regret actions' and 'win-win actions'[3]. No regrets actions are considered as cost-effective now and under a range of future climate scenarios and do not involve hard trade-offs with other policy objectives, while low-regret actions are defined as relatively low cost while providing relatively large benefits under predicted future climates. Win-win actions contribute to adaptation whilst also having other social, economic and environmental policy benefits, including in relation to climate change mitigation.

Taking into account these definitions, the most promising opportunities are likely to be win-win actions which promote adaptation while yielding a range of other benefits. For example, peatland restoration can enhance water storage and so promote adaptation while generating a range of other potential benefits including carbon sequestration, improvements in water flow, enhanced biodiversity and greater potential for tourism and recreation. As a further example, the provision of green infrastructure could assist in promoting urban cooling, and therefore adaptation, while also providing a wide range of other benefits including cultural services and enhanced wellbeing, improved surface water management and biodiversity enhancements. Win-win actions implemented as part of PES schemes have an obvious advantage in that buyers may be interested in paying for other benefits and the climate change adaptation gains will be a positive, but incidental benefit.

Uncertainty regarding the precise nature and significance of climate change effects over the longer term and, in particular, uncertainty as to whether or not specific changes in land management practices today will deliver the resilience needed in future, is likely to render it very challenging in some cases to persuade would-be buyers of the benefits of paying for climate change adaptation-based interventions through PES schemes.

This argument lends further weight to the need to promote win-win actions as part of scheme design. In some cases, however, it may be possible to persuade buyers of the merits of paying for no-regrets or low-regrets actions if they are specifically interested in promoting climate change adaptation and if these actions are likely to yield significant short- to medium-term benefits in terms of adaptation, for example in relation to flood risk. For example, downstream communities subject to flood risk may be very willing to contribute to a PES scheme focused on floodplain restoration where the benefits in terms of flood risk management are clearly apparent. Similarly, local residents may be content to fund sustainable drainage systems if the flood management benefits are evident.

In these cases, the nature of the climate risk may be well understood with the impacts already being felt; the benefits of investing in the natural environment could therefore clearly outweigh the future costs of inaction. Communities might also be willing to pay for interventions where the evidence around cause-and-effect is less clear cut but the costs are nonetheless likely to be reasonably low, for example paying for woodland planting in strategic upstream locations to help manage flood risk. However, as Defra acknowledge, "A barrier to using PES for flood risk

[3] Martin, S. (2012). Examples of 'no-regret', 'low-regret' and 'win-win' adaptation actions [online] available at: www.climatexchange.org.uk/adapting-to-climate-change/examples-no-regret-low-regret-and-win-win-adaptation-actions/ (accessed 15 August 2013).

management is that the benefits on the ground may not be particularly visible or tangible, leading to scepticism around the benefits and a lack of demand from beneficiaries"[4].

Aside from schemes predicated on reducing flood risk, on the basis of the research undertaken, it appears that there are relatively few interventions that might solely promote adaptation without generating other benefits, many of which are more likely to be more attractive to would-be buyers. For example, Forest Research is investigating those areas in Greater London where new greenspaces could help combat the Urban Heat Island effect.[5] However, in all likelihood, would-be buyers of ecosystem services would be more interested in paying for the other services generated by additional greenspace (for example, equality and wellbeing benefits, noise attenuation, biodiversity benefits and townscape improvements).

The specific opportunities for PES identified through this study are summarised in the Table 1.

Table 1: Natural environment solutions and priorities for PES development

Natural environment solution	Priority for PES development	Potential funding sources
Incorporate sustainable drainage systems (SuDs), which include permeable pavements, trees and vegetation, green roofs, stormwater retention ponds, and wetlands and swales	High	— Developers — Local residents — Local businesses — Local authorities — Environment Agency — Water companies
Making space for natural flooding by restoring natural flows and particularly floodplain meadows (wetlands)	High	— Local and regional farmers, residents, businesses — Recreational users of the area — Insurers — Environment Agency — Developers
Slowing the flow of surface water in flood risk areas by low-level flood storage bunds, woodland creation, large woody debris (LWD) dams, and blocking drains	Medium	— Water companies — Insurance companies — Environment Agency — Developers
Planting field and hedgerow trees, copses, and woodland to provide shade for livestock and windbreaks for crops, also buffering peak rainfall events, slowing water runoff. Buffer strips besides water courses can reduce nutrient leaching	Medium	— Farmers — Local authorities — Water companies
Increase urban green infrastructure	Medium	— Local residents — Local businesses — Developers — Local authorities

[4] Defra (2013). Developing the potential for Payments for Ecosystem Services: an Action Plan [online] available at: www.gov.uk/government/uploads/system/uploads/attachment_data/file/200889/pb13918-pes-actionplan-20130522.pdf (accessed 15 August 2013).
[5] Forest Research (2012). Using green infrastructure to relieve urban heat-related stress [online] available at: www.forestry.gov.uk/fr/INFD-8ZBDHC (accessed 15 August 2013).

Natural environment solution	Priority for PES development	Potential funding sources
Improving land management upstream in order to improve water quality downstream e.g. fencing river banks, reducing fertiliser/pesticide use, coppicing overshaded woodlands, scrub clearance, improved farming through intensive monitoring, advice, equipment calibration and financial support for winter cropping, improvements to slurry stores, and use of alternative chemicals	Medium	— Water companies
Restoring and preserving degraded peatlands. Specific activities include restoring blanket bogs by blocking drainage ditches, restoring areas of eroded and exposed peat, hay meadows and heather moorland, establishing clough woodland, providing new farm buildings for indoor wintering of livestock, new waste management facilities to reduce run-off pollution of water courses, and fencing to keep livestock away from areas such as river, streams, and special habitats	Medium	— Water companies — Corporations (for the purposes of CSR) — Insurance companies — Environment Agency — Tourists and visitors — Charitable organisations
Implementing measures to allow natural coast development and realignment of coastal flood defences to restore inter-tidal coastal habitats (e.g. salt marsh, floodplains, and dunes) and natural transition zones between coastal and terrestrial habitats	High	— Local authorities — Environment Agency — Developers (compensatory habitat) — Tourists and visitors — Charitable organisations — Capture fishery and aquaculture enterprises
Increasing woodland cover and connectivity of existing cover	M	— Corporations (for the purposes of CSR) — Charitable organisations

The research also identified a number of challenges to the implementation of PES in the context of climate change adaptation (see Table 2).

Table 2 Challenges with implementing PES schemes for climate change adaptation

Challenge	Description
Lack of evidence to inform the business case	A common barrier to the uptake of PES schemes is convincing evidence to demonstrate both the links between changes in land management practices and the actual climate benefits these are meant to confer, and the cost-effectiveness of such schemes in relation to hard engineering solutions ('grey' infrastructure). This highlights the need to focus, at least initially, on win-win or no or low regrets options and to establish a sound baseline against which changes can be measured.

Challenge	Description
Establishing longer planning horizons to address long term climate changes	While some beneficiaries, for example communities at risk from flooding, may be willing to enter into PES schemes if the climate change adaptation benefits are apparent in the short- to medium-term, they are less likely to pay into schemes where the returns will only be apparent in the longer-term and, moreover, subject to increased uncertainty. Depending on the realities of future climate change, a more significant step change in investment in natural environment solutions may be necessary; however, PES has currently conceived and implemented is unlikely to assist in adapting to the long-term impacts of climate change.
Finding new means to aggregate buyers and facilitate collective action	Assuming that, for example, the case for establishing PES schemes premised on flood risk management through natural environment solutions can be increasingly made, the question arises of how best to aggregate the beneficiaries and transform them into buyers in order to make schemes a reality. In the case of a PES scheme focused on restoring a natural floodplain, the beneficiaries may be households and businesses spread over a reasonably wide area and it is currently difficult to envisage the mechanism(s) through which they might be brought together. To overcome these so-called collective action problems, a supporting institutional environment is needed.
Implementing monitoring and evaluation to understand efficacy	Related to the preceding challenges, workshop participants reinforced the need for the development and implementation of monitoring and evaluation plans that allow the efficacy (or otherwise) of the scheme to be established. A key component of effective monitoring is the establishment of a baseline for the ecosystem service that is being marketed and, where possible, any other key ecosystem services linked to it. This is particularly important in schemes that are designed to enhance climate change adaptation because the evidence between the contributions made by natural environment solutions to improvements in climate change resilience is the subject of on-going research.
Pilot studies to inform the feasibility of natural environment solutions	There is a lack of evidence from which to draw experience and lessons learned from the practical application of PES in the context of seeking to enhance climate change adaptation. More information is required about, for example, how the insurance sector could play a larger role in the market for ecosystem services; or how local planning authorities could be encouraged to contribute to flood risk insurance. This may include, for example, developing a clearer understanding of the drivers for climate action amongst different groups of buyers, the scale(s) at which they operate and the potential for public-private partnerships.

1.3.2 *Further research*

In addition to the opportunities and challenges already discussed, the following list of questions arose throughout the project for which resolutions were not immediately available. It is considered that further research into these questions could help to advance not just the consideration of the role of PES in facilitating adaptation to climate change, but also PES scheme design more generally.

1. ***What do climate-friendly natural environment solutions look like?*** How can climate change be incorporated within such solutions? For example, will new urban green spaces have to be planted with drought-resistant species?

2. ***Issues of scale:*** Could a number of small scale PES schemes, geographically dispersed, achieve the same results as fewer, larger schemes, in terms of enhancing adaptation to climate change? For example, could small reforestation projects scattered across a catchment achieve the same as a single, large scale reforestation project?

3. ***Beneficiary identification:*** Who are the beneficiaries of specific natural environment solutions for climate change adaptation? Can they be readily identified? How can free-riders be encouraged to contribute?

4. ***Buyer identification:*** Who are the buyers of the ecosystem services? How do we address the differing spatial catchment of buyers? For example office workers that have direct access to an urban green space relative to those that have to travel further to enjoy the benefits. How can a PES scheme designed to enhance climate change adaptation through the provision of urban green spaces be designed to account for different buyers?

5. ***Financial mechanisms:*** What mechanisms are available to fund natural environment solutions? If different degrees of benefit are obtained by different beneficiaries, how should payment/funding be arranged? Should payment be flat-based or should it vary depending on level of benefit derived by the buyer?

   Can new buyers and instruments be introduced to the market? For example, can local planning authorities pay insurance on behalf of citizens? Can the Environmental Stewardship component of the Rural Development Programme for England be utilised as a vehicle for greater consideration of natural environment solutions to enhance climate change adaptation?

   Are buyers more likely to respond to payment structures that include only maintenance costs, which are likely to be relatively small, periodic payments and offer greater flexibility for mobile populations? Or can they be induced to cover capital costs, which are likely to once-off, larger payments?

6. ***Monitoring/measurement:*** Which organisations will undertake monitoring / measurement / verification of the benefits? What are the necessary pre-requisites of such organisations to engender trust from buyers and sellers? Will they be in operation long enough to keep step with the time period over which climate change adaptation is likely to be experienced?

   If direct measures of climate change adaptation cannot be identified, what are suitable proxies? For example, a measure may be designed to reduce the probability of a 1:100 year flood, but how can this be confirmed without being able to measure the new flood return interval?

2. INTRODUCTION

2.1 Background

The UK Climate Projections, published in 2009 (UKCP09), represent the best available climate change science in the UK and illustrate the extent of the climate changes that the UK may face over the next 90 years using three different greenhouse gas emission scenarios (low, medium and high)[6]. The projections indicate that the UK can expect to experience:

- hotter and drier summers and more frequent heatwaves;
- higher frequency of intense precipitation events (>25mm per day), and prolonged rainfall events, particularly during the winter months; this will mean that flooding is more likely to occur although this may also present an opportunity for greater winter storage;
- more intense, more frequent occurrence of some severe weather events (intense rainfall, floods, heat waves);
- less intense, less frequent occurrence of very cold weather and snow/frost/ice; and
- rising sea levels.

The Climate Change Act (2008) sets out a framework for dealing with adaptation, recognising that the country needs to be prepared to deal with the changes to the climate that we are already starting to face, alongside wider economic and demographic trends. More specifically, it requires the government to assess the UK's risks from climate change, prepare a strategy to address them, and encourage critical organisations to do the same.

The UK Climate Change Risk Assessment (CCRA), published in January 2012, provides the first comprehensive assessment of the potential impacts of climate change and the risks and opportunities for the UK. It recognises that unless appropriate adaptation action is taken to respond to these, the UK could incur significant costs or miss out on important opportunities.

2.2 Responding to climate risk

The Intergovernmental Panel on Climate Change (IPCC) defines adaptation as "the adjustment in natural or human systems in response to actual or expected climate stimuli or their effects, which moderates harm or exploits beneficial opportunities"[7]. As noted in Cimato and Mullan[8], some adaptation is expected to occur autonomously: faced with a changing environment, individuals and the natural environment will adapt when it is their interest and power to do so. However, the level of adaptation in the UK will be determined by all the decisions taken by multiple actors, and in some instances market failures and other barriers can prevent society from achieving the appropriate level of adaptation[9].

[6] See http://ukclimateprojections.defra.gov.uk/ (last accessed 29/04/2013)
[7] IPCC, (2007): Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment
Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 976pp [online] available at http://www.ipcc-wg2.gov/publications/AR4/index.html (last accessed 29/04/2013)
[8] Cimato, F. and Mullan, M (2010) Adapting to Climate Change: Analysing the Role of Government. Defra Evidence and Analysis Series Paper 1 [online] available at https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/69194/pb13341-analysing-role-government-100122.pdf (last accessed 29/04/2013).
[9] Ibid.

Following publication of the CCRA, Defra commissioned a study on the Economics of Climate Resilience (ECR)[10] to generate an understanding of the extent of current and expected adaptation actions, the relative effectiveness of those actions, and the barriers to their implementation. The findings of the ECR study have informed the UK's first National Adaptation Programme (NAP) which was published in July 2013[11].

The NAP addresses the priority risks set out in the CCRA and presents a range of time-bound actions and responsibilities to help UK businesses, local authorities and civil society to prepare for, and become more resilient to, climate change impacts. The NAP provides an opportunity to begin to consider how investing in natural solutions and green infrastructure can increase resilience to climate change and specifically recognises the potential role that payments for ecosystem services (PES) may play in encouraging land managers to deliver important services, including adaptation measures that benefit wider society.

Also in July 2013, the Adaptation Sub-Committee (ASC) of the Committee on Climate Change published the second in a series of progress reports to assess how the country is preparing for the risks and opportunities from climate change. Together, the progress reports will provide the baseline evidence for the Committee's statutory report to Parliament in 2015 on the government's progress in implementing the NAP. The second report focuses specifically on assessing how climate change might affect the delivery of key ecosystem services provided by the land and explores the way that land is used in England and the extent to which decisions about the way in which land is managed are helping the country to prepare for climate change[12]. The report identifies PES as a mechanism to deliver additional adaptation benefits) by improving the incentive for land owners to invest in the creation and restoration of habitats in semi-natural, upland peat and coastal areas.

Although conceptually intuitive, adaptation has complex practical implications. In particular, the adaptation actions undertaken by individuals and the nature of the benefits they provide (i.e. whether they are private gains or accrue to society more widely) depends on a number of factors. These include the types of incentives with which people are faced and the extent to which actions are coordinated within society. Furthermore, the impacts of climate change are likely to be unevenly distributed between and within regions, communities and social groups. Adaptation will influence the vulnerability of different individuals and the environment to different levels, depending on local and context specific needs and capacity.

One of the ways in which resilience in both natural and man-made systems can be increased is through investment in the natural environment. This means not only implementing measures to sustain the benefits we currently receive from the natural environment in the face of a changing climate but also securing a healthy natural environment that will enable society to better adapt.

2.2.1 *Ecosystem-based adaptation*

Well-functioning ecosystems provide valuable services such as food, clean water, carbon sequestration, flood and erosion control and habitat for wildlife, while at the same time promoting resilience to the impacts of climate change. This has been recognized by the United Nations Framework Convention on Climate Change (UNFCCC) in decision 1/CP.16 which invites Parties to enhance action on adaptation by "*building resilience of socio-ecological*

[10] Frontier Economics (2013) Economics of Climate Resilience. Report for Defra. [online] available at: http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=18016 (last accessed 29/04/2013)

[11] Defra (2013) The National Adaptation Programme: Making the country resilient to a changing climate. [online] available at https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/209866/pb13942-nap-20130701.pdf (last accessed 09/07/2013)

[12] Adaptation Sub-Committee (2013) Managing the land in a changing climate. Progress report 2013 [online] available at http://www.theccc.org.uk/wp-content/uploads/2013/07/ASC-2013-Book-singles_2.pdf (last accessed 14/08/2013)

systems, including through economic diversification and sustainable management of natural resources"[13].

In recent years there has therefore been a growing interest in what has been termed 'ecosystem-based adaptation' (EBA). Vignola *et* al. define EBA as *"... the adaptation policies and measures that take into account the role of ecosystem services in reducing the vulnerability of society to climate change, in a multi-sectoral and multi-scale approach*"[14]. More simply, the Convention on Biological Diversity (CBD) defines EBA as "*the use of biodiversity and ecosystem services to help people adapt to the adverse effects of climate change*". This includes the "*sustainable management, conservation and restoration of ecosystems, as part of an overall adaptation strategy that takes into account the multiple social, economic and cultural co-benefits for local communities*"[15]. EBA recognises that investment in the natural environment can produce or enhance benefits in ways which may not otherwise be considered in economic planning and which can often represent better value for money than more technological solutions[16].

In 2011, the UK National Ecosystem Assessment (NEA) concluded that, of the range of services provided by eight broad terrestrial and aquatic habitat types in the UK, about 30% are in decline with many others in a reduced or degraded state, often as a consequence of long-term declines in habitat extent or condition[17]. Despite improvements in the provision of some ecosystem services over the past 10-20 years as a result of changes in policy and legislation, advances in technology and changing attitudes and behaviour, the NEA highlights the fact that many ecosystem services are still delivering at far below their full potential[18]. Moreover, a growing population and the increasing impacts of climate change mean that pressures on ecosystem services are unlikely to diminish. This has significant implications for the future contribution of the natural environment towards alleviating pressures from climate change unless action can be taken to manage and restore ecosystems and the services they produce.

The declines in habitat extent and condition and the consequent deterioration in ecosystem services witnessed over the past 60 years ultimately reflect a historic failure to properly value the benefits we derive from nature. *The Natural Choice*, the government's 2011 Natural Environment White Paper (NEWP), emphasises that while some ecosystem services such as food and timber have a financial value in the marketplace, others such as climate regulation and flood control that are nevertheless equally vital to our continued wellbeing do not[19]. This, in turn, has created an imbalance in the way in which decisions affecting the natural environment are made and, historically, has led to a focus on short-term financial gain and the consequent over-exploitation of many natural assets.

2.3 Incentives for investment in the natural environment

In 2010 the government published an independent review of England's wildlife areas which considered the extent to which these represent a coherent and robust ecological network capable of responding to the challenges posed by climate change and other pressures (the

[13] See http://unfccc.int/resource/docs/2010/cop16/eng/07a01.pdf#page=2 (last accessed 28/04/2013)
[14] Vignola R., Locatelli B., Martinez C., Imbach P., 2009, Ecosystem-based adaptation to climate change: what role for policy-makers, society and scientists? Mitigation and Adaptation Strategies for Global Change 14(8): 691-696 [online] available at http://research.fit.edu/sealevelriselibrary/documents/doc_mgr/470/Global_Ecosystem_Based_Adaptation_to_CC_-_Vignola_2009.pdf (last accessed 28/04/2013)
[15] Ibid.
[16] See, for example, Sunderland, T. (2012). Microeconomic Evidence for the Benefits of Investment in the Environment - review. Natural England Research Reports, Number 033 [online] available at http://publications.naturalengland.org.uk/publication/32031?category=49002 (last accessed 28/02/2012).
[17] UK National Ecosystem Assessment (2011). The UK National Ecosystem Assessment: Synthesis of the Key Findings. UNEP-WCMC, Cambridge.
[18] UK National Ecosystem Assessment (2011). The UK National Ecosystem Assessment: Synthesis of the *Key Findings*. UNEP-WCMC, Cambridge.
[19] HM Government (2011). *The Natural Choice: securing the value of nature* [online] available at: http://www.official-documents.gov.uk/document/cm80/8082/8082.asp .

'Lawton Review'). The Lawton Review emphasised that, as our understanding of the links between biodiversity, ecosystem function and ecosystem services continues to improve and we are increasingly able to place values on such services, *"[t]he urgent and logical next step is to develop [ecosystem] markets that enable these values to be realised for services such as water quality, flood risk management, climate regulation and other benefits"*.[20] We are now therefore in a stronger position to begin to reflect the value of all ecosystem services in decision-making. In particular, the Lawton Review argued that there is an urgent need to develop market mechanisms through which landowners can realise the value of the ecosystem services that their land provides to society.[21] The government's response to the Lawton Review acknowledges that *"[H]arnessing the use of markets and ensuring correct economic incentives are in place could have an increasingly important role in delivering our natural environment outcomes"*[22].

One such market-based mechanism is Payments for Ecosystem Services (PES). The basic idea behind PES is that the beneficiaries, or users, of ecosystem services provide payment to the stewards, or providers, of ecosystem services. PES schemes therefore provide an opportunity to put a price on previously un-priced ecosystem services such as climate regulation, water quality regulation and the provision of habitat for wildlife and, in doing so, brings them into the wider economy. If designed well, PES can provide financial incentives to the owners/managers of natural resources to enhance the supply of ecosystem services. The right PES schemes could therefore play an important role in facilitating adaptation.

The Natural Environment White Paper published in 2011 supports the use of PES and committed the government to the delivery of a PES Action Plan. The PES Action Plan was published in May 2013 to promote practical and innovative development of PES schemes, identifying what actions government can take to enable such mechanisms to go forward. It highlights specific opportunities for incorporating PES across different policy and ecosystem contexts and identifies synergies and potential linkages between them[23]. The Action Plan also specifically recognises climate change as a key driver of potential PES schemes.

2.4 Approach to the study

The study was conducted as a largely desk-based review of the relevant literature to identify and characterise:

- key **climate change risks and opportunities** across a range of sectors and habitat types. The scope of the review of climate risks and opportunities covered all 11 sectors identified in the CCRA (including those not directly related to the natural environment). Generating a broad understanding of the nature and significance of climate risks and adaptation priorities across all sectors was considered a necessary precursor to identifying the broadest possible range of natural environment solutions particularly as these may cut across sectors and policy areas and may generate benefits beyond climate change adaptation;

- the **adaptation priorities** identified in the CCRA;

- **how the natural environment may facilitate adaptation** to a changing climate;

[20] Lawton, J.H., Brotherton, P.N.M., Brown, V.K., Elphick, C., Fitter, A.H., Forshaw, J., Haddow, R.W., Hilborne, S., Leafe, R.N., Mace, G.M., Southgate, M.P., Sutherland, W.A., Tew, T.E., Varley, J., and Wynne, G.R. (2010). *Making Space for Nature: a review of England's wildlife sites and ecological network*. Report to Defra [online] available at: http://archive.defra.gov.uk/environment/biodiversity/documents/201009space-for-nature.pdf (accessed 25/04/2011).
[21] Ibid.
[22] Defra (2011). *Government response to the Making Space for Nature review* [online] available at: http://www.defra.gov.uk/publications/files/pb13537-lawton-response-110607.pdf (last accessed 6/07/2011).
[23] Defra (2013) Developing the potential for Payments for Ecosystem Services: an Action Plan. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/200889/pb13918-pes-actionplan-20130522.pdf (last accessed 19/06/13)

- the potential role for **PES** in stimulating investment in natural environment solutions to climate change.

This approach is depicted as a 'logic chain' in Figure 2.

Specialist input on the range of natural environment solutions that may apply in different habitat types and the prospects for PES was provided by means of a one-day workshop held in London in April 2013.

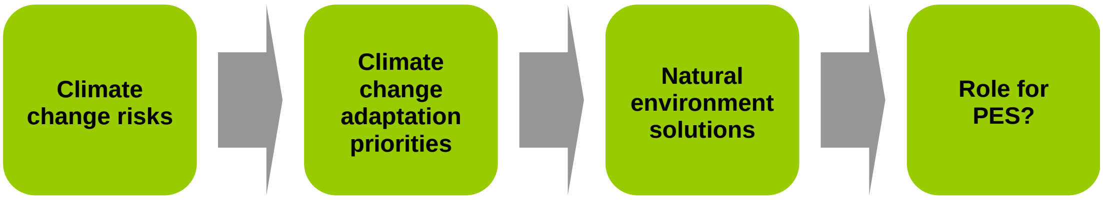

Figure 2 Project 'logic chain'

2.5 Structure of this report

The overall purpose of this report is to provide a short evidence and analysis review that will inform UK adaptation policy.

The key aim of the project is to increase the awareness of the potential role that PES mechanisms can play in facilitating adaptation to climate change through the delivery of natural environment solutions, which could include green infrastructure solutions.

More specifically, the objectives of the report are to:

- provide an overview of the potential use of PES mechanisms for delivery of natural environment solutions for climate change adaptation;
- identify specific barriers and challenges for PES that may exist in the context of climate change and propose specific actions both for government and other stakeholders as appropriate; and
- provide an overview of how the impacts of future climate change could be reflected in the design of PES to ensure the longer term sustainability of PES schemes through, amongst other things, 'adaptive management' and the way in which PES agreements are structured.

The remainder of this report is structured as follows:

- **Chapter 2** provides an overview of the climate change adaptation risks and adaptation priorities in relation to the natural environment;
- **Chapter 3** describes the types of ecosystem services and investments in the natural environment that could contribute towards alleviating climate risks and provides a brief review of the existing evidence relating to the effectiveness of natural environment solutions;
- **Chapter 4** investigates the prospects for PES mechanisms, as one amongst a range of possible policy instruments, for overcoming some of the market failures associated with delivery of ecosystem services and encouraging investment in natural environment solutions. It also considers the specific measures needed to ensure the longer-term sustainability of PES schemes in light of the impacts of a changing climate;

- **Chapter 5** identifies the specific barriers and challenges for PES that might exist in the context of climate change adaptation and the measures that may be undertaken to overcome them; and

- **Chapter 6** sets out the conclusions from the research and our suggestions to Defra and other stakeholders for stimulating the emergence of PES schemes for the delivery of natural environment solutions for climate change adaptation.

3. CLIMATE CHANGE RISKS, OPPORTUNITIES AND ADAPTATION PRIORITIES

3.1 Overview

The effects of climate change (and particularly severe weather events) are influenced by topography, catchments and land uses. Planning adaptation measures in response to climate change requires an understanding of the variability of climate impacts, the vulnerability of different receptors (communities, infrastructure and natural assets) and the degree of risk aversion of those responsible for managing the risks.

This chapter presents a brief overview of the key climate risks and opportunities and adaptation priorities identified in the CCRA, the ECR Phase 1 study and other relevant sources of information. It focuses specifically on those risks, opportunities and adaptation priorities that have clear links to the natural environment.

3.1.1 *The UK Climate Change Risk Assessment*

The UK CCRA, published in January 2012, was the first assessment of its kind for the UK and the first in a 5 year cycle. It provides an assessment of the magnitude and timing of impacts caused by changes in climatic conditions, variability, and extremes, as well as an indication of the levels of confidence in the evidence base in relation to each of the predicted impacts.

The CCRA reviewed the evidence for over 700 potential impacts of climate change in the UK context. Detailed analysis was then undertaken for over 100 of these impacts across 11 key sectors, on the basis of their likelihood, the scale of their potential consequences, and the urgency with which action may be needed to address them.

The analysis of risks and opportunities set out in the CCRA was informed by the most recent UK Climate Projections published by Defra in 2009 (UKCP09). UKCP09 projections include the results of three sets of projected greenhouse gas (GHG) emission scenarios – low, medium, and high. The three scenarios account for the uncertainties that exist about future trends and behaviours such as population growth, technological progress, and socio-economic development. The changes described over the next 40 years are based on past and current emissions and as a result, all three scenarios display similar patterns. After this period, however, projected weather patterns diverge as they become increasingly dependent upon the predicted changes to emissions from the different scenarios. The scenarios also reflect different assumptions about local, regional, and global socio-economic changes; including changes to the economy, population, technology, energy, and agriculture.[24]

The UKCP09 high emissions scenario projections show that between the 2030s and 2050s, the UK is likely to experience:

- on average, hotter and drier summers, with mean daily temperatures increases of 1.9 – 2.8°C and mean daily precipitation reductions of 9% - 15%;
- on average, warmer and wetter winters, with mean daily temperature increases of 1.7 – 2.3°C and mean daily precipitation increases of 5% - 8%;
- rising sea levels, increasing the risk of coastal flooding and asset damage;
- an increase in the annual number of heatwaves, days with significantly high temperatures and prolonged dry spells, potentially leading to increased water demand and reduced supply. Heatwaves and droughts also have impacts on raw water quality, ecosystems and biodiversity through lower river flows;

[24] UKCIP (2009). Climate change projections. UKCIP: Oxford [online] available at http://ukclimateprojections.defra.gov.uk/content/view/944/517/ (last accessed 26/02/2013)

- a decrease in the annual number of frost days and prolonged periods of cold weather; although it is not known whether the intensity and severity of cold days will increase or decrease; and
- an increase in frequency in the annual number of days with heavy rainfall and prolonged periods of rainfall, increasing the risk of flooding and leading to impacts (negative and/or positive) on water capture and storage.

Table 3 shows a range of projections for changes to the frequency of selected extreme weather events using the UKCP09 high emissions scenario at the 90 per cent probability level (10 per cent probability level for the cold weather variables) for the UK. This represents a realistic projection of the greatest possible ranges of impacts. UKCP09 projections under the medium emissions scenario (50 per cent level) are shown in brackets.

Baseline data and projections have been rounded up to the nearest whole number. Therefore, a baseline of 0 days per year does not necessarily represent an absolute zero (i.e. no events occurred over the baseline period). Rather, it means that, on average over the 30 year baseline period, the particular extreme event occurred less than 0.5 times per year.

Table 3: UKCP09 projections for the frequency of extreme weather events[25]

	Baseline observed (average for 1961-90)	2030s (2020-2049 mean)	2050s (2040-2069 mean)	2080s (2070-2099 mean)
Annual number of heatwaves (2 days with max daily temp of >29˚C and min daily temp of >15˚C)	0	Up to 5 (2)	Up to 7 (3)	Up to 9 (4)
Annual number of days when temperature is >25˚C	5	Up to 38 (12)	Up to 58 (22)	Up to 37 (10)
Annual number of days when temperature is >28˚C	0	Up to 18 (8)	Up to 28 (12)	Up to 77 (36)
Annual maximum temperature (˚C)	27.0	Up to 33.1 (28.8)	Up to 35.9 (31.0)	Up to 38.1 (30.6)
Annual number of frost days (when min temperature is 0°C or lower)	56	Up to 47 (30)	Up to 40 (25)	Up to 25 (14)
Annual number of prolonged periods of cold weather (3+ consecutive days where the temperature falls below 0°C)	11	Up to 10 (9)	Up to 9 (7)	Up to 3 (2)
Annual number of prolonged periods of cold weather (5+ consecutive days where the temperature falls below 0°C)	7	Up to 6 (4)	Up to 4 (3)	Up to 2 (1)
Annual number of dry spells (5+ days with no precipitation)	11	Up to 15 (12)	Up to 17 (15)	Up to 21 (16)

[25] Based on information contained in UKCIP (2009). Climate change projections. UKCIP: Oxford [online] available at http://ukclimateprojections.defra.gov.uk/media.jsp?mediaid=87893&filetype=pdf (last accessed 21/02/2013)

	Baseline observed (average for 1961-90)	2030s (2020-2049 mean)	2050s (2040-2069 mean)	2080s (2070-2099 mean)
Annual number of dry spells (10+ days with no precipitation)	5	Up to 6 (3)	Up to 8 (4)	Up to 11 (7)
Annual number of dry spells (20+ days with no precipitation)	1	Up to 1 (1)	Up to 2 (1)	Up to 2 (1)
Number of days per year when precipitation is greater than 25mm per day (Met Office definition of 'heavy rain')	3	Up to 13 (8)	Up to 18 (10)	Up to 20 (10)
Number of days per year when precipitation is greater than 40mm per day (likely to cause flash flooding as defined by UKCIP)	0	Up to 2 (1)	Up to 2 (1)	Up to 4 (1)
Annual number of prolonged rainfall events (3+ consecutive days when precipitation is greater than 25 mm/day)	0	Up to 1 (0)	Up to 1 (0)	Up to 4 (1)

3.1.2 *The Economics of Climate Resilience (ECR)*

The Economics of Climate Resilience[26] (ECR) was commissioned to inform the National Adaptation Programme, and sets out an economic framework for adaptation in the UK. The ECR seeks to understand the extent of current and expected adaptation actions, the relative effectiveness of those actions and the barriers to their implementation.

The analysis found that many individuals and organisations across the full range of sectors are already taking action to adapt to climate change. However, there is a high variance in the adaptive capacity of organisations and individuals within the sectors. For example, while the Forestry Commission is well placed to diversify the species and provenance of trees in their woodlands, small woodland owners lack the information and the resources to improve the resilience of their woodlands to the pressures of climate change.

One of the main conclusions of the ECR was that adaptive capacity is much higher where individuals or organisations are able undertake the adaptation actions themselves and do not need to rely on third parties or other sectors to help them adapt. This is particularly relevant to the current paper as PES may offer a mechanism for organisations' to improve their own resilience to climate change through encouraging other parties to change their behaviour and land management actions.

3.1.3 *The UK National Ecosystem Assessment (NEA)*

The UK National Ecosystem Assessment[27] (NEA) was published in June 2011 and emphasised that many ecosystem services, particularly those related to air, water and soil quality, declined during the second half of the 20th Century. Moreover, the NEA highlights the

[26] Frontier Economics (2013) Economics of Climate Resilience. Report for Defra. [online] available at: http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=18016 (last accessed 29/04/2013)
[27] UK National Ecosystem Assessment (2011) The UK National Ecosystem Assessment Technical Report. UNEP-WCMC, Cambridge. [online] available at: http://uknea.unep-wcmc.org/LinkClick.aspx?fileticket=m%2bvhAV3c9uk%3d&tabid=82 (last accessed 29/04/2013)

potential role of climate change in accelerating the increase in pressures on ecosystem services. While climate change has not been a major driver for most ecosystems to date, it is expected to play a significant role in future change, with some changes already evident: for example, range changes of the more mobile species, such as insects and birds, plus changes in the timing of flowering and fruiting have been observed, which may eventually have an impact on a range of ecosystem services.

The UK NEA provides guidance on which habitat types are vulnerable to the predicted impacts of climate change. This can be used to guide where actions to bolster the resilience of habitats may be most usefully undertaken.

The remainder of this chapter sets out a summary of the main findings of the CCRA, the Economics of Climate Resilience, the UK NEA and other relevant literature in terms of the key climate risks, opportunities, and adaptation priorities identified across six broad habitat types: enclosed farmland and semi-natural grassland; woodlands; freshwater; mountains, moorlands and heaths; marine and coastal; and urban. More specifically, the chapter seeks to present an understanding of:

- the climate risks and opportunities facing each of six broad habitat types and the economic sectors they support;
- the nature and significance of the impacts of each risk;
- general adaptation measures that can be undertaken to increase the resilience of the habitat and the economic sectors they support;

The climate change risks and opportunities that are considered here relate to the natural environment (either because the natural environment is directly affected or because the natural environment may provide at least part of the adaptation solution). In addition, the adaptation solutions that would be undertaken by 'self-interested' individuals and organisations are excluded.

The rationale for restricting the risk, opportunities and adaptation measures considered is to focus on those actions that are most suitable for initiating a PES scheme around. Adaptation measures such as building storage facilities to protect harvested crops from more intense precipitation events would be undertaken by the self-interested farmer and PES is therefore neither necessary nor appropriate. In addition, those risks and opportunities that are unrelated to the natural environment are not suitable as the basis of a PES scheme.

3.1.4 *The European Union Initiative on Green Infrastructure*

The European Commission (EC) has recently released the EU Green Infrastructure Strategy, which is designed to help to conserve and enhance natural capital and to achieve the Europe 2020 objectives[28]. The Strategy is seen as a key step in implementing the EU 2020 Biodiversity Strategy[29], and identifies a number of GI measures that could be incorporated within existing EU policies and instruments.

Through the Strategy, the EC seeks to create an enabling framework to encourage and facilitate GI projects within existing legal, policy and financial instruments. Member States will be encouraged to build on these opportunities to boost the implementation of GI and exploit its benefits for sustainable development.

[28] European Commission (EC) (2013) Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Green Infrastructure (FI) – Enhancing Europe's Natural Capital. COM (2013) 249 Final, Brussels.
[29] EC (2011) EU Biodiversity Strategy to 2020. COM(2011) 244 final, OJ C 264 of 8.9.2011

By the end of 2017, the Commission will review progress on developing GI and publish a report on the lessons learnt together with recommendations for future action.

3.2 Enclosed farmland and semi-natural grasslands

3.2.1 *Overview*

The UK National Ecosystem Assessment defines enclosed farmland as "the cropped and grass fields that cover much of the UK's lowlands, along with the networks of hedges and ditches and the small woodlands interspersed among them". It is largely managed to produce food, which can lead to trade-offs for other ecosystem services, such as water quality, biodiversity and climate change. However, sensitive farming practices can also support ecosystem services.

Semi-natural grasslands comprise only 1% of the UK land area and only 2% of grasslands and are made up of a rich variety of grasses and herbs that vary according to local climate, soils and topology. They are the remnants of habitats created by low intensity, traditional farming. The majority of these have been converted to 'improved' grassland which is dominated by a few agricultural grasses.

Agriculture is a key sector in the UK economy, covering around 70 per cent of the UK's total land area, employing more than half a million people, and contributing around £7 billion to the economy each year (around 0.5% of total UK GDP). Although many of the climate change impacts on the agriculture sector may be negative, potentially valuable new opportunities may also arise that could benefit existing agricultural activities and encourage farm diversification.

In order to present the analysis clearly, a list of five key climate parameters was identified:

- warmer temperatures and increased frequency of heatwave events;
- drier summers and increased frequency of dry spells;
- more intense rainfall events with increased risk of flooding;
- rising sea levels and increasing frequency of storm surges; and
- shifts in the global climate.

The key climate risks and opportunities facing enclosed farmland and semi-natural grassland habitats are set out in Table 4. However, it should be noted that these risks and opportunities are not necessarily mutually exclusive and that the magnitude of impacts may be significantly higher through combinations of the parameters (e.g. hotter summers and prolonged dry spells) or when hot, dry summers are followed by intense rainfall (which cannot permeate the dried surfaces and therefore increases run-off and increases risk of flooding).

3.2.2 *Risks and opportunities*

The key climate risks and opportunities facing these habitats and the agricultural sector they support are set out in Table 4.

Table 4: Climate risks and opportunities facing the agriculture sector

Climate parameters	Opportunities	Risks
Warmer temperatures and increased frequency of heatwave events	— Increases in sunshine levels leading to higher crop productivity for certain species (e.g. fruit and forage) (ECR) — Increase in CO_2 concentrations leading to increasing yields particularly for ‘C3’ crops such as wheat (ECR)	— Greater risk of crop pests and diseases due to higher temperatures — Increased water demand for crops — Increasing temperatures leading to reduced yields for certain products such as cereals and annual crops (e.g. grassland) (ECR) — Lower crop quality due to heat stress
Drier summers and increased frequency of dry spells	— Switch to different types of production that would not previously have been possible under wetter summers	— Increased risk of droughts and water scarcity constraints on agriculture — Reduced water availability in summer and increasing over abstraction of water resources — Reduced forage yield in summer — Lower crop quality due to reduced soil moisture — Reduced crop yields (wheat and sugarbeet) due to droughts and heat waves (ECR) — Impact on plant and bird species dependent on a high water table in wet grasslands (UK NEA)
More intense rainfall events with increased risk of flooding	— *None identified*	— Increase in flood risk and waterlogging for high quality horticultural and arable land leading to loss of crops and lower productivity — Deterioration of soil and water quality due to greater erosion and higher run-off
Storm/wind (ECR)	— *None identified*	— Increasing damage to crops from storms (particularly hail) and high winds
Rising sea levels and increasing frequency of storm surges	— *None identified*	— Loss of agricultural land due to flooding, coastal erosion, and sea level rise — Seawater intrusion in coastal areas

Climate parameters	Opportunities	Risks
Shifts in the global climate	— Growth in agriculture markets due to higher global food prices resulting from increased demand and reduced supply in cereal producing regions	— Negative environmental consequences (e.g. on biodiversity, water quality and soils) resulting from increased UK production as a result of global production shifts — Increased volatility in global markets poses a potential risk to UK production as farmers have no certainty year on year about prices ad so may have problems planning

Source: Based on Defra (2012) Climate Change Risk Assessment for the Agriculture Sector[30], the UK NEA Technical Chapter on Enclosed Farmland and Semi-Natural Grassland and the Economics of Climate Resilience – Agriculture and Forestry Theme: Agriculture[31]

One of the main climate risks is the increase in extreme weather events, including both floods and drought. There is strong evidence that the area of high-quality agricultural land classed as likely to be flooded at least once every three years will increase from 30,000 ha at present to 130,000 ha by the 2080s. The loss of productive agricultural land due to sea water intrusion and coastal flooding is also a concern in coastal areas.

The likely increase in rainfall intensity and frequency of intense storms could increase the risk of soil erosion throughout the UK while also contributing to increased nutrient runoff from agricultural land, which may affect the quality of water abstracted downstream.

The risk of droughts is also likely to increase and, at the same time, rising agricultural water demand due to a drier climate, combined with rising water demand from other sectors (e.g. energy and water companies), may create water scarcity for agriculture in some regions (particularly the south east).

The evidence that climate change will increase crop pests and diseases is weak. However, the interactions between crops, pests and pathogens are complex and currently poorly understood in the context of climate change. Furthermore, it is difficult to assess the future risk of pests and diseases as these are managed and controlled in a number of ways and may only be partly explained by a changing climate.

Warmer temperatures and higher CO_2 concentrations may also lead to higher crop yields, extension of the growing season, and the expansion of agriculture into new areas; however, this may also result in heat stress and loss of soil moisture which may offset the increase in productivity. Pigs and poultry are particularly vulnerable to heat stress and heat stress in dairy cows is predicted to lead to a substantial reduction in milk production per year by the 2050s.

Globally, food prices could increase substantially in response to yield reductions in the main cereal-exporting regions of the world and a growing demand for food due to rapid population increase. Greater farm income could encourage the adoption of new technologies to adapt to the identified climate risks; however, any increase in profitability may be offset to some extent by higher energy prices.

The evidence for the impact of climate change on semi-natural grasslands is mixed. Projections suggest that wet grasslands and the flora and fauna which they support will be adversely impacted by drier summers and increased frequency of dry spells. However evidence for the impact on other grassland is uncertain. One study suggests that that drought-prone acid grassland, lowland hay meadows and lowland calcerous grassland will be

[30] Defra (2012) UK Climate Change Risk Assessment. Sector Report: Agriculture [online] available at http://ccra.hrwallingford.com/CCRAReports/reportviewer.html?sector=agriculture&link=LinkTarget_1 (last accessed 22/02/2013)
[31] Frontier Economics, Irbaris and Ecofys (2013)The Economics of Climate Resilience – Agriculture and Forestry Theme: Agriculture (online) available at: http://randd.defra.gov.uk/Default.aspx?Module=More&Location=None&ProjectID=18016

minimally impacted, while upland hay meadows will be adversely impacted.[32] However, these conclusions have been disputed.[33]

3.2.3 *Adaptation measures*

The key challenges to adaptation in the agricultural sector involve the significant degree of uncertainty surrounding:

- the way in which different climate impacts interact with one another;
- the potential impact on agricultural pests and diseases;
- the impacts on water availability in different regions;
- the impacts on animal health and welfare; and
- the wider ability of rural communities to adapt to the effects of climate change.

Despite these challenges there are a number of general adaptation measures which could be adopted to mitigate climate risk for enclosed farmland and semi-natural grasslands (see Table 5). In addition to these specific adaptation measures, there are also important overlaps with the flood and coastal erosion sector, and the water sector. As a result, adaptation measures may exist which could have significant benefits across all three sectors. Encouraging the use of on-farm dams or reservoirs could, for example, increase the water supply, maintain agricultural production, and reduce flood risk on farms.

Table 5: General adaptation measures for the agricultural sector and for grasslands

General adaptation measures
— Change crop species (e.g. drought-tolerant and disease resistant species)
— Installation of storage infrastructure to protect seed, crop and silage from changing weather patterns (ECR)
— Improve irrigation techniques to increase water efficiency during dry spells
— Adopt intercropping, alter plant spacing, and change fallow practices to conserve soils
— Store water on farms through rain water harvesting, small on-farm dams, ponds etc.
— Restore floodplains and wetlands on farmland
— Improve soil husbandry and increase organic content of soils to improve soil structure and water storage capacity
— Plant field and hedgerow trees, copses, woodland, and buffer strips besides water courses
— Implement management practices that support biodiversity, especially of key pollinating species

Source: Based on Defra (2012) Climate Change Risk Assessment for the Agriculture Sector[34], the UK NEA Technical Chapter on Enclosed Farmland and Semi-Natural Grassland and the Economics of Climate Resilience – Agriculture and Forestry Theme: Agriculture[35]

[32] Harrison P.A., Berry P.M. & Dawson T.P. (eds) (2001) Climate change and nature conservation in the Britain and Ireland: modelling natural resource responses to climate change (the MONARCH project). UKCIP Technical Report, Oxford. [online] Available at: http://www.ukcip.org.uk/index.php?option=com_content&task=view&id=331&Itemid=9

[33] Beale, C.M., Lennon, J.J. & Gimona, A. (2008) Opening the climate envelope reveals no macro-scale associations with climate in European birds. Proceedings of the National Academy of Sciences of the United States of America, 105, 14908-14912.

In general the adaptive capacity of the agricultural sector is relatively high. This is due to the fact that many decisions made on farms can be made over a relatively short time period (e.g. selection of crop varieties or changes to farm infrastructure). However, when adaptation actions require a longer lead-in time or coordination with multiple stakeholders, adaptive capacity is lower. This might include ensuring adequate access to water resources or responding to coastal erosion.[36]

Adaptive capacity also varies across and between sub-sectors and in relation to the farm type, farm size and agricultural product. The ECR suggested that there were a number of key vulnerabilities:

- smaller farms with limited access to finance and short time horizons;
- sub-sectors where income from farming is low (e.g. pig farming); and
- tenants who have relatively short-term leases and are therefore unable or unwilling to invest in adaptation measures.

3.3 Woodlands

3.3.1 *Overview*

Woodlands provide a range of ecosystem services to society and are highly valued parts of the landscape. However, there are some concerns about the condition of woodland in the UK, with threats including overgrazing, development, habitat fragmentation, invasive species, unsympathetic forestry practices, lack of appropriate management, air pollution and new pests and diseases.

Historically, woodland dominated most of the UK landscape. This declined significantly through a combination of human and climate factors until it reached a low of 4.7 per cent at the beginning of the last century. Over the past ninety years, forest and woodland cover has been extensively restored and around 13% of the UK's total land area is now covered with woodland and 41,000 people are employed in the forestry and primary wood-processing industries[37]. The rate of increase has, however, slowed in recent years.

While there is no primary woodland in the UK, restoration in cover has resulted from afforestation (e.g. of marginal grazing land in the uplands) and re-growth of existing woodland from wartime felling. The last two decades have seen increased rates of creation of new native woodlands on farmland and in old industrial areas. While the initial driver for expansion was timber production (a provisioning service), which accounts for the substantial proportion (32%) of conifer species in current woodland cover in England, since the mid-1980s forestry policy has increasingly targeted a basket of services (including biodiversity, cultural, and regulating services), resulting in increased planting of broadleaved tree species and a diversification of plantation structures.

3.3.2 *Risks and opportunities*

The key climate risks and opportunities facing this habitat and the sectors it supports are set out in Table 6.

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[34] Defra (2012) UK Climate Change Risk Assessment. Sector Report: Agriculture [online] available at http://ccra.hrwallingford.com/CCRAReports/reportviewer.html?sector=agriculture&link=LinkTarget_1 (last accessed 22/02/2013)
[35] Frontier Economics, Irbaris and Ecofys (2013)The Economics of Climate Resilience – Agriculture and Forestry Theme: Agriculture (online) available at: http://randd.defra.gov.uk/Default.aspx?Module=More&Location=None&ProjectID=18016
[36] Ibid.
[37] Defra (2012) UK Climate Change Risk Assessment. Sector Report: Forestry Sector [online] available at http://ccra.hrwallingford.com/CCRAReports/reportviewer.html?sector=forestry&link=LinkTarget_1 (last accessed 25/02/2013)

Table 6: Climate risks and opportunities for woodlands and the forestry sector

Climate parameters	Opportunities	Risks
Warmer temperatures and increased frequency of heatwave events	— Warmer temperatures and higher CO2 concentrations may increase growth rates for certain species in some areas — Lengthen growing periods	— Warmer temperatures may increase the threat from insect pests, fungal, and other pathogens. Affected forests may experience reduced productivity, timber quality and increased tree mortality
Drier summers and increased frequency of dry spells	— None identified	— Loss of forest productivity due to drought especially in the southeast of England — Drought may exacerbate the susceptibility of some tree species to pests and diseases — Increased risk and severity of wildfires
More intense rainfall events with increased risk of flooding	— None identified	— Damage to trees due to extreme weather such as floods and storms
Rising sea levels and increasing frequency of storm surges	— None identified	— None identified
Shifts in the global climate	— None identified	— None identified

Source: Based on Defra (2012) Climate Change Risk Assessment for the Forestry Sector[38] [39], the UK NEA Technical Chapter on Woodlands and the Economics of Climate Resilience – Agriculture and Forestry Theme: Forestry[40]

Tree productivity in the UK could be affected by climate change in two main ways: firstly, an increase in temperatures and atmospheric CO_2 concentrations may lead to higher productivity as the conditions for growth improve; on the other hand, an increase in drought conditions may negatively affect tree productivity, especially in southern and eastern England where projections indicate the decline in soil moisture will be most severe.[41]

Climate change could therefore have both positive and negative impacts on forestry in the UK, with some species and regions benefitting and others losing out as the climate space shifts. The productivity of Sitka spruce, for example, is projected to decline by around 10 m^3/ha/year in the south-west of England and increase by more than 3 m^3/ha/year in the Grampians.[42]

Higher temperatures could also increase the risk of wildfires as well as allow the spread of new pests and diseases, with particular concerns over Red band needle blight and Green

[38] Defra (2012) UK Climate Change Risk Assessment. Sector Report: Forestry Sector [online] available at http://ccra.hrwallingford.com/CCRAReports/reportviewer.html?sector=forestry&link=LinkTarget_1 (last accessed 25/02/2013)
[39] Ibid.
[40] Frontier Economics, Irbaris and Ecofys (2013)The Economics of Climate Resilience – Agriculture and Forestry Theme: Agriculture (online) available at: http://randd.defra.gov.uk/Default.aspx?Module=More&Location=None&ProjectID=18016
[41] Defra (2012) UK Climate Change Risk Assessment. Sector Report: Forestry Sector [online] available at http://ccra.hrwallingford.com/CCRAReports/reportviewer.html?sector=forestry&link=LinkTarget_1 (last accessed 25/02/2013)
[42] Ibid.

spruce aphid. Increasing severity of winds and storms may further damage the forestry sector.[43]

3.3.3 *Adaptation measures*

Woodland ecosystems have a natural ability to adapt to changing climate conditions, however, the magnitude of the projected changes may require management interventions to maintain timber productivity and protect ecosystem services. The long timescales involved in tree growth mean that adaptation decisions, such as planting drought-resistant species and planting in lower fire-risk areas, need to be taken early. Further, the introduction of new species may have knock on effects on water supply, biodiversity, the spread of pests and diseases, and climate regulation.

Larger woodlands owners such as the Forestry Commission, commercial forestry companies and large estates are considered to have relatively high adaptive capacity. This is supported by existing guidelines on forestry and climate change and by broad policy support for multi-functional woodlands. However, adaptive capacity amongst small woodland owners is more restricted.

The ECR suggests that there are weaknesses within the existing forestry system, which could exacerbate the vulnerability of the sector to climate change. These include:

- the prioritisation of native tree species with local provenances over other species by the nature conservation community;
- the long term nature of forestry, which means that species and management actions set under existing conditions may not be suitable over the longer term;
- the narrow range of species that are currently considered for 'commercial forestry' in the UK; and
- the lack of significant stocks of alternative species and provenances in forest nurseries

Despite these weaknesses, there are a number of general adaptation measures which could be adopted to mitigate climate risks in woodlands and the sectors they support (see Table 7). Further, the wide range of ecosystem services provided by woodlands mean that there are important overlaps with almost all of the other sectors and some adaptation measures could have multiple co-benefits. Increasing woodland cover, for example, sequesters and stores carbon, provides biodiversity habitat, improves water and air quality, reduces flood risk, provides a source of sustainable energy, creates tourist destination and recreation areas, reduces soil erosion, and protects river banks.

Table 7: Adaptation measures for woodlands

General adaptation measures
— Adopt alternative land management systems to maintain tree cover
— Introduce new tree species to increase resilience through diversification and maintain timber production
— Select more drought-tolerant species when replanting

[43] Ibid.

General adaptation measures
— Bring unmanaged woodlands back into management to promote regeneration and natural evolutionary processes (ECR)
— Extend existing woodlands and create new woodlands that connect with each other to aid species movement and flood risk reduction (ECR)
— Increase drainage to accommodate increased rainfall and restrict felling of trees in catchments that are considered at risk from flooding (ECR)

Source: Based on Defra (2012) Climate Change Risk Assessment for the Forestry Sector[44], the UK NEA Technical Chapter on Woodlands and the Economics of Climate Resilience – Agriculture and Forestry Theme: Forestry

3.4 Freshwaters - openwaters, wetlands and floodplains

3.4.1 *Overview*

The hydrological cycle, along with the rivers, lakes, ponds, wetlands and groundwaters that form its terrestrial phases, provides a range of important ecosystem services. More than 389,000 km of river channels flow across England, Wales and Scotland, while almost 6,000 permanent large lakes cover a total area of almost 200,000 hectare (ha).[45]

Freshwaters support a wide range of other habitats and a number of critical ecosystem services; they provide water resources for agricultural irrigation, public domestic supply and abstraction for industry.

In the UK, around 18 billion litres of water are collected, treated, and supplied to customers every day, with a further 16 billion litres of wastewater also collected and treated.[46] In addition, many industrial and agricultural enterprises abstract their own supplies from rivers or groundwater.

Abstraction of water at this scale has resulted in a number of rivers, lakes, and groundwater bodies at risk of failing to maintain good quantitative status.[47] This is a particular concern for groundwater bodies; of which 174 are classified as having poor quantitative status compared to 134 classified as good[48]. As a result, water availability is one of the biggest issues facing the UK water sector with pressures on supplies already evident, especially in southern and eastern England.

Water quality is also a significant issue, with many rivers and groundwater sources in a reduced or degraded state. For groundwater bodies, 124 have poor overall ecological status and 81 bodies have an upward trend in pollutants.[49] While surface waters have historically also been degraded, over recent years there has been a widespread improvement in water quality, with the classification of 7,000 km and 12,000 km of English and Welsh rivers improving significantly since 1990.[50]

[44] Defra (2012) UK Climate Change Risk Assessment. Sector Report: Forestry Sector [online] available at http://ccra.hrwallingford.com/CCRAReports/reportviewer.html?sector=forestry&link=LinkTarget_1 (last accessed 25/02/2013)
[45] Ibid.
[46] *Ibid.*
[47] UK NEA (2012) 'Chapter 9 Freshwaters: Openwaters, Wetlands and Floodplains', UNEP WC-MC, Cambridge.
[48] *Ibid.*
[49] *Ibid.*
[50] *Ibid.*

3.4.2 *Risks and opportunities*

The key climate risks and opportunities facing this habitat and the sectors it supports are set out in Table 8.

Table 8: Climate change risks and opportunities for freshwaters and the economic sectors they support

Climate parameters	Opportunities	Risks
Warmer temperatures and increased frequency of heatwave events	— None identified	— Increased demand for water due to higher temperatures — Water quality decreases as a result of increasing algal blooms — Desiccation of natural wetlands especially in late summer and the autumn and the species they support (UK NEA) — Alter species composition in headwaters and alter the abundances of important organisms, including salmonids (UKNEA)
Drier summers and increased frequency of dry spells	— None identified	— More unsustainable water abstractions due to greater use of irrigation in agriculture — Reduced summer flows in many rivers — Increase in number of people living in areas with water supply-demand deficits — Increased risk of drought — Growing environmental costs of over abstraction with impacts on water quality and changes in river morphology — Water quality decreases as a result of lower water levels which increases pollutant concentrations
More intense rainfall events with increased risk of flooding	— None identified	— Increased sewer spillages — Increased pollution runoff in rural lowlands from saturated winter soils
Rising sea levels and increasing frequency of storm surges	— None identified	— Increased saline intrusion into coastal aquifers as a result of sea level rise
Shifts in the global climate	— None identified	— Water stress abroad could reduce resilience of supply chains dependent on international water

Source: Based on Defra (2012) Climate Change Risk Assessment for the Water Sector[51], the UK NEA Technical Chapter on Freshwater – openwaters, wetlands and floodplains.

[51] Defra (2012) UK Climate Change Risk Assessment. Sector Report: Water Sector [online] available at http://ccra.hrwallingford.com/CCRAReports/reportviewer.html?sector=water&link=LinkTarget_1 (last accessed 26/02/2013)

The UK NEA states that “lakes, rivers and other wetlands are likely to be among the most sensitive of all habitats to climate change. Temperature and precipitation affect fundamental attributes of aquatic systems, such as discharge, thermal regimes, stratification, oxygen and solute concentrations. In turn, these effects interact with existing pressures, such as acidification and eutrophication, while also having major consequences for freshwater organisms”.[52] These changes will also have profound impacts on the economic sectors that freshwaters support.

Climate change is projected to lead to significant reductions in summer flows across the UK (particularly in southern and eastern England), with some headwaters potentially drying up completely during summer as well as major impacts on a number of iconic rivers systems in the uplands.[53]

At the same time climate change may also increase urban water demand which can rise from an average of around 160 litres of water per day to almost 200 litres per day when temperatures reach 20°C[54]. Greater reliance on less carbon intensive, more water intensive fuels such as biofuels, hydropower, and shale gas could significantly increase the demand for water in energy production. Further, water abstractions for irrigated agriculture may also increase due to a more arid climate as well as intensification and expansion of the sector.[55]

As a result of these factors, unsustainable abstractions are likely to increase and nearly half of water resource zones could be at risk of deficit during a drought by the 2020s due to the combined effect of climate change and population growth.[56]

Water quality may also deteriorate due to increased concentration of pollutants resulting from lower rivers flows, increased risk of seawater intrusion in coastal areas, and greater incidence of algal blooms due to higher temperatures. The risk of sewer overflows is also likely to increase due to more frequent heavy rainfall events which may also lead to a decline in water quality.[57,58]

3.4.3 *Adaptation measures*

The key challenge to adaptation for the water sector is the lack of incentives to use water efficiently due to the failure of market price signals. Only a minority of urban water users, for example, have water meters installed in their properties, and since non-metered households do not realise the benefits of water efficiency through lower water bills, they have little incentive to take action. The CCRA notes that in the UK, legal barriers and concerns over impacts on low income households currently prevent universal installation of water meters, although international evidence suggests that these barriers can be overcome with effective policy design.[59] An additional challenge arises due to the fact that the current system of abstraction licences does not include the environmental costs of water use or allow flexibility to respond to periods of water scarcity.

Despite these challenges there are a number of general adaptation measures which could be adopted to reduce climate risks to freshwaters and the sectors these support (see Table 9). In addition to these adaptation measures there are also important overlaps with almost all of the other sectors. As a result, some of the adaptation measures proposed for the water sector

[52] UK National Ecosystem Assessment (2011) The UK National Ecosystem Assessment Technical Report. UNEP-WCMC, Cambridge. [online] available at: http://uknea.unep-wcmc.org/LinkClick.aspx?fileticket=m%2bvhAV3c9uk%3d&tabid=82 (last accessed 29/04/2013)
[53] Defra (2012) UK Climate Change Risk Assessment. Sector Report: Water Sector [online] available at http://ccra.hrwallingford.com/CCRAReports/reportviewer.html?sector=water&link=LinkTarget_1 (last accessed 26/02/2013)
[54] *Ibid.*
[55] *Ibid.*
[56] Adaptation Sub-Committee (2010), ‘How well prepared is the UK for climate change?’ [online] available at http://hmccc.s3.amazonaws.com/ASC/CCC_ASC_Report_web_2.pdf (last accessed 26/02/2013)
[57] *Ibid.*
[58] *Ibid.*
[59] OECD (2010), ‘Pricing Water Resources and Water and Sanitation Services’, OCED, Paris.

could have significant benefits across multiple sectors. For example, restoring degraded peatlands stores and sequesters carbon, provides biodiversity habitat, improves downstream water quality, leads to restoration of the water table, and secures water supply during droughts.

Table 9: Adaptation measures for the water sector

General adaptation measures
— Ensure good provision of permeable green infrastructure within catchments to sustain infiltration into aquifers[60]
— Avoid planting conifer woodlands, which have a very high water use, in water scarce catchments[61]
— Manage abstraction to use water from areas of relative surplus instead of relative scarcity
— Encourage restoration of the water table in deep peats through the reduction or removal of drains and plantations
— Create, restore and maintain wetlands to provide water storage during intense precipitation events[62]
— Ensure sustainable water supply through SuDS and water butts to collect and store rainwater in urban areas
— Increase the use of buffer strips around agricultural land to reduce diffuse pollution that could be exacerbated by increases in precipitation
— Reduce abstractions from surface waters to restore environmental flows
— Restore and preserve degraded peatlands by restoring blanket bogs by blocking drainage ditches, restoring areas of eroded and exposed peat

Source: Based on Defra (2012) Climate Change Risk Assessment for the Water Sector[63], the UK NEA Technical Chapter on Freshwater – openwaters, wetlands and floodplains.

3.5 Mountains, moorlands and heaths

3.5.1 *Overview*

The UK NEA describes mountains, moorlands and heaths as “predominantly open, unenclosed and extensive landscapes, which many perceive as ‘wild land’, relatively untouched by people. In reality, the character of these often remote expanses commonly reflects hundreds, if not thousands, of years of human interference. These are, therefore, mostly cultural landscapes, kept in an ‘open state’ by practices such as grazing, cutting and burning.”

Mountains, moorlands and heaths comprise around 18% of the land cover in the UK with the majority found in Scotland. They provide a range of important ecosystem services, including supplying around 70% of the UK’s drinking water, storing around 40% of UK soil carbon,

[60] http://www.greeninfrastructurenw.co.uk/resources/GI_How & where can it help the NW mitigate and adapt to climate change.pdf
[61] *Ibid.*
[62] http://www.environment-agency.gov.uk/static/documents/Research/(20)_Wetland_Vision_Summary.pdf
[63] Defra (2012) UK Climate Change Risk Assessment. Sector Report: Water Sector [online] available at http://ccra.hrwallingford.com/CCRAReports/reportviewer.html?sector=water&link=LinkTarget_1 (last accessed 26/02/2013)

supporting a range of protected habitats and species and providing a setting for cultural heritage and recreation. As such they support the water, agricultural and tourism sectors.

However, there have been substantial changes to the extent and condition of these habitats with a large proportion having been converted to grassland for agriculture. Other factors that have led to their deterioration include woodland planting on deep peat soils, changes in grazing pressures and airborne pollution. Climate change may also become an important driver of changes to the extent and condition of these habitats and the ecosystem services they support.

3.5.2 *Risks and opportunities*

The key climate risks and opportunities facing this habitat and the sectors it supports are set out in Table 10.

Table 10: Climate risks and opportunities for mountains, moorlands and heath

Climate parameters	Opportunities	Risks
Warmer temperatures and increased frequency of heatwave events	— Providing that soil moisture does not become limiting, higher temperatures are expected to result in increased biomass production of heathlands[64]	— Shift in species distribution — hotter and drier conditions are likely to have a direct effect on wildfire occurrence and on the length of the wildfire season in the UK[65]
Drier summers and increased frequency of dry spells	— None identified	— Desiccation of moorlands and heaths and release of carbon from peat soils[66] — Shift in species distribution — Summer drought may curb plant growth and induce changes in plant species composition, such as the suppression of bracken by heather[67]
More intense rainfall events with increased risk of flooding	— None identified	— Increased water pollution and levels of Dissolved Organic Carbon (DOC) and Particulate Organic Carbon (POC) in water draining from peatlands[68]

[64] Peñuelas, J., Gordon, C., Llorens, L., Nielsen, T., Tietema, A., Beier, C., Bruna, P., Emmett, B., Estiarte, M. & Gorissen, A. (2004) Nonintrusive field experiments show different plant responses to warming and drought among sites, seasons, and species in a north-south European gradient. Ecosystems, 7: 598-612.
[65] Cavan, G. and McMorrow, J (2009) Interdisciplinary Research on Ecosystem Services: Fire and Climate Change in UK Moorlands and Heaths. Summary report prepared for Scottish Natural Heritage. University of Manchester (online) available at www.fires-seminars.org.uk
[66] The IUCN Peatland Carbon Programme
[67] Gordon, C., Woodin, S.J., Alexander, I.J. & Mullins, C.E. (1999) Effects of increased temperature, drought and nitrogen supply on two upland perennials of contrasting functional type: Calluna vulgaris and Pteridium aquilinum. New Phytologist, 142: 243-258.
[68] Yallop, Clutterbuck, Thacker (2010) Increases in humic dissolved organic carbon export from upland peat catchments: the role of temperature, declining sulphur deposition and changes in land management (online) available at: http://www.int-res.com/articles/cr_oa/special/BUppp2.pdf

Climate parameters	Opportunities	Risks
Rising sea levels and increasing frequency of storm surges	— None identified	— None identified
Shifts in the global climate	— None identified	— None identified

The impacts of climate change on the extent and condition of mountains, moorlands and heaths has so far been limited with changes in land-use and atmospheric pollution playing a more prominent role. However, climate change is likely to have an increasing impact and combinations of changes in precipitation, heat and drought could lead to ecosystem degradation. For example, it has been shown that a summer drought followed by a very cold winder spell was most damaging to heather species; while winter damage occurred in bracken plants that had been subject to raised temperatures in summer.[69]

UK peatlands represent both a threat and an opportunity in terms of climate change. If they continue to be degraded through intense management, atmospheric pollution and visitor pressure, water quality is likely to deteriorate further and emissions of GHGs are likely to increase.[70] However, if they are restored, the evidence suggests that current GHG emissions can be reduced and the habitats can be turned back into carbon stores. Restoration is also likely to lead to improvements in water quality and flood risk in downstream conurbations.[71]

3.5.3 *Adaptation measures*

Table 11 sets out some of the adaptation measures that may be applied to upland habitats to help alleviate flood risk and improve water quality.

Table 11: Adaptation measures for mountains, moorlands and heaths and the sectors they support

General adaptation measures
— Restore functioning blanket bog by restoring Sphagnum mosses
— Manage burning to avoid damaging blanket bog and peat
— Re-vegetate bare peat
— Do not introduce new drainage on blanket bogs and avoid deepening of any existing drains
— Sustainable livestock grazing: seasonal grazing sustainable stocking levels, less trampling
— Block all active moorland grips and re-profile eroding gullies

[69] Gordon, C., Woodin, S.J., Alexander, I.J. & Mullins, C.E. (1999) Effects of increased temperature, drought and nitrogen supply on two upland perennials of contrasting functional type: Calluna vulgaris and Pteridium aquilinum. New Phytologist, 142: 243-258.
[70] Worall et al (2010) Peatlands and climate change (online) available at: http://www.iucn-uk-peatlandprogramme.org/sites/all/files/Review%20Peatlands%20and%20Climate%20Change,%20June%202011%20Final.pdf
[71] *Ibid.*

3.6 Marine and coastal

3.6.1 *Overview*

The UK NEA defines marine habitats as covering areas that are either permanently immersed in seawater or are inundated with saline water at some stage in the tidal cycle. This includes estuaries, beaches, coasts and all sub-tidal habitats out to the limit of the UK's marine area. Mainland Britain has a wide range of marine habitats which support a high diversity of animals and plants (approximately 8,500 marine species).[72]

UK territorial waters provide essential resources such as fisheries, gas, oil, building materials, tourism and recreation destinations, and are home to critical infrastructure assets. Direct marine-related activities contribute around £45 billion each year to the UK economy and support 900,000 jobs. Further, up to 95% of imports and exports are transported via a maritime route meaning that the marine sector has significant implications for other sectors within the economy.[73]

3.6.2 *Risks and opportunities*

The key climate risks and opportunities facing this sector are set out in Table 12.

Table 12: Climate risks and opportunities for the marine and fisheries sector

Climate parameters	Opportunities	Risks
Warmer temperatures and increased frequency of heatwave events	– Opening of Arctic shipping routes due to melting of sea ice creating new trade routes for the UK, reducing fuel costs, and creating access to new fishing grounds – Expansion of some species range due to shifting climate space e.g. yellow legged gull	– Warmer sea temperatures may increase carbon cycling which may disrupt fisheries – Northward spread of invasive non-native species – Possible increase in transmission of marine pathogens – Growth in phytoplankton – Changing climate space may alter some species negatively e.g. puffin – Timings of the peak abundance of fish stocks may change (ECR) – increased level of desiccation in the intertidal area, restricting the distribution of intertidal species (UK NEA)
Drier summers and increased frequency of dry spells	– None identified	– Drying out of sand dunes which will lead to the loss of rare species and the release of carbon stores (UK NEA)

[72] UK National Ecosystem Assessment (2011) The UK National Ecosystem Assessment Technical Report. UNEP-WCMC, Cambridge. [online] available at: http://uknea.unep-wcmc.org/LinkClick.aspx?fileticket=m%2bvhAV3c9uk%3d&tabid=82 (last accessed 29/04/2013)
[73] Defra (2012) UK Climate Change Risk Assessment. Sector Report: Marine Sector [online] available at http://ccra.hrwallingford.com/CCRAReports/reportviewer.html?sector=marine&link=LinkTarget_1 (last accessed 25/02/2013)

Climate parameters	Opportunities	Risks
More intense rainfall events with increased risk of flooding	– None identified	– Decline in water quality due to sewer overflows as a result of more frequent intense rainfall – Increased contamination of shellfish may lead to increase in norovirus amongst humans
Rising sea levels and increasing frequency of storm surges	– None identified	– Disruption to shipping and ferry transport due to rougher seas
Shifts in the global climate	– Increases in fish catch for species such as plaice and sole	– Ocean acidification may disrupt fisheries and food webs – Decreases in fish catch for species such as cod and haddock – Disruption to breeding of seabirds and invertebrates – Changes in distribution of fish, timing of migration, overall reproductive output (recruitment), and growth rates

Source: Based on Defra (2012) Climate Change Risk Assessment for the Marine and Fisheries Sector[74], The Economics of Climate Resilience – Natural Environment Theme: Sea Fish, and the UK NEA Technical Chapters on Coastal Margins and Marine Habitats

Climate change may lead to a decline in marine water quality through, for example, more frequent sewer overflows; any resulting increase in eutrophication may disrupt marine food webs and impact fisheries. Higher water temperatures could increase the rate of 'carbon cycling' at the ocean surface, diverting resources away from seabed species and potentially disrupting food webs and fisheries.[75] Acidification of the ocean is also likely to impact food webs although the exact outcomes are unclear.

Despite the uncertainties, the combination of higher temperatures and acidification is already having a detectable impact on fish populations, with changes in distribution, the timing of migration, overall reproductive output (recruitment), and growth rates.[76,77] Some of these changes are positive (increases in catches of plaice and sole) whilst others are negative (decreases in catches of cod and haddock)[78].

The impact of climate change on other marine species is also mixed, with some species establishing themselves in the UK for the first time (e.g. yellow-legged gull) and other established species losing out (e.g. puffins may lose breeding sites in the south-west and east).[79] Projections also suggest that marine invasive species may be able to expand their range by the 2080s to encompass the entire UK due to higher temperatures[80].

[74] Defra (2012) UK Climate Change Risk Assessment. Sector Report: Marine Sector [online] available at http://ccra.hrwallingford.com/CCRAReports/reportviewer.html?sector=marine&link=LinkTarget_1 (last accessed 25/02/2013)
[75] Ibid.
[76] Defra (2010) 'Charting Progress 2:Healthy and Biologically Diverse Seas' http://chartingprogress.defra.gov.uk/fish (last accessed 25/02/2013)
[77] UK NEA (2012) 'Chapter 12 Marine', UNEP WC-MC, Cambridge.
[78] Defra (2012) UK Climate Change Risk Assessment. Sector Report: Marine Sector [online] available at http://ccra.hrwallingford.com/CCRAReports/reportviewer.html?sector=marine&link=LinkTarget_1 (last accessed 25/02/2013)
[79] Ibid.
[80] UK NEA (2012) 'Chapter 12 Marine', UNEP WC-MC, Cambridge.

A significant potential opportunity is the increased melting of Arctic sea ice as result of climate change which may open up commercially viable routes for shipping (the North West Passage and the North East Passage to the Pacific and Asia), saving millions of pounds in fuel costs, shorter journeys, and avoidance of Suez and Panama Canal fees. Increased storminess, particularly during winter, may negatively impact shipping and ferry routes[81].

3.6.3 *Adaptation measures*

One of the key challenges to adaptation for the marine and fisheries sector is the level of uncertainty over the impact of climate change on the distribution of commercial fish species, in particular the impacts of ocean acidification. There is also significant uncertainty over the impacts on the transmission of sea-borne diseases and spread of non-native species as well as the impact on wider biodiversity such as marine mammals and sea birds.

However, due to the inherent variability of the marine environment, this sector has extensive experience of coping with climate impacts and there are a number of general adaptation measures which could be adopted to mitigate climate risks as set out in Table 13.

In addition, there are important overlaps with the business, industry, and services; energy; and biodiversity and ecosystem services sectors. As a result, adaptation measures which could have significant benefits across multiple sectors may exist. Encouraging consumers to purchase fish species which are projected to increase around the UK due to climate change could take pressure off traditional target species, benefit the marine fishing industry in the long run by ensuring stocks are not overfished, and reduce energy costs as fishing boats will not have to travel to fishing grounds further from the UK.

Table 13: Adaptation measures for the marine and fisheries sector

General adaptation measures
— Allow natural coast development and implement realignment of coastal flood defences to restore inter-tidal coastal habitats (mud flats, salt marshes, floodplains, and dunes) and natural transition zones between coastal and terrestrial habitats
— Encourage members of the public to purchase and consume the different species of fish that may increase around the UK as a result of climate change
— Change location of fishing patterns (ECR)

Source: Based on Defra (2012) Climate Change Risk Assessment for the Marine and Fisheries Sector[82], The Economics of Climate Resilience – Natural Environment Theme: Sea Fish, and the UK NEA Technical Chapters on Coastal Margins and Marine Habitats

3.7 Urban areas and the built environment

The UK's built environment includes 27 million homes, commercial and industrial properties, hospitals, schools, and other buildings, as well as the wider urban environment. Around 70% of buildings that will be in use in the 2050s have already been built. As such, a significant proportion of the built environment was designed for the climate that existed when it was built and so many buildings are not necessarily designed for current and future climates.

It is, however, increasingly recognised that investment in green infrastructure can provide multifunctional benefits in the urban environment and help adapt towns and cities to climate

[81] Defra (2012) UK Climate Change Risk Assessment. Sector Report: Marine Sector [online] available at http://ccra.hrwallingford.com/CCRAReports/reportviewer.html?sector=marine&link=LinkTarget_1 (last accessed 25/02/2013)
[82] Defra (2012) UK Climate Change Risk Assessment. Sector Report: Marine Sector [online] available at http://ccra.hrwallingford.com/CCRAReports/reportviewer.html?sector=marine&link=LinkTarget_1 (last accessed 25/02/2013)

change. The ecosystem services provided by nature help reduce the urban heat island effect, manage storm and surface water, reduce air and water pollutants, and provide amenities and health, as well as supporting biodiversity (see Chapter 3).

3.7.1 *Risks and opportunities*

The key climate risks and opportunities facing this sector are set out in Table 14.

Table 14: Climate risks and opportunities facing the built environment

Climate parameters	Opportunities	Risks
Warmer temperatures and increased frequency of heatwave events	– Milder winters may reduce energy bills and cold related deaths and hospital admissions	– Increased urban heat island effect – Increased risk buildings become too hot leading to illness/death and lower economic productivity
Drier summers and increased frequency of dry spells	– None identified	– Less reliable supplies, more frequent restrictions and water shortages in the longer term – Increased risk of subsidence for properties and higher insurance claims – Drying out of grass and other vegetation, reducing the climate refuge benefit of green space
More intense rainfall events with increased risk of flooding	– None identified	– Greater flood risk may lead to more properties at risk of flooding and increasing flood damage to properties
Rising sea levels and increasing frequency of storm surges	– None identified	– None identified
Shifts in the global climate	– None identified	– None identified

Source: Based on Defra (2012) Climate Change Risk Assessment for the Built Environment Sector[83] and the UK NEA Technical Chapter on Urban Habitats

Milder winters may reduce energy bills (up to 40% by the 2080s) as well as cold-related deaths and illness; however, warmer summers may increase the risk of illness from overheating and increase the amount of energy used for cooling.[84]

The urban heat island effect may become more significant, with a projected increase in average summer night-time temperatures in London between 1 and 9°C by the 2080s. Droughts and lower water availability during summer may cause vegetation to dry out as well as leading to less reliable supplies, more frequent restrictions, and potential water shortages. The number of people in the UK affected by water supply-demand deficits may increase to up to 59 million by the 2050s.[85]

[83] Defra (2012) UK Climate Change Risk Assessment. Sector Report: Built Environment [online] available at http://ccra.hrwallingford.com/CCRAReports/reportviewer.html?sector=builtenvironment&link=LinkTarget_1 (last accessed 25/02/2013)
[84] Ibid.
[85] Ibid.

Wetter winters, more prolonged dry periods in summer, and increased temperatures may increase the risk of subsidence, particularly in densely populated parts of south-east England, where there are large areas of shrink-swell clay soils. Further, the number of properties with a significant likelihood of flooding is projected to rise from 560,000 currently, to between 980,000 and 1.5 million by the 2080s.[86]

3.7.2 *Adaptation measures*

The key challenges to adaptation for the built environment are policy and market barriers. In some policy areas, including certain aspects of building regulations, the risks from climate change are not yet explicitly considered. In other areas, policy goals can conflict with climate adaptation. For example, households may not be authorised to paint their roofs white (to increase the albedo affect) if they are listed properties, properties in conservation areas, or it is deemed not to be within the character of the area.

In some cases it is not considered cost-effective to modify existing buildings to adapt to climate change. For example, while maintaining and refurbishing existing drainage infrastructure is necessary it can be expensive and often does not generate a particularly high return. The CCRA also identifies a number of key barriers to investment in sustainable drainage systems (SuDS) compared to conventional drainage including: a lack of consistent standards for developers to identify affordable drainage that is fit-for-purpose; a lack of a coherent policy framework to address ownership and ongoing maintenance arrangements; behavioural inertia; and the fact that developers are faced with the whole-life cost of SuDS (where on-going financing is not possible) the benefits of which usually accrue downstream.[87]

In the case of modifying new buildings to adapt to increased flood risk, climate change adaptation can create a misalignment of incentives between investors, developers, and occupiers. Investors and developers may not provide well-adapted buildings until occupiers demonstrate a demand for them. However, occupiers are unlikely to pay a premium for adaptation that incurs additional upfront costs. The CCRA also identified a number of key barriers to individuals adopting property level protection measures including: a lack of information about the best products; a feeling that managing flood risk is not their responsibility; concerns about impacts on the appearance and resulting saleability of the property; and the perception that the high upfront costs of protection outweigh the uncertain benefits.[88]

Despite these challenges there are a number of general adaptation measures which could be adopted to mitigate climate risk to the built environment as set out in Table 15. In addition to these adaptation measures, there are also important overlaps with the energy, floods and coastal erosion, health, and water sectors. As a result, adaptation measures which could have significant benefits across multiple sectors may exist. Encouraging tree planting and green infrastructure within urban areas, for example, could reduce temperatures and the need for air conditioning, provide health benefits, improve water quality, and reduce surface run-off. In Manchester, for example, studies suggest that a projected increase in temperature of 3ºC by 2050 could be avoided by increasing greenspace by 10%,[89] while in Toronto, the ‘Ahead of the storm’ climate change action plan sets out a commitment to double the tree canopy in the city in order to increase shade, reduce the urban heat island effect, and reduce water runoff.[90]

[86] Ibid.
[87] Defra (2012) UK Climate Change Risk Assessment. Sector Report: Built Environment [online] available at http://ccra.hrwallingford.com/CCRAReports/reportviewer.html?sector=builtenvironment&link=LinkTarget_1 (last accessed 25/02/2013)
[88] Ibid.
[89] Ibid.
[90] Kazmierczak, A. and Carter, J. (2010) Adaptation to climate change using green and blue infrastructure. A database of case studies.

Table 15: Adaptation measures for the built environment

General adaptation measures
— Emphasise climate adaptation in planning policy
— Ensure building regulations set minimum water and energy efficiency standards, ensure structural stability, and limit heat gain
— Ensure new buildings can cope with rising temperatures through the use of different construction materials and ventilation systems
— Use roads and paths as emergency flood channels
— Increase urban green infrastructure including parks, green car parks, urban trees, green roofs and walls, high albedo roof and road surfaces, and green aeration corridors. Design in conjunction with mapping of wind directions and air flows
— Incorporate sustainable drainage systems (SuDs) which include permeable pavements, trees and vegetation, green roofs, stormwater retention ponds, and wetlands and swales

Source: Based on Defra (2012) Climate Change Risk Assessment for the Built Environment Sector[91] and the UK NEA Technical Chapter on Urban Habitats

[91] Defra (2012) UK Climate Change Risk Assessment. Sector Report: Built Environment [online] available at http://ccra.hrwallingford.com/CCRAReports/reportviewer.html?sector=builtenvironment&link=LinkTarget_1 (last accessed 25/02/2013)

4. NATURAL ENVIRONMENT ADAPTATION OPPORTUNITIES

4.1 Background

As noted in Section 1.2, the first NAP sets out the government's response to the CCRA and identifies what government, businesses and society are doing to become less vulnerable to the impacts of climate change (or more 'climate ready') and what actions are needed to address the priority risks identified in the CCRA.

The IPCC defines vulnerability as:

"The degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity"[92]

The IPCC recognises that different states of vulnerability may exist, including:

- vulnerability to current climate;
- vulnerability to future climate change in the absence of adaptation and mitigation measures;
- residual vulnerability which remains after adaptive and mitigation capacities have been implemented; and
- vulnerability where the impacts are significant.

Vulnerability is therefore highly dependent on context and scale and is a function of:

- exposure to hazards;
- sensitivity (in terms of the nature and magnitude of impacts); and
- capacity of human and natural systems to adapt.

This last point is important since it determines the ability of a system to adjust to climate change (including both variability and extremes), to mitigate potential damages, to take advantage of opportunities, and to cope with the consequences[93].

In this case, adaptation refers to the adjustments that are made to accommodate expected future changes in climate. As noted in the introductory chapter, the IPCC defines adaptation as:

"*Adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities*"[94]

Adaptation can be planned (such as policy development), reactive (such as emergency repair work), anticipatory (such as building flood defences), or spontaneous/autonomous (such as ecological changes in natural systems).

In order for adaptation responses to be effective, these need to be part of comprehensive framework (see Figure 3) which:

[92] Intergovernmental Panel on Climate Change (IPCC) Working Group 2 (2001) Third Assessment Report, Annex B: Glossary of Terms [online] available at http://www.ipcc.ch/pdf/glossary/tar-ipcc-terms-en.pdf (last accessed 26/02/2013).
[93] *Ibid*.
[94] IPCC (2007) Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Annex I., M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 976pp [online]

- Considers responses to climate change as a strategic priority;
- Pays special attention to impacts on vulnerable groups, assets, etc.;
- Increases the capacity of staff and other stakeholders to improve their understanding of climate change risks;
- Ensures good communication of risks and responses;
- Takes climate change into account in any decisions around the development of infrastructure and the way in which land is managed and used; and
- Embeds adaptation in all policies and activities.

Figure 3: Adaptation framework

4.2 Ecosystem-based adaptation

The UK is already investing in infrastructure to reduce the vulnerability of its citizens to the effects of sea-level rise and flooding. England. In 2008-2009, the Environment Agency spent approximately two thirds of its flood risk management budget (£427 million) on building, improving and keeping flood defences such as managed river channels, walls and raised embankments, flood barriers and pumps in good condition[95].

While many recent climate change adaptation initiatives have focused on the use of technologies and the design of climate-resilient infrastructure, there is growing recognition of the role healthy ecosystems can play in facilitating adaptation to a changing climate. As natural buffers, ecosystems are often cheaper to maintain and, in the appropriate circumstances, can complement or even substitute for hard engineering structures such as embankments or concrete walls, while also providing a range of additional benefits. For example, saltmarshes contribute to storm protection, coastal defence, and groundwater recharge, while woodlands can help stabilise soil, alleviate floods and provide shading for humans and wildlife.

The Economics of Ecosystems and Biodiversity (TEEB) initiative estimated the costs and benefits of ecosystem restoration for adaptation across nine biomes[96], and found that benefit/cost ratios over 40 years ranged from around 3 (for coral reefs) to 75 (for grasslands), indicating large net benefits from investing in EBA when the value of the public goods and services of ecosystems is included, and social returns on investment are computed[97]. In addition, a recent European Commission-funded project compared information on the costs and benefits of ecosystem-based approaches against more traditional engineering approaches for addressing climate change impacts across Europe. Although the study did not carry out a comprehensive assessment of costs and benefits due to the lack of quantitative data, it concluded that "*the majority of projects using ecosystem-based approaches can be considered beneficial from an economic point of view if one takes account of the long-term social and ecological benefits that are associated with the projects […] making those projects using ecosystem-based approaches potentially more cost-effective than traditional engineered approaches*"[98].

The concept of ecosystem-based adaptation builds on the Convention on Biological Diversity's (CBD) definition of an ecosystem approach which is "*a strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way*"[99]. Using this definition as a basis, Defra's Ecosystem Approach Action Plan (EEAP) identified a number of core principles through which an ecosystems approach can be applied in a wide range of policy areas and decision-making contexts:

- 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; and

[95] Environment Agency (2009) Flooding in England: A National Assessment of Flood Risk [online] available at http://www.tritonsystems.co.uk/pdf/EA_Flooding_in_England.pdf (last accessed 30/04/2013)
[96] Coral reefs, coastal, mangroves, inland wetlands, lakes/rivers, tropical forests, other forests, woodland/shrubland and grassland
[97] TEEB (2009) TEEB Climate Issues Update. September 2009 [online] available at http://www.teebweb.org/wp-content/uploads/Study%20and%20Reports/Additional%20Reports/TEEB%20climate%20Issues%20update/TEEB%20Climate%20Issues%20Update.pdf?bcsi_scan_E956BCBE8ADBC89F=0&bcsi_scan_filename=TEEB%20Climate%20Issues%20Update.pdf (last accessed 30/04/2013)
[98] Naumann, S., G. Anzaldua, P. Berry, S. Burch, McKenna, D., A. Frelih-Larsen, H. Gerdes and M. Sanders (2011) Assessment of the potential of ecosystem-based approaches to climate change adaptation and mitigation in Europe. Final report to the European Commission, DG Environment, Contract no. 070307/2010/580412/SER/B2, Ecologic institute and Environmental Change Institute, Oxford University Centre for the Environment [online] available at http://ec.europa.eu/environment/nature/climatechange/pdf/EbA_EBM_CC_FinalReport.pdf (last accessed 30/04/2013)
[99] See http://www.cbd.int/ecosystem/default.shtml

- promoting adaptive management of the natural environment to respond to changing pressures, including climate change.

This last point is important and reflects the need for a more dynamic approach to management of the natural environment that strengthens resilience to climate and ensures continued provision of ecosystem services.

The remainder of this chapter presents a synthesis of the evidence of the potential role of investments in the natural environment in facilitating climate change adaptation in the UK as well as inputs from a number of ecosystem specialists at a workshop held in London in April 2013 (see Appendix A for a list of participants). The process of evidence-gathering and analysis was focused around the following series of questions:

- what are the principal natural environment solutions that could facilitate climate change adaptation in the UK?
- what are the specific regulating ecosystem services that would be enhanced through natural environment measures?
- what impacts (positive and negative) would these measures have on other ecosystem services and which measures generate multiple benefits?
- where do the most obvious ‘no regret’ or ‘low regret’ options lie?
- what case studies are available from the UK and elsewhere that demonstrate the role of ecosystem services in facilitating climate change adaptation?

4.2.1 *Options for managing flood risk (excluding coastal flooding)*

The landscape plays an important role in storing and distributing freshwater and its ability to do this can be weakened or enhanced by economic activity and the condition of the ecosystems that give rise to water storage benefits.

The Pitt Review: *Learning Lessons from the 2007 floods*[100] advocated more working with natural processes and rural land-use options instead of relying exclusively on hard defences. However, the evidence around the role of land management in reducing flood risk highlights the complexity and highly contextual nature of the relationship.

Research by Nisbet et al (2011)[101] found that forests and woodland have long been associated with an ability to **slow down run-off and reduce downstream flooding**. Work by Armson *et al.* (2011)[102], for example, has shown that trees can reduce surface water runoff by up to 60 per cent compared to asphalt. However, while there is evidence of a forest impact on flood flows at a local level (< 100 km^2) and for smaller flood events[103], forest hydrology studies in the UK and worldwide generally provide little support for a significant effect on extreme flood flows

[100] webarchive.nationalarchives.gov.uk/20100807034701/http://archive.cabinetoffice.gov.uk/pittreview/thepittreview.html (last accessed 19/06/2013)
[101] Nisbet, T., Silgram, M., Shah, N., Morrow, K., and Broadmeadow, S. (2011) Woodland for Water: Woodland measures for meeting Water Framework Directive objectives. Forest Research Monograph, 4, Forest Research, Surrey, 156pp.
[102] Armson, D., Stringer, P., and Ennos, A. R. (2011). The Effect of Trees and Grass upon Temperatures and Surface Water Runoff in Urban Areas, University of Manchester, Faculty of Life Sciences.
[103] Robinson, M., Cognard-Plancq, A.L., Cosandey, C., David, J., Durand, P., Fuhrer, H.W., Hall, R., Hendriques, M.O., Marc, V., McCarthy, R., McDonnell, M., Martin, C., Nisbet, T., O’Dea, P., Rodgers, M. and Zollner, A. (2003). Studies of the impact of forests on peak flows and baseflows: a European perspective. Forest Ecology and Management, 186: 85-97; O’Connell, P.E., Beven, K.J., Carney, J.N., Clements, R.O., Ewen, J., Fowler, H., Harris, G.L., Hollis, J., Morris, J., O’Donnell, G.M., Packman, J.C., Parkin, A., Quinn, P.F., Rose, S.C., Shepherd, M. and Tellier, S. (2004). Project FD2114: Review of impacts of rural land use and management on flood generation. Defra R&D Technical Report FD2114. Defra, London; and Broadmeadow, S. and Nisbet, T. R. (2010). Opportunity mapping for woodland to reduce flooding in the Yorkshire and the Humber region. Forest Research Monograph 1. Forest Research, Hampshire.

at a wider landscape level.[104] This may be partly due to the relatively short lengths of available data records, but also the difficulty of isolating a forestry effect from the mix of land uses and activities present within larger catchments. For example, research has shown that forest related hydrological effects are very difficult to discern when <20% of a catchment is affected[105]

A detailed review by Natural England found that there are good opportunities to reduce run-off from farms through measures such as grass buffers, temporary ponds, appropriate ditching and decommissioning of canals[106]. Although there is no proven rule that organic and other less intensive forms of farming will always reduce flood risk, in general terms less intensive farms have fewer of the factors which support faster run off. The few UK studies and those from abroad support the view that less intensive farming leads to reduced flood risk due to greater presence of the features above and healthier soil[107].

The Forestry Commission[108] has commissioned projects in the Lake District National Park and Yorkshire and the Humber region, which have sought to identify areas where woodland establishment has the greatest potential to reduce flooding. The output maps identify priority areas for three types of woodland that can contribute to flood management: Riparian planting in the upper catchment; wider catchment planting, in particular in areas of high risk soils; and floodplain woodland.

There is limited evidence about whether peatland habitats attenuate or exacerbate downstream flooding. There is evidence that restoration of degraded peatlands can reduce stream peakflow and hence may reduce downstream flood risk at relatively small spatial and temporal scales, but more research is needed to provide evidence about the effect of restoration in the longer term and at a landscape scale. Although there is evidence that restoration of peatland habitats via **grip and gully blocking reduces stream peakflow** and hence may reduce downstream flood risk[109], this effect is short-lived, and once the capacity of the soil to store water has been reached (e.g. following a heavy storm), restoration has little effect on flood risk[110].

Overall, however, the key issue in relation to dealing with large floods is the extent to which water from tributaries arrives at the vulnerable site at the same time, meaning that action which reduces local flooding could make a larger flood event worse[111]. This means that some areas which shed water rapidly may be necessary to ensure flood waters reach the critical region out of phase. This is part of the reason why, although local effects are well understood, there are currently no clear evidenced connections between local land management changes

[104] Robinson, M. and Dupeyrat, A. (2003). Effects of commercial forest felling on streamflow regimes at Plynlimon, mid-Wales. Hydrological Processes, 19: 1213-1226; Robinson, M., Cognard-Plancq, A.L., Cosandey, C., David, J., Durand, P., Fuhrer, H.W., Hall, R., Hendriques, M.O., Marc, V., McCarthy, R., McDonnell, M., Martin, C., Nisbet, T., O'Dea, P., Rodgers, M. and Zollner, A. (2003). Studies of the impact of forests on peak flows and baseflows: a European perspective. Forest Ecology and Management, 186: 85-97; Food and Agriculture Organisation (FAO). (2005). Forests and floods: Drowning in fiction or thriving on facts? RAP Publication 2005/03. FAO and CIFOR, Indonesia; and Calder, I.R. and Aylward, B. (2006). Forests and floods: Moving to an evidence-based approach to watershed and integrated flood management. Water International, 31: 541- 543.

[105] Cornish, P.M. (1993). The effects of logging and forest regeneration on water yields in a moist eucalypt forest in New South Wales, Australia. Journal of Hydrology, 150: 301- 322.

[106] O'Connell, P. E., Beven, K. J., Carney, J. N., Clements, R. O., Ewen, J., Fowler, H., Harris G. L, Hollis, J., Morris, J., O'Donell, G. M., Packman, J. C, Parkin, A., Quinn, P. F., Rose, S. C., Shepherd, M. & Telliers, S.(2005). Review of impacts of rural land use and management on flood generation Impact study report. Defra.

[107] Ibid.

[108] http://www.forestry.gov.uk/fr/INFD-7T9JRD (last accessed 19/06/2013)

[109] United Utilities (2010) SCaMP Sustainable Catchment Management Programme. Monitoring Progress Report Year 4. Penny Anderson Associates Ltd [online] available at: http://www.unitedutilities.com/SCaMPdatalibrary.aspx (last accessed 08/12/ 2010).

[110] Evans, M.G., Burt, T.P., Holden, J. and Adamson, J.K. (1999). Runoff generation and water table fluctuations in blanket peat: evidence from UK data spanning the dry summer of 1995. *Journal of Hydrology* 221: 141-160; Holden, J. and Burt, T.P. (2003). Runoff production in blanket peat covered catchments. *Water Resources Research* 39(7): 1191. O'Brien, H.E, Labadz, J.C. and Butcher, D.P. (2007). Review of management and restoration options for blanket bog. . DEFRA project BD1241.

[111] O'Connell, P. E., Beven, K. J., Carney, J. N., Clements, R. O., Ewen, J., Fowler, H., Harris G. L, Hollis, J., Morris, J., O'Donell, G. M., Packman, J. C, Parkin, A., Quinn, P. F., Rose, S. C., Shepherd, M. & Telliers, S.(2005). Review of impacts of rural land use and management on flood generation Impact study report. Defra.

and large flood events. However, as noted by Sunderland (2012)[112], the scarcity of evidence in this area may be due to the inherent difficulties in this research challenge and the little amount of research which has been done at the appropriate scale. Whilst flood risk modelling is highly developed for existing catchments O'Connell et al. (2005) do not consider any of the current attempts to model effects of land management robust enough for policy-making. An Environment Agency whole catchment modelling project for the river Parret in Somerset concluded that, although other measures could be beneficial, major rainstorm events would require significant detention of water at upstream locations[113]. This would require new infrastructure which could be green, grey or a mixture, but positive impact on flood risk would require a catchment wide approach.

In urban areas, Sustainable Drainage Systems (SuDS) have proved effective mechanisms for managing rainfall in a way that mimic natural systems natural processes by catching and slowing the flow of rain water to streams and rivers, and filtering it to remove pollution along the way. Examples of SuDS include interconnected ponds, reedbeds and living green walls and roofs (see Box 1).

Box 1: Sustainable Drainage Systems

SuDS (or Sustainable Drainage Systems) are an approach to managing rainfall in development that replicates natural drainage, managing it close to where it falls. SuDS have been defined as: "a sequence of management practices and control structures designed to drain surface water in a sustainable way".

SuDS can be designed to slow water down (attenuate) before it enters streams, rivers and other watercourses; they provide areas to store water in natural contours and can be used to allow water to infiltrate into the ground, evaporate from surface water or provide opportunities for evapotranspiration from vegetation and surface water. They may also encourage natural groundwater/aquifer recharge.

SuDS are technically regarded a sequence of management practices, control structures and strategies designed to efficiently and sustainably drain surface water, while minimising pollution and managing the impact on water quality of local water bodies.

SuDS have been known to deliver:

- Improvements in the water supply/demand balance
- Reduction in water pollution from urban run-off
- Provision of environmental amenity

SuDS may encompass a range of structures or practices, including:

Permeable pavements	Filter strips
Green roofs	Detention basins
Infiltration basins and trenches	Retention ponds
Rainwater harvesting	Ponds
Soakaways	Wetlands
Swales	

Sources:

http://www.susdrain.org/
National SuDS Working Group (2004) Interim Code of Practice for Sustainable Drainage Systems [online] available at *http://www.environment-agency.gov.uk/static/documents/Business/icop_final_0704_872183.pdf*

[112] Sunderland, T. (2012(. Microeconomic Evidence for the Benefits of Investment in the Environment - review. Natural England Research Reports, Number 033.
[113] Park, J. & Cluckie, I. 2006. Whole catchment modelling project. Technical Report to the Environment Agency; cited in Sunderland, T. (2012(. Microeconomic Evidence for the Benefits of Investment in the Environment - review. Natural England Research Reports, Number 033.

Table 16 provides a summary of the range of natural environment solutions for managing flood risk across all habitat types together with the specific ecosystem services that they support. Where possible, links to relevant case studies that illustrate how the measures have been applied in practice are also provided.

Table 16: Natural environment solutions for managing flood risk

Natural environment solutions	Habitats to which apply	Ecosystem services provided	Illustrative case studies	Links to further information
Develop local storage solutions (e.g. rainwater harvesting, small on-farm dams, ponds, etc)	Agriculture and grasslands	**Hazard regulation (flood risk);** water supply	-	-
Restoration of natural flows, floodplains and wetlands	Agriculture and grasslands Woodlands Mountains, moorland and heathland Urban	**Hazard regulation (flood risk)**; soil quality; water quality; wild species diversity	Mayesbrook Park River	*Thames Rivers Restoration Trust (n.d.) Restoration For All [online]: http://www.trrt.org.uk/index.aspx?articleid=15955*
			Quaggy Greenwich	*Quaggy Waterways Action Group (2011) The River Quaggy Flood Alleviation Scheme (online): http://www.qwag.org.uk/quaggy/flood.php*
			East London Green Grids	*Mayor of London (2008) East London Green Grid Framework (online): http://www.london.gov.uk/thelondonplan/guides/spg/spg_09.jsp*
Restoration of upland areas (mires) through grip and gully blocking	Mountains, moorland and heathland	**Hazard regulation (flood risk)**; carbon storage; water quality; wild species diversity	Dartmoor and Exmoor Mires Projects	http://www.dartmoor-npa.gov.uk/lookingafter/laf-naturalenv/dartmoormiresproject http://www.montwt.co.uk/pumlumon.html
Revegetation of bare peat to increase surface roughness, interception and infiltration	Mountains, moorland and heathland	**Hazard regulation (flood risk)**; carbon sequestration	The Pumlumon Project	http://www.montwt.co.uk/pumlumon.html

Natural environment solutions	Habitats to which apply	Ecosystem services provided	Illustrative case studies	Links to further information
Improve soil husbandry and increase organic content of soils to improve soil structure and water storage capacity	Agriculture Woodlands	**Hazard regulation (flood risk)**; soil quality	CRP united States	United States Department of Agriculture (2013) Conservation Programs (online): https://www.fsa.usda.gov/FSA/webapp?area=home&subject=copr&topic=crp
Woodland and scrubland planting beside water courses to increase roughness of habitats, slow peak flows and increase flood storage	Agriculture and grasslands Mountains, moorland and heathland	**Hazard regulation (flood risk)**; carbon sequestration; wild species diversity	Bush Tender Australia	Department of Sustainability and Environment (2008). *BushTender: Rethinking Investment for native vegetation outcomes. The application of auctions for securing private land management agreements* (online) available here.
			CRP United States	United States Department of Agriculture (2013) Conservation Programs (online): https://www.fsa.usda.gov/FSA/webapp?area=home&subject=copr&topic=crp
			EWGS England	Forestry Commission (2013) English Woodland Grant Scheme (online): http://www.forestry.gov.uk/ewgs
Increase woodland cover and connectivity of existing woodland	Woodlands	**Hazard regulation (flood risk)**; fuelwood; wild species diversity; carbon sequestration; air quality; soil quality, recreation / amenity	Woodland Carbon Code	Forestry Commission (2013) Woodland Carbon Code (online): http://www.forestry.gov.uk/carboncode
Creation of low-level flood storage bunds (e.g. large woody debris dams)	Woodlands	**Hazard regulation (flood risk)**	Slowing the flow at Pickering	Reports and papers on the ‘Slowing the Flow at Pickering’ WebPages of the Forestry Commission website (online) availabel here.

Natural environment solutions	Habitats to which apply	Ecosystem services provided	Illustrative case studies	Links to further information
Incorporate sustainable drainage systems (SuDS), including parks, permeable car parks, green roofs and walls, ponds	Urban	**Hazard regulation (flood risk)**; water quality; carbon sequestration, air quality, wild species diversity; recreation / amenity	Upton SuDS	http://www.microdrainage.co.uk/assets/documents/upton_rev1.pdf
			Sustainable Drainage Systems Cambridge	https://www.cambridge.gov.uk/sustainable-drainage-systems
			SUDs Augustenborg	Kazmierczak, A. and Carter, J. (2010) Adaptation to climate change using green and blue infrastructure.(online) http://www.grabs-eu.org/membersArea/files/malmo.pdf
			Green Streets Manchester	http://www.redroseforest.co.uk/web/content/view/43/143/
			Plymouth Green Infrastructure Project	http://www.plymouth.gov.uk/greeninfrastructureproject
			Green roofs Basel	Kazmierczak, A. and Carter, J. (2010) Adaptation to climate change using green and blue infrastructure. A database of case studies (online) http://www.grabs-eu.org/membersArea/files/basel.pdf
			'Ahead of the Storm' Toronto	http://www.toronto.ca/teo/pdf/ahead_of_the_storm.pdf

4.2.2 *Options for managing erosion*

As identified in section 3.4, the natural environment plays an important role in storing and distributing freshwater. In so far as the natural environment plays this role, it also contributes to the reduction of water-based erosion that may arise as a result of flooding and generally wetter winters that are predicted under climate change scenarios. The natural environment can also contribute to the reduction of wind-based erosion, which may arise as a result of reduced groundcover during hotter, drier summers.

The Entry Level Stewardship Programme provides examples of how natural environment solutions can be incorporated within farming practices to reduce the risk of erosion. [114] Key practices include:

- grassing field corners to slow down overland flow of water or where runoff collects and makes it difficult to farm;
- grassing natural drainage pathways (e.g. valley bottoms) to reduce the channelling of runoff water that can produce rills and gullies;
- fencing watercourses to prevent livestock from causing direct contamination and erosion of river banks; and
- establishing buffer strips to slow, filter and trap pollutants before they enter ditches or watercourses.

Woodlands also provide a natural environment solution that can reduce soil erosion. Programmes such as the: Sediment Study (Lake District); English Woodland Grant Scheme (EWGS); Environmental Stewardship; and the Woodland Carbon Code demonstrate the benefits that woodlands can provide in relation to soil erosion services.

In an urban setting, natural environment solutions can also be used to reduce erosion. The following solutions contribute to reducing erosion, through the provision of vegetation that binds soil and intercepts surface water flows:

- parks;
- green car parks; and
- urban tree plantings.

Programmes such as Green Streets Manchester[115]; Plymouth Green Infrastructure Project[116]; Cambridgeshire Green Infrastructure Strategy[117]; Stafford Master Plan; and Vegetation for Landslide Prevention, Seattle[118] provide case studies in the adoption of these solutions.

Table 17 provides a summary of the range of natural environment solutions to managing erosion risk across all habitat types together with the specific ecosystem services that they support. Where possible, links to relevant case studies that illustrate how the measures have been applied in practice are also provided.

[114] Farming for cleaner water and healthier soil: Making the most of Environmental Stewardship and the Campaign for the Farmed Environment. Available at: http://publications.naturalengland.org.uk/publication/36016?category=45001
[115] What is the Green Streets project? Available at: http://www.redroseforest.co.uk/web/content/view/43/143/
[116] Plymouth Green Infrastructure Project. Available at: http://www.plymouth.gov.uk/greeninfrastructureproject
[117] Cambridgeshire Green Infrastructure Strategy. Available at: http://www.cambridgeshire.gov.uk
[118] Seattle: Using vegetation to limit the hazard of landslides. Available at: http://www.grabs-eu.org/membersArea/files/seattle.pdf

Table 17: Natural environment solutions for reducing the risk of erosion

Natural environment solutions	Habitats to which apply	Ecosystem services provided	Illustrative case studies	Links to further information
Improve soil husbandry and increase organic content of soils to improve soil structure and water storage capacity	Enclosed farmland Woodlands	**Hazard regulation** (**erosion control**; flood control); soil quality	CRP united States	United States Department of Agriculture (2013) Conservation Programs (online): https://www.fsa.usda.gov/FSA/webapp?area=home&subject=copr&topic=crp
			ELS England	http://www.naturalengland.gov.uk/ourwork/farming/funding/es/els/default.aspx
			Nurture Lakeland	http://www.nurturelakeland.org/
Planting shelterbelt to help prevent damage to crops and reduce soil erosion by wind	Enclosed farmland, semi-natural grasslands	**Hazard regulation (erosion control**); soil quality, crops, water quality, local climate regulation, wild species diversity		Shelter woods to prevent wind erosion: http://publications.naturalengland.org.uk/publication/33003
Increase tree cover, including field and hedgerow trees, copses and buffer strips beside water courses	Woodlands	**Hazard regulation (erosion control**; flood control); fuelwood; wild species diversity; carbon sequestration; air quality; soil quality, recreation / amenity	Woodland Carbon Code	Forestry Commission (2013) Woodland Carbon Code (online): http://www.forestry.gov.uk/carboncode
			Upstream Thinking	http://www.wrt.org.uk/projects/upstreamthinking/upstreamthinking.html
Protect, restore, and maintain existing destinations by encouraging sustainable transport, managing footpaths, protecting iconic species, and improving water quality		Tourism and recreation; soil quality regulation; **erosion control**; cultural and spiritual values; wild species diversity; water quality regulation	Nurture Lakeland Lake District	http://www.nurturelakeland.org/
			Plymouth Green Infrastructure Project	http://www.plymouth.gov.uk/greeninfrastructureproject

Natural environment solutions	Habitats to which apply	Ecosystem services provided	Illustrative case studies	Links to further information
Advise and encourage land managers (particularly farmers) to adopt management practices that support biodiversity	Enclosed Farmland; Mountains, moorlands and heath; Woodlands	Tourism and recreation; soil quality regulation; **erosion control**; cultural and spiritual values; wild species diversity; water quality regulation	Rainham Marshes	http://www.rspb.org.uk/community/placestovisit/rainhammarshes/b/rainhammarshes-blog/default.aspx
			Thames Basin Heaths	http://www.surreyheath.gov.uk/planning/planningpolicyandconservation/ThamesBasinSPA.htm
			Bush Tender Australia	Department of Sustainability and Environment (2008). *BushTender: Rethinking Investment for native vegetation outcomes. The application of auctions for securing private land management agreements* (online) available here.
			CRP United States	United States Department of Agriculture (2013) Conservation Programs (online): https://www.fsa.usda.gov/FSA/webapp?area=home&subject=copr&topic=crp
Restore and preserve degraded peatlands by restoring blanket bogs by blocking drainage ditches, restoring areas of eroded and exposed peat	Mountains, moorland and heathland	Hazard regulation (**erosion control**); carbon storage; water quality; wild species diversity	SCaMP	*http://www.hydrology.org.uk/Publications/durham/bhs_14.pdf*
			Dartmoor and Exmoor Mires Projects	http://www.dartmoor-npa.gov.uk/lookingafter/laf-naturalenv/dartmoormiresproject
			The Pumlumon Project	http://www.montwt.co.uk/pumlumon.html

4.2.3 *Options for reducing the effects of coastal flooding and erosion associated with sea-level rise and storm surges*

Salt marshes act as an important natural form of sea defence, dissipating wave energy before it reaches the sea wall or other infrastructure/high ground behind it. Seawall defences protected by fronting coastal habitats tend to require lower capital and maintenance costs, thanks to the buffering role that coastal habitats can play. For instance, research suggests that, due to wave height reduction, seawalls which are fronted by vegetated saltmarshes can be significantly lower than those fronted by un-vegetated tidal flats[119]. However, the NEA notes that significant areas of saltmarsh have been lost due to agricultural improvement and forestry, as well as land-claim, while rapid coastal development for industry, housing, military activities and tourism has affected all habitats. The quality of these habitats has been impacted by widespread installation of artificial sea-defence structures and increased armouring of soft cliffs, which reduces sediment supply and natural dynamics, crucial to contributing to

[119] Moller, I. (2006). Quantifying saltmarsh vegetation and its effect on wave height dissipation: Results from a UK East coast saltmarsh. Estuarine, Coastal and Shelf Science, 69, 337-351.

protection elsewhere. Furthermore, reductions in traditional forms of management, such as grazing of embankments, have led to the risk of increased erosion and potential flooding.

In the costal context, natural environment solutions include:

- allowing natural coast development;
- re-aligning coastal flood defences to restore inter-tidal coastal habitats (e.g. mudflats, saltmarsh, floodplains and dunes) and creating a new line of defence (if required) which could be cheaper to build and maintain; and
- incorporating natural transition zones between coastal and terrestrial habitats.

Over 50 intertidal and coastal habitat creation schemes have been implemented in the UK over the past two decades; case examples include the Hesketh Out Marsh managed realignment (Ribble Estuary, Lancashire) and four managed realignments in the Blackwater Estuary in Essex[120]. In the United States, the Common Ground Relief Wetland Restoration programme in New Orleans is also noteworthy (see Table 16). Box 2 contains information about additional programmes - the Wallasea Island and Alkborough Flats managed realignment schemes – that demonstrate the role of natural environment solutions in coastal margins.

Box 2: Enhancement of ecosystem services in coastal margins through managed realignment

Managed realignment is an actively controlled process which includes defence retreat to higher ground, moving defences inland, widening flood plains or other types of shortening or lowering defences, and in the process creates space for new intertidal habitats, including tidal mudflats and saltmarshes that provide a number of ecosystem services including coastal protection and flood defence. These areas also provide productive habitats for plants, invertebrates and molluscs, and they are also important fish nursery and spawning areas[121], as well as feeding, breeding and roosting areas for birds.

Wallasea Island (Allfleet's Marsh and RSPB Wallasea Island Wild Coast project)

In 2006, a managed realignment was undertaken at Allfleet's Marsh on the north bank of Wallasea Island (at the confluence the Crouch and Roach Estuaries near to Rochford in Essex) by Defra. This compensatory scheme was relatively large and covered 115ha, creating mostly mudflats but also some 20ha of saltmarsh. In 2009, the RSPB purchased the majority of the remainder of Wallasea Island to implement a coastal habitat restoration project of a scale that has not been seen before in the UK or, indeed, Europe. This project has been termed the 'Wallasea Island Wild Coast Project, and will involve the 'managed realignment' of the island's coastal defences. When complete, it will be managed alongside the adjacent Allfleet's Marsh so that the restored area of marshes and mudflats on this site will cover 783ha. This equates to an area of over 1,300 football pitches. However, it is not only its spatial extent that makes it unique. The scheme also involves the first ever use of terrestrial sediments to raise a whole island's ground levels and reshape its landscape back to the conditions that existed prior to it being claimed from the sea several hundred years ago. Given the condition of its seawalls, and with its current land levels, there is an increasing risk that tides will not only break through its seawalls but would do so in such a large volume that it would cause significant, and potentially irreversible, increases to the flow speeds in the adjacent Roach Estuary. This would then have an adverse effect on flood protection, recreation and commercial activities in the estuary. Such effects will be avoided by the Wild Coast project which, by raising ground by up to 4m and sensitively re-shaping it, will reduce the future volumes of water exchanged with the estuary. This project will also result in major biodiversity gains, enhance fisheries and offset losses of marshes and mudflats in other areas (from sea level rise). It will also provide extensive public access, improve

[120] ABPmer's Online Managed Realignment Guide: http://www.abpmer.net
[121] Colclough, S., Fonseca, L., Astley, T., Thomas, K. & Watts, W. (2005). Fish Utilisation of Managed Realignments. Fisheries Management and Ecology, 12, 351 – 360.

public understanding of the coastal environment, increase community engagement with this part of the coastline and will inspire decision makers to plan for predicted future sea level rise. As it will promote sedimentation, the intertidal habitats will be able to keep pace with future sea level rise and sequester both carbon and contaminants in the process.

Source: http://www.rspb.org.uk/reserves/guide/w/wallaseaisland; http://www.abpmer.net/omreg/case_studies.aspx

Alkborough Flats Managed Realignment Scheme

The Alkborough Flats site, located on the south bank of the inner Humber Estuary at the confluence of the River Ouse and the River Trent, is the location of a coastal setback scheme in the Humber Estuary. It is one of the largest managed realignment sites and also one of the largest flood storage schemes in Europe. The scheme was designed to deliver flood risk management and biodiversity benefits as well as social and economic benefits to the local community while maintaining the viability of local farms affected by the change of land use and the navigability of the Humber Estuary. It constitutes part of a wider Humber Estuary Strategy that aims to protect the homes and businesses of over 400,000 people. Allowing the Alkborough Flats to flood helps to safeguard land throughout the Humber Trade Zone by reducing high water levels elsewhere within the Humber Estuary and its tidal tributaries. At the same time, the Alkborough Flats scheme has direct longer-term wildlife conservation benefits through 370ha of re-created intertidal habitat, but also indirectly as it allows the wider estuary to change and adapt to sea level rise. The scheme is a partnership between the Environment Agency, Natural England, Associated British Ports (ABP) and North Lincolnshire Council.

An ecosystem services evaluation of the scheme (Everard, 2009) has shown a net positive impact on ecosystem services. The loss of area suitable for food production was more than offset by the gains due to fibre and fuel production, regulating and cultural services (with 'natural hazard regulation' accounting for a large proportion of the estimated overall gross benefit value of some £28 million over 25years).

Sources: http://www.alkboroughandwalcot.co.uk/index_files/FlatsProject1.htm; http://www.rspb.org.uk/ourwork/conservation/sites/england/alkborough.aspx; Everard, M. (2009). Ecosystem services case studies. Environment Agency: Bristol [online] available at: http://publications.environment-agency.gov.uk/pdf/SCHO0409BPVM-E-E.pdf (accessed 17/07/2011).

Table 18 provides a summary of the range of natural environment solutions to managing the risks associated with sea level rise and storm surges together with the specific ecosystem services that they support. Where possible, links to relevant case studies that illustrate how the measures have been applied in practice are also provided.

Table 18: Natural environment solutions for managing coastal flooding and erosion risk associated with sea level rise and storm surges

Natural environment solutions	Habitats to which apply	Ecosystem services provided	Illustrative case studies	Links to further information
Allow natural coast development and implement realignment of	Coastal margins	Crops, Livestock & fodder, Capture fisheries; Freshwater (supply), global	Alkborough Flats Managed Realignment Scheme	http://www.alkboroughandwalcot.co.uk/index_files/FlatsProject1.htm

Natural environment solutions	Habitats to which apply	Ecosystem services provided	Illustrative case studies	Links to further information
coastal flood defences to restore inter-tidal coastal habitats (salt marsh, floodplains, and dunes) and natural transition zones between coastal and terrestrial habitats		climate regulation; hazard regulation, **flood protection**; groundwater recharge; erosion regulation; water quality; tourism and recreation; wild species diversity	Wallasea Island (Allfleet's Marsh and Wild Coast Projects)	*http://www.rspb.org.uk/reserves/guide/w/wallaseaisland*; http://www.abpmer.net/omreg/case_studies.aspx
			Hesketh Out Marsh	http://www.rspb.org.uk/reserves/guide/h/heskethoutmarsh/
			Blackwater Estuary realignments (including Abbott's Hall)	http://www.wildlifetrusts.org/living-landscape/living-landscape/schemes/blackwater-estuary
			Wetland restoration New Orleans	http://www.commongroundrelief.org/wetlands

4.2.4 *Options for reducing the risk of water scarcity during dry spells / drought*

Climate change projections suggest that the incidence of droughts could increase in the future. Natural environment solutions can be used to reduce the impacts of such events through, for example:

- on-farm water storage through rain water harvesting and the creation of on-farm dams and ponds;
- introduction of new (drought tolerant) tree species to increase resilience through diversification (e.g. plant seeds of southern tree species in northern woodlands);
- restoring and preserving degraded peatlands, which can, in turn, restore the water table and thereby secure water supply during droughts; and
- Sustainable Drainage Systems (SuDS) in built-up areas may contribute towards recharging groundwater to prevent drought. (see Box 1)

Such measures can be used to capture and retain surface water runoff, which can then be used to improve resilience of such spaces during times of drought. Developments such Chavasse Park in Liverpool[122], have implemented SuDS to help manage surface water. Layers of clay that are capable of retaining and slowly discharging water, have been overtopped with subsoil and manufactured topsoil and placed above the substrate to help prevent flooding of the car park beneath the Park while specially constructed cells and a water harvesting tank retain water onsite to irrigate the park in periods of drought (when evapotranspiration is reduced) so it can continue to cool the city air.

For biodiversity, particularly in the context of wildlife, increasing incidence of drought can mean that food sources become unavailable, forcing wildlife to travel further in search of alternatives sources. Natural environment solutions such as creating connected ecological network by managing linear corridors and landscape restoration activities, can be used to

[122] Chavasse Park, Liverpool. Available at: http://www.greeninfrastructurenw.co.uk/climatechange/doc.php?docID=150

facilitate movement between habitats. The Character Area Climate Change Project, which includes the Cumbria High Fells, is an example of projects that, through habitat restoration, are aiming to improve the adaptation potential of local biodiversity.

Table 19 provides a summary of the range of natural environment solutions to managing the risks associated with prolonged dry spells together with the specific ecosystem services that they support. Where possible, links to relevant case studies that illustrate how the measures have been applied in practice are also provided.

Table 19: Natural environment solutions for managing the risks associated with prolonged dry spells / drought

Natural environment solutions	Habitats to which apply	Ecosystem services provided	Illustrative case studies	Links to further information
Reduce abstractions from surface waters to restore environmental flows	Freshwater Enclosed Farmland	**Water supply**; wild species diversity; recreation and tourism; food and fibre	Murray Darling Basin Plan Australia	Murray Darling Basin Authority (2013) Basin Plan (online): http://www.mdba.gov.au/what-we-do/basin-plan
			BEF water certificates	BEF (2013) Water Restoration Certificates (online): http://www.b-e-f.org/our-solutions/water/water-restoration-certificates/why-wrcs/
Restoring and preserving degraded peatlands, which can, in turn, restore the water table and thereby secure water supply during droughts	Mountain, moorlands and heath	Carbon storage and sequestration; wild species diversity; **water supply**; water quality; flood risk regulation; soil quality	SCaMP England	*http://www.hydrology.org.uk/Publications/durham/bhs_14.pdf*
			Pumlumon project Wales	http://www.montwt.co.uk/pumlumon.html
Sustainable Drainage Systems (SuDS) in built-up areas may contribute towards recharging groundwater to prevent drought	Urban	Freshwater (**water supply**); flood protection	Upton SuDS	http://www.microdrainage.co.uk/assets/documents/upton_rev1.pdf
			Sustainable Drainage Systems Cambridge	https://www.cambridge.gov.uk/sustainable-drainage-systems
			SUDs Augustenborg	Kazmierczak, A. and Carter, J. (2010) Adaptation to climate change using green and blue infrastructure (online): http://www.grabs-eu.org/membersArea/files/malmo.pdf

Natural environment solutions	Habitats to which apply	Ecosystem services provided	Illustrative case studies	Links to further information
Develop local storage solutions (e.g. rainwater harvesting, small on-farm dams, ponds, water harvesting tanks)	Enclosed farmland, semi-natural grasslands and urban	Hazard regulation (flood risk); **water supply** (during dry spells); local climate regulation (urban cooling)	Chavasse Park, Liverpool	http://www.greeninfrastructurenw.co.uk/climatechange/doc.php?docID=150
Introduction of new (drought tolerant) tree species to increase resilience through diversification (e.g. plant seeds of southern tree species in northern woodlands)	Woodlands Urban	Timber; wild species diversity; freshwater (**water supply**)	-	-

4.2.5 *Options for reducing the effects of high temperatures and heatwaves*

The natural environment makes a number of important contributions to local climate regulation. Trees and woodlands generate a **cooling** effect, which can reduce local temperatures by 3-4˚C.[123] **Shading** of rivers streams and other water bodies by trees can deliver similar cooling, with beneficial effects for fisheries and wildlife, and street trees can have a similar effect in urban areas.[124] Increasing temperatures will increase the shade and shelter value of trees in towns[125], and also for livestock in the country. A study in Greater Manchester[126], for example, highlights the role of green infrastructure in:

- the provision of cooler microclimates and reducing surface water run-off; and
- providing shade to water surfaces to reduce evaporation during periods of drought and high temperature.

A literature review by Natural England on the Microeconomic Evidence for the Benefits of Investment in the Environment[127] found that:

[123] Morecroft, M.D., Taylor, M.E. and Oliver, H.R. (1998). Air and soil microclimates of deciduous woodland compared to an open site. *Agricultural and Forest Meteorology*, 90: 141 - 156.
[124] Handley, J. and Gill (2009) Combating climate change - a role for UK forests. An assessment of the potential of UK's trees and woodlands to mitigate and adapt to climate change. In Read, D.J., Freer- Smith, P.H., Morison, J.I.L., Hanley, N., West, C.C. and Snowdon, P. (eds.) (2009) *Combating climate change – a role for UK forests. An assessment of the potential of the UK's trees and woodlands to mitigate and adapt to climate change. The synthesis report*. The Stationery Office, Edinburgh.
[125] Handley, J.F. & Gill, S.E. (2009) Woodlands helping society to adapt. Combating climate change—a role for UK forests (eds D.J. Read, P.H. Freer-Smith, J.I.L. Morison, N. Hanley, C.C. West & P.R. Snowdon), pp. 180–195. The Stationery Office, Edinburgh.
[126] Gill, S., Handley, J., Ennos, A., and Pauleit, S. (2007) Adapting Cities for Climate Change: The Role of The Green Infrastructure. Built Environment, Vol 3, No 1, pages 115-133 [online] available at http://www.fs.fed.us/ccrc/topics/urban-forests/docs/Gill_Adapting_Cities.pdf (last accessed 6/01/2012).
[127] Sunderland, T. (2012). Microeconomic Evidence for the Benefits of Investment in the Environment - review. Natural England Research Reports, Number 033.

- wet areas can help to balance temperature deviations[128]. A single large tree can transpire 450 litres of water in a day, which uses 1,000 Mega Joules of heat energy, making urban trees an effective way to reduce urban temperature[129];

- urban parks are on average 1 degree cooler than built up areas during the day[130], but the type of park does matter - parks with hard paved surfaces and few trees or shrubs can be hotter[131]. Green roofs act as effective insulators[132], reducing the requirement for air-conditioning;

- although in principle vegetative shading could reduce the risk from diseases caused by UV radiation, there is little published evidence of the benefits of vegetation in this context[133]; and

- rising temperature in rural areas may also threaten valuable biodiversity, such as salmon and trout. An experiment in the New Forest found that river shading from new trees prevented water temperature from reaching the lethal limit for brown trout[134].

Table 20 provides a summary of the range of natural environment solutions to managing the risks associated with higher temperatures and heatwaves together with the specific ecosystem services that they support. Where possible, links to relevant case studies that illustrate how the measures have been applied in practice are also provided.

Table 20: Natural environment solutions for managing the risks associated with higher temperatures and heatwaves

Natural environment solutions	Habitats to which apply	Ecosystem services provided	Illustrative case studies	Links to further information
Increase urban green infrastructure including parks, green car parks, urban trees, green roofs and	Urban	**Local climate regulation**; Hazard regulation (flood risk); carbon sequestration;	Green Streets Manchester	http://www.redroseforest.co.uk/web/content/view/43/143/
			Plymouth Green Infrastructure Project	http://www.plymouth.gov.uk/greeninfrastructureproject

[128] Bolund, P. and Hunhammar, S. (1999) Ecosystem services in urban areas. Ecological Economics, 29, 293-301
[129] Ibid.
[130] Bowler, D., Buyung-Ali, L., Knight, T. & Pullin, A.S. (2010). How effective is 'greening' of urban areas in reducing human exposure to ground level ozone concentrations, UV exposure and the 'urban heat island effect'? Collaboration for Environmental Evidence, Bangor: Bangor University
[131] Chang, C.R., Li, M.H. & Chang, S.D. (2007). A preliminary study on the local cool-island intensity of Taipei city parks. Landscape and Urban Planning, 80, 386-395.
[132] Kumar, R. & Kaushik, S.C. (2005). Performance evaluation of green roof and shading for thermal protection of buildings. Building and Environment, 40, 1505-1511.
[133] Bowler, D., Buyung-Ali, L., Knight, T. & Pullin, A.S. (2010). How effective is 'greening' of urban areas in reducing human exposure to ground level ozone concentrations, UV exposure and the 'urban heat island effect'? Collaboration for Environmental Evidence, Bangor: Bangor University
[134] Nisbet, T., Silgram, M., Shah, N., Morrow, K., and Broadmeadow, S. (2011) Woodland for Water: Woodland measures for meeting Water Framework Directive objectives. Forest Research Monograph, 4, Forest Research, Surrey, 156pp [online] available at http://www.forestry.gov.uk/pdf/FRMG004_Woodland4Water.pdf/$file/FRMG004_Woodland4Water.pdf

Natural environment solutions	Habitats to which apply	Ecosystem services provided	Illustrative case studies	Links to further information
walls, high albedo roof and road surfaces, and green aeration corridors. Design in conjunction with mapping of wind directions and air flows		air quality; wild species diversity	Green roofs Basel	Kazmierczak, A. and Carter, J. (2010) Adaptation to climate change using green and blue infrastructure. A database of case studies (online) http://www.grabs-eu.org/membersArea/files/basel.pdf
			'Ahead of the Storm' Toronto	http://www.toronto.ca/teo/pdf/ahead_of_the_storm.pdf
Plant field and hedgerow trees, copses, woodland, and buffer strips besides water courses	Enclosed farmland; semi-natural grassland; woodland	**Local climate regulation**; wild species diversity; flood risk regulation;	EWGS	Forestry Commission (2013) English Woodland Grant Scheme (online): http://www.forestry.gov.uk/ewgs
Create green transport network for cycling and walking e.g. tree lined streets, linked green spaces, suitable signposts, leaflets, cycling routes etc.	Urban	**Local climate regulation**; wild species diversity; flood risk regulation;	East London Green Grid	*Mayor of London (2008) East London Green Grid Framework (online): http://www.london.gov.uk/thelondonplan/guides/spg/spg_09.jsp*
			Plymouth Green Infrastructure Project	http://www.plymouth.gov.uk/greeninfrastructureproject
			Green Net Graz Austria	GRaBS green and blue infrastructure exemplars from the city of Graz (online): http://www.grabs-eu.org/downloads/Expert_Paper_Green_and_Blue_Infrastructure_Exemplars_CityofGraz_FINAL_VERSION.pdf

4.2.6 *Options for reducing the effects of climate change on water quality*

Climate change is expected to lead to increased use of pesticides[135]. Furthermore, while nutrient inputs may decrease, increased temperature, reduced summer rainfall, and increased winter rainfall and the increased use of irrigation may increase the transmission of pesticides, leading to reduced water quality[136]. Climate change may also reduce soil organic content[137],

[135] Boxall, A., Hardy, A., Beulke, S., Boucard, T., Burgin, L., Falloon, P., Haygarth, P., Hutchinson, T., Kovats, S. & Leonardi, G. 2010. Impacts of climate change on indirect human exposure to pathogens and chemicals from agriculture. Ciência & Saúde Coletiva, 15, 743-756

[136] *Ibid.*

[137] Jenkinson, DS, Adams, DE & Wild, A. 1991. Model estimates of CO_2 emissions from soil in response to global warming. Nature, 351, 304-306.

which would exacerbate problems of polluted runoff. Without mitigating action this would increase human exposure to agricultural contaminants[138].

There is strong evidence to support woodland creation, in appropriate locations, to achieve water management and water quality objectives. **Woodlands contribute to tackling diffuse pollution** through acting as a barrier and intercepting pollutants before they reach water courses. They help to **trap and retain nutrients and sediment in polluted runoff**[139]. Targeted woodland buffers along mid-slope or down-slope field edges, or on infiltration basins, appear effective for slowing down runoff and intercepting sediment and nutrients, but the evidence base is limited[140]. Wider targeted woodland planting in the landscape can reduce fertiliser and pesticide loss into water, as well as protecting the soil from regular disturbance and so reduce the risk of sediment delivery to watercourses.

In urban areas, **green roofs and forests are effective at limiting the diffuse pollution load entering urban drains** during small storm events by intercepting rain water and reducing peak run-off[141]. Sustainable Drainage Systems (SuDS), such as detention pools, can also be an effective method of removing pollutants from water and do not collect levels of pollutants which would require notified disposal[142].

Box 3: Case studies illustrating the role of natural environment solutions in achieving water quality management objectives

Sustainable Catchment Management Programme (SCaMP)

United Utilities (UU) supplies water to around 7 million people in the North West of England, a large proportion of which comes from upland surface water sources. UU is a major landowner in the north west of England, with 56,000 ha of catchment land, historically acquired to provide a degree of control in protecting both water quality and flows. Much of this land is also of high conservation importance.

The Sustainable Catchment Management Programme (SCaMP) is aimed at securing management of two key areas of land: UU's Bowland and Southern (Longdendale, Goyt and Peak District) Estates. It will help restore important habitats and enhance biodiversity, protect and improve raw water quality, and enable a sustainable future for the company's agricultural tenants. UU has been allowed to fund this programme of work by its financial regulator, OFWAT, as part of its five-year investment programme for 2005-2010 (PRO9).

SCaMP has been developed in association with the Royal Society for the Protection of Birds (RSPB), a key partner with UU in defining and delivering the work.

The aim of the programme is to develop an integrated approach to catchment management incorporating sustainable upland farming that delivers:

- Government targets for SSSIs
- Biodiversity plans for priority habitats and species
- Improved raw water quality

This will be achieved by entering into long-term agreements with tenant farmers which will define farming plans compatible with the above objectives. Whole-farm plans will be produced which will identify specific land management techniques to be applied on all catchment and SSSI land within the

[138] Boxall, A., Hardy, A., Beulke, S., Boucard, T., Burgin, L., Falloon, P., Haygarth, P., Hutchinson, T., Kovats, S. & Leonardi, G. 2010. Impacts of climate change on indirect human exposure to pathogens and chemicals from agriculture. Ciência & Saúde Coletiva, 15, 743-756
[139] Nisbet, T., Silgram, M., Shah, N., Morrow, K., and Broadmeadow, S. (2011) Woodland for Water: Woodland measures for meeting Water Framework Directive objectives. Forest Research Monograph, 4, Forest Research, Surrey, 156pp.
[140] *Ibid.*
[141] Mentens, J, Raes, D & Hermy, M. 2006. Green roofs as a tool for solving the rainwater runoff problem in the urbanized 21st century? Landscape and Urban Planning, 77, 217-226.
[142] Heal, KV, Hepburn, DA, Lunn, RJ & Tyson, J. (2006). Sediment management in sustainable urban drainage system ponds. Water Science and Technology, 53, 219-228.

funded areas. The plans are based upon giving the tenant the best chance of accessing higher-level agri-environmental support grants to ensure that the plans are both environmentally and economic sustainable. As a result, the plans have been developed in consultation with English Nature, the RSPB and the Rural Development Service.

A key part of the programme is to monitor and evaluate the effect of any land management changes that UU agree and implement with tenants. UU has established a monitoring programme that looks at the effects of land management change on vegetation, hydrology and water quality.

For more information, see *http://www.hydrology.org.uk/Publications/durham/bhs_14.pdf*

New York Harbour System

In 2010 New York City published a plan to improve water quality in the New York Harbor System through reducing Combined Sewer Outflows following storms. The approach aims to use green infrastructure approaches (such as street trees, swales, bioinfiltration, and blue and green roofs), to capture the first inch of rainfall on 10% of the impervious area in combined sewer watersheds over 20 years. It is estimated that this will reduce combined sewer overflows by 1.5 billion gallons a year. The report estimates that a mixture of green and grey infrastructure will allow it to meet its objectives for $5.3 billion as opposed to a purely grey strategy costing $6.8 billion.

For more information see

http://www.nyc.gov/html/dep/html/stormwater/nyc_green_infrastructure_plan.shtml

In summary, any measures which increase rainwater infiltration are likely to reduce the number of occasions in which sewerage systems are overwhelmed by large volumes of water resulting in water quality issues. Table 21 sets out some examples of natural environment solutions for addressing water quality issues associated with extreme weather events that can be linked to climate change.

Table 21: Natural environment solutions for managing the risks associated with reduced water quality associated with weather events (drought and flooding)

Natural environment solutions	Habitats to which apply	Ecosystem services provided	Illustrative case studies	Links to further information
Improve land management upstream e.g. fencing river banks, reducing fertiliser / pesticide use, coppicing overshaded woodlands, scrub clearance, improved farming through intensive monitoring, advice, equipment calibration and financial support for winter cropping, improving slurry stores	Enclosed Farmland; Mountains, moorland and heaths Freshwaters	**Water quality**	Upstream Thinking	http://www.wrt.org.uk/projects/upstreamthinking/upstreamthinking.html
			Vittel PES scheme,	The Vittel payments for ecosystem services: a “perfect” PES case?’ a report produced for IIED and DFID, 2006 available from: http://pubs.iied.org/G00388.html
			Wessex Water England	http://www.wessexwater.co.uk/environment/threecol.aspx?id=7199&linkidentifier=id&itemid=7199
			West County Angling Passport	www.westcountryanglingpassport.org.uk

Natural environment solutions	Habitats to which apply	Ecosystem services provided	Illustrative case studies	Links to further information
Restore floodplains and wetlands on farmland	Agriculture and grasslands Woodlands Mountains, moorland and heathland Urban	Hazard regulation (flood risk); soil quality; **water quality**; wild species diversity	Bush Tender Australia	Department of Sustainability and Environment (2008). *BushTender: Rethinking Investment for native vegetation outcomes. The application of auctions for securing private land management agreements* (online) available here.
			CRP United States	United States Department of Agriculture (2013) Conservation Programs (online): https://www.fsa.usda.gov/FSA/webapp?area=home&subject=copr&topic=crp
Advise and encourage land managers (particularly farmers) to adopt management practices that support aquatic biodiversity	Enclosed farmland and semi-natural grassland	**Water quality**; wild species diversity	Rainham Marshes	http://www.rspb.org.uk/community/placestovisit/rainhammarshes/b/rainhammarshes-blog/default.aspx
			Thames Basin Heaths	http://www.surreyheath.gov.uk/planning/planningpolicyandconservation/ThamesBasinSPA.htm
Slow the flow of surface water in flood risk areas by low-level flood storage bunds, woodland creation, large woody debris (LWD) dams, grip and gully blocking in peatlands etc.	Enclosed farmland Mountains, moorlands and heaths	Hazard regulation (flood risk); soil quality; **water quality**; wild species diversity	Slowing the Flow Pickering	Reports and papers on the 'Slowing the Flow at Pickering' WebPages of the Forestry Commission website (online) availabel here.
			Pumlumon Project, Wales	http://www.montwt.co.uk/pumlumon.html
			Upstream Thinking	http://www.wrt.org.uk/projects/upstreamthinking/upstreamthinking.html
Restoration of river corridors and catchments	Freshwaters – openwaters, wetlands and floodplains	Hazard regulation (flood risk); soil quality; **water quality**; wild species diversity	Catskills watershed management New York	Appleton, A.F. (2002). *How New York City used an Ecosystem Services Stratgey carried out through an Urban-Rural Partnership to preserve the pristine quality of its drinking water and save billions of dollars* (online) available here.
Restore and preserve degraded	Mountains, moorland	Hazard regulation	SCaMP	*http://www.hydrology.org.uk/Publications/durham/bhs_14.pdf*

Natural environment solutions	Habitats to which apply	Ecosystem services provided	Illustrative case studies	Links to further information
peatlands by restoring blanket bogs by blocking drainage ditches, restoring areas of eroded and exposed peat	and heathland	(flood risk); carbon storage; **water quality**; wild species diversity	Dartmoor and Exmoor Mires Projects	http://www.dartmoor-npa.gov.uk/lookingafter/laf-naturalenv/dartmoormiresproject
			The Pumlumon Project	http://www.montwt.co.uk/pumlumon.html

5. THE ROLE OF PES IN DELIVERING ADAPTATION SOLUTIONS

5.1 Introduction

Current investment in the natural environment is challenged by the fact that resources are scarce, and public authorities at all levels of government are increasingly under pressure to do more with less. As such, most investments in the natural environment seek funding from a range of sources, including the national lottery fund, trusts, charities, business and increasingly, the private sector and local communities. The potential of PES to access new funding streams and provide incentives to secure ecosystem service provision by linking the providers of ecosystem services more closely with the beneficiaries means that it could potentially play an important role in leveraging investment in the natural environment.

A move away from 'government-funded' flood management to 'beneficiary-pays' flood management was suggested in Sir Michael Pitt's review of the 2007 floods. In response the Environment Agency initiated an external contributions policy, which aims to routinely seek support from major beneficiaries towards project costs, in return for allowing some influence over the scope and timing of works. There is also scope for insurers to create incentives for homeowners and developers to avoid building in areas of flood risk and to improve the resilience of existing developments.

The ASC's 2013 Progress Report also recommends that government should explore the scope for developing effective market mechanisms that place an economic value on nature, such as PES and biodiversity offsetting, to help it achieve its policy goals to enhance England's semi-natural habitats by 2020. This recommendation is put forward in light of the uncertainty regarding the amount of funding that might be made available for environmental improvements in the next (post-2013) phase of the Rural Development Plan for England (RDPE) and the challenges that the government will face in achieving its policy goals if there is a significant reduction in funding.

While central government spending on the natural environment is likely to remain the most important source of funding in the short to medium term, there is the potential to supplement this expenditure with 'beneficiary-based' spending secured through PES schemes.

5.2 Payments for ecosystem services

When the benefits of an ecosystem service accrue mainly to those who make management decisions and bear the costs of provision, as in the production of crops or livestock, private markets are likely to work relatively well at encouraging service provision. However, when the benefits of an ecosystem service flow primarily to those who do not bear the costs of provision, for example in the case of water purification or climate regulation, public interests and the interests of the resource manager may be misaligned and the actions of the individual may lead to negative externalities for society[143].

PES schemes, effectively, provide incentives to address market failure (see Box 4)[144] by altering the economic incentives faced by land managers or owners in order to limit adverse impacts on ecosystem service provision and/or increase the supply of an ecosystem service, or services where it has been lost or degraded.

The basic idea behind PES is that those who provide ecosystem services – like any service – should be paid for doing so. PES therefore provides an opportunity to put a price on previously un-priced ecosystem services like climate regulation, water quality regulation and the provision

[143] Jack, B.K., Kouskya, C. and Simsa, K.R.E. (2008). Designing payments for ecosystem services: Lessons from previous experience with incentive-based mechanisms. *PNAS* 105(28): 9465-9470.
[144] See Dunn, H. (2011) Payments for Ecosystem Services. Defra Evidence and Analysis Series, Paper 4 [online] available at https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/69329/ecosystem-payment-services-pb13658a.pdf (last accessed 12/08/2013) for an analysis of the market failures associated with ecosystem services and the scope for PES.

of habitat for wildlife and, in doing so, brings them into the wider economy. In practice, PES is often used in reference to schemes that involve a continuing series of payments to land or other natural resource managers in return for a guaranteed flow of ecosystem services, or management actions likely to enhance or secure their provision.

Box 4: Sources of market failure and the scope for PES (after Dunn, 2011)[145]

Public goods: Ecosystem services are often public goods, which means that the consumption of a service by one individual does not decrease the amount or level of that service available to another individual (non-rivalry) and that nobody can be effectively excluded from using the good (non-excludable). For example, an upland area may provide ecosystem services to a population downstream in terms of water filtration and alleviation of flood risk. In this case, one individual benefiting from improved water quality and lower flood risk is not going to affect other individuals benefitting (non-rival) and no individual can be excluded from these benefits (non-excludable). These characteristics (non-rival and non-excludable) mean that although there is value in these services, there are large incentives for individuals to 'free ride' rather than to pay to maintain them. Government intervention is required to ensure these ecosystem services are maintained for the public benefit.

In practice, however, many ecosystem services may be quasi-public goods or **club goods** whereby many individuals may consume the service (e.g. water supply) without affecting the consumption of others but where it is possible to exclude individuals from consuming the service.

Externalities: Ecosystem services may be affected by externalities, or uncompensated side effects of human actions. For example, a decision to convert an area of land from forest to agriculture may not reflect the potential impact on carbon or on water regulation services and will not, without government intervention, be taken into account in the private decision on land-use conversion. The costs associated with the loss of forest ecosystem services are therefore imposed on society and result in under-provision of the ecosystem services concerned.

Information failure: In the context of complexity in ecosystems and uncertainty in how ecosystems services are delivered or respond to different factors, information failure is likely to be playing a key role in the current losses in ecosystems and services. Information failures can occur when the information necessary for people or firms to make optimal decisions is incomplete or difficult/costly to acquire. As a result, existing opportunities to improve both economic and environmental outcomes may not be realised.

However, PES is only one instrument among many for combating ecosystem degradation. Others include regulation; the provision of services by government (for example, the Public Forest Estate provides numerous services of public benefit); private contracts between providers and recipients; voluntary efforts on the part of businesses, communities and individuals; and incentive-or market-based mechanisms, including taxes and charges, subsidies, tradable permits and PES.

What differentiates PES from the other market-based instruments is its focus on the 'beneficiary pays' (rather than 'polluter pays') principle. PES provides financial incentives (paid for by the service ***beneficiaries***) to land or resources managers in return for specific actions that are reliably known to enhance ecosystem service provision. These incentives can be either output-based (i.e. the buyers pay the sellers for the actual ecosystem services provided) or input-based (i.e. providers are paid for implementing an intervention).

This emphasis on identifying the beneficiaries who value a particular service and encouraging recognition of the contribution to service provision made by land and resource managers means that PES can address some of the barriers to the uptake of natural environment solutions on both the demand and supply side, in particular by:

[145] *Ibid.*

- providing incentives for land managers to invest in activities or measures that enhance the supply of ecosystem services;
- generating finance from ecosystem service beneficiaries, particularly from the private sector; and
- helping to target policy incentives to areas where they can optimise the supply of services in places where they are most needed, as well as where they can be most efficiently delivered and function in harmony with other environmental objectives.

More specifically, by rewarding land and resource owners and managers on the basis of the services they provide, PES provides an explicit financial incentive for land and resource owners and managers to provide public goods for which they are not currently paid. There is evidence that spatial targeting of payments in this way also enhances the economic efficiency of payment schemes (compared to uniform grant schemes), offering the possibility of providing better value for taxpayers' money[146].

The appeal of PES in securing alternative funding sources for environmental protection, addressing incentives, and targeting policy has led, in the last 10-15 years, to a rapid proliferation of PES schemes around the world; with more than 300 PES or PES-like programmes operating in 2010 at national, regional, and local levels according to the OECD[147].

Globally, the majority of PES schemes typically focus on four broad types of ecosystem service: watershed protection (including erosion management); carbon sequestration; biodiversity conservation; and landscape aesthetics. A further type of service that sometimes forms part of PES is public access (i.e. for recreation or cultural services).

While some services lend themselves to private-financed PES programmes, others tend to feature in public-financed schemes. For example, watershed protection often forms the basis for private-financed schemes in which the beneficiaries of downstream ecosystem services, such as water utilities benefitting from water quality regulation, contract directly with service providers, such as upstream watershed managers, via localised exchange arrangements ('self-organised private deals'[148]). These schemes tend to arise because many water-related services are club goods, i.e. only those located in the watershed benefit and, as such, it is possible to exclude 'free riders'.

In contrast, biodiversity conservation often figures strongly in public-financed schemes in which the government contracts with ecosystem service providers on behalf of the public because it is not generally possible to exclude members of the public from benefiting from efforts to improve biodiversity conservation. Public-financed schemes tend to include a focus on wildlife enhancement because public goods such as biodiversity are widely enjoyed by diffuse beneficiaries and, as such, private provision of public goods is unlikely to arise because the benefits cannot be fully captured.

5.2.1 *Key PES principles*

PES has been defined as:

- a voluntary transaction where;
- a well-defined ecosystem service (or a land-use likely to secure that service);

[146] OECD (2010) Paying for biodiversity: Enhancing the cost-effectiveness of payments for ecosystem services. OECD, Paris.
[147] *Ibid.*
[148] The Katoomba Group, UNEP and Forest Trends (2008). Payments for Ecosystem Services: Getting Started - A Primer [online] available at: http://www.katoombagroup.org/documents/publications/GettingStarted.pdf?bcsi_scan_AB11CAA0E2721250=0&bcsi_scan_filename=GettingStarted.pdf

- is being 'bought' by a (minimum of one) ecosystem service buyer;
- from a (minimum of one) ecosystem service provider; if and only if
- the ecosystem service provider secures ecosystem service provision[149].

Drawing on this definition, the Defra Best Practice Guide on Payments for Ecosystem Services[150] identifies seven key principles which should underpin any PES scheme:

- **Voluntary:** stakeholders enter into a PES agreement on a voluntary basis.
- **Beneficiary pays:** payment is made by the beneficiaries of ecosystem services (individuals, communities and businesses or governments acting on their behalf).
- **Direct payment:** payments are made directly to ecosystem service providers (in practice this is often via an intermediary or broker).
- **Additionality:** payments are made for actions over-and-above those which land or resource managers would generally be expected to undertake. (Note that precisely what constitutes additionality will vary from case-to-case, but the actions paid for must at the very least go beyond regulatory compliance).
- **Conditionality:** payments are dependent on the delivery of ecosystem service benefits (outputs). In practice, due to the level of uncertainty and variability in many natural processes, payments are often based on the implementation of management practices (inputs) which the contracting parties agree are likely to give rise to these benefits.
- **Ensuring permanence:** management interventions paid for by beneficiaries should not be readily reversible, thus providing continued service provision.
- **Avoiding leakage:** PES schemes should be set up to avoid leakage, whereby securing an ecosystem service in one location does not lead to the loss or degradation of ecosystem services elsewhere.

However, as noted in the Guide, while these principles should inform the development of PES, in practice schemes may adhere to them to a greater or lesser degree. The literature on PES suggests that few existing schemes fulfil all these principles in practice and, as such, aiming for a 'perfect' PES scheme may create unrealistic expectations.

In addition to these principles, establishing the baseline provision is critical, i.e. the likely future provision of the relevant ecosystem services in the absence of the PES scheme, since this facilitates accurate monitoring which, in turn, indicates the level of additionality being delivered by the PES scheme, thereby reassuring buyers that the requisite services are indeed being provided.

This is particularly important when considering the effects of a changing climate. This is due not only to the fact that 'buyers' will require reassurance that the PES scheme will continue to deliver the service being paid for in future, but also because climate change may have implications for the future value of the service being provided, especially for those ecosystem services that are particularly vulnerable to a changing climate (such as water supply and flood risk regulation).

[149] Wunder, S. (2005) Payments for environmental services: Some nuts and bolts. CIFOR Occasional paper no.42.
[150] Smith, S., Rowcroft, P., Everard, M., Couldrick, L., Reed, M., Rogers, H., Quick, T., Eves, C. and White, C. (2013). Payments for Ecosystem Services: A Best Practice Guide. Defra, London. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/200920/pb13932-pes-bestpractice-20130522.pdf (last accessed 28/05/13).

5.3 Opportunities for PES in England

PES offers certain advantages over other instruments for achieving natural environment solutions for climate change adaptation. However, as noted above, it exists within a broader suite of policy tools, all of which have strengths and weaknesses in relation to achieving the intended environmental outcomes. It is important to recognise, for example, that land or resource managers may be subject to regulation which, if properly enforced, could limit adverse impacts on ecosystem service provision. They may also undertake measures to protect and enhance services where this is in their best interests, for example, through reducing water usage to make cost savings. Many land or resource managers may also seek to protect or enhance ecosystem service provision in their role as custodians. PES schemes should therefore be carefully designed so as not to undermine existing stewardship on the part of land or resource managers.

Forest Trends, the Katoomba Group and UNEP (2008)[151] identified situations in which PES schemes are likely to have the greatest potential, including areas where:

- **Demand for ecosystem services is clear and financially valuable to one or more players**; PES are most likely to occur when there is at least one beneficiary of ecosystem services with both an incentive to invest in the maintenance of this service and available funds for doing so
- **Supply is threatened**; if resources are clearly diminishing to the point of scarcity because of a declining ecosystem service then a PES deal holds potential
- **Specific resource management actions have the potential to address supply constraints**; for PES to be a viable option, it is essential to identify what resource management practices could be changed and what ecosystem services results will ensure improvement of ‘supply’ issues
- **Effective brokers or intermediaries exist**; these can assist with tasks including documenting ecosystem service conditions, identifying specific resource management alternatives, engaging and negotiating with prospective buyers, and activities related to implementation (including monitoring, certification and verification)
- **Resource tenure is clear**; the supplier must have control over the area where the PES agreement is to be implemented, and the buyer must have assurance, and recourse to ensure, that contract provisions of the deal are secure

Within England there is strong policy support for incorporating PES schemes into the environmental policy toolkit. Defra has stated its commitment to promoting the emergence of PES schemes through the 2011 Natural Environment White Paper[152], which proposes various measures to bring the value of nature into mainstream society. In particular, the White Paper emphasises “real opportunities for land managers to gain by protecting nature’s services, and trading nature’s benefits with businesses, civil society and the wider public sector”[153]. Then, in its first State of Natural Capital Report published in April 2013, the Natural Capital Committee offers strong support for PES approaches and their potential[154].

[151] Forest Trends, the Katoomba Group, and UNEP (2008). *Payments for Ecosystem Services: Getting Started – A Primer* [online] available at: http://www.katoombagroup.org/documents/publications/GettingStarted.pdf (accessed 28/05/2013)
[152] HM Government (2011). The Natural Choice: securing the value of nature. [online] http://www.ukeof.org.uk/documents/Defra-white-paper.pdf
[153] *Ibid.*
[154] Natural Capital Committee (2013) The State of Natural Capital: Towards a framework for measurement and valuation [online] available at http://www.defra.gov.uk/naturalcapitalcommittee/files/State-of-Natural-Capital-Report-2013.pdf (last accessed 14/08/2013).

5.4 Analysis of the areas with greatest potential for PES in England

As a general rule of thumb, the existing UK and international experience suggests that the potential for PES schemes appears to be greatest in relation to water quality and water quantity (including both water resource supply and flood risk attenuation). This is due to the fact that it is relatively straightforward to identify providers and beneficiaries and there are numerous examples globally on which programme designers can draw.

There are, nevertheless, other opportunities worthy of consideration, particularly in relation to carbon sequestration (from woodlands and peatland restoration for example), cultural services, and wild species diversity. This may be through, for example, user fees and visitor payback schemes or better targeting of public payments to farmers and woodland managers for the regulating, cultural and supporting services they provide.

To identify the potential opportunities that PES could play in facilitating adaptation to climate change in England, this section analyses the climate related risks facing the country, the necessary investments in the natural environment that could alleviate these risks, and the role that PES could play in securing investment. This section also identifies those areas where PES has the greatest potential by considering issues such as:

- the opportunities for changing land management activities to generate or enhance the supply of ecosystem services that may facilitate adaptation to climate change;
- whether there are clearly discernible ecosystem service beneficiaries who may be willing to pay for the ecosystem service(s) in question; and
- the extent to which payments may provide an explicit financial incentive for land and resource owners to provide public goods for which they are not currently paid.

Nature is a complex, interconnected system and ecosystem services are not generated independently of one another. Therefore, attempts to maximise the supply of one service are likely to influence the production of other services (positively or negatively). In some cases, 'win-win' solutions may be possible, for example where river restoration enhances amenity, biodiversity and fishery benefits, while in other instances trade-offs between services may be apparent, for example where non-native tree species are planted with the aim of sequestering carbon.

With this in mind, a summary of the specific opportunities for PES in relation to addressing some of the barriers and challenges identified in Section 3 are set out in Table 22. The opportunities presented in the table were identified based on the 'long list' of opportunities relating to each of the broad habitat types identified in Section 2 of this report which were then narrowed down to those with specific PES potential (i.e. those with clearly discernible providers and beneficiaries, where there is a well-defined service being offered/provided and where the additionality criterion could be satisfied). The opportunities for PES were then prioritised through a workshop involving specialists from across each of the broad habitat types. During the workshop participants were asked to consider, for each of the main climate risks (rising temperatures and heat stress; dry spells and drought; sea-level rise and storm surges; and intense rainfall and flooding) and for each habitat:

- whether each of the natural environment solutions identified for climate change adaptation was appropriate and/or whether any were missing;
- who the relevant beneficiaries of the solutions/interventions and who the likely buyers/investors would be;
- what are likely barriers to implementation (actual or potential);

- the potential for developing PES to realise each of the opportunities identified (high, medium or low); and
- the measures needed to support the emergence of PES.

Opportunities were prioritised in terms of PES potential using the following criteria:

- High – a PES scheme that is already operational or meets the majority of the key principles;
- Medium – a PES scheme that is not yet operational, but has the potential to meet the key principles; and
- Low – a PES scheme that meets few of the key principles, where the concept of PES in those circumstances is currently unproven and/ or where other policy tools may be more effective in delivering the desired outcome(s).

Following the workshop held in April 2013, the specific opportunities identified and the relative priority accorded to each were reviewed (and amended where necessary) in light of the evidence and recommendations presented in each of the PES Action Plan and the second ASC Progress Report.

Table 22: Opportunities for PES to address climate change adaptation

Natural environment solution	Climate change aspects it can address	Beneficiaries	Potential buyers	Barriers	Priority	Examples of measures needed
Incorporate sustainable drainage systems (SuDs), which include permeable pavements, trees and vegetation, green roofs, stormwater retention ponds, and wetlands and swales (*Note, this is more likely to be feasible in new developments rather than with retrospective implementation*)	Fluvial and pluvial flood risk Drought	— Urban residents / businesses	— Developers — Local businesses — Local Authorities — Environment Agency — Water companies	— Perception of effectiveness of SuDs — Cost to developers (could affect the viability of development) — The question of who maintains SUDS once they have been installed	H	— Regulation and enforcement — Means to aggregate beneficiaries, e.g. a levy paid by residents for SUDS maintenance
Making space for natural flooding by restoring natural flows and particularly floodplain meadows (wetlands)	Fluvial and pluvial flood risk	— Communities and businesses in downstream areas at risk of flooding	— Downstream farmers, residents, businesses — Recreational users of the area — Insurers — Environment Agency — Developers	— Technically difficult — Other cost-effective means of dealing with flood risk (i.e. grey infrastructure) — Long time scales — Uncertain evidence base	H	— Establishment of an intermediary — Mechanism for aggregating buyers — Flood risk modeling for specific catchments — Monitoring and verification

Natural environment solution	Climate change aspects it can address	Beneficiaries	Potential buyers	Barriers	Priority	Examples of measures needed
Slowing the flow of surface water in flood risk areas by low-level flood storage bunds, woodland creation, large woody debris (LWD) dams, and blocking drains	Fluvial and pluvial flood risk	— Downstream residents, farmers, and businesses — Water companies	— Water companies — Insurers — Environment Agency — Developers	— Uncertainty of the impact of the measures in specific catchments — Cost of scientific and technical expertise to undertake flood risk modeling — Aggregating buyers while controlling transaction costs	M	— Establishment of an intermediary — Mechanism for aggregating buyers — Flood risk modelling for specific catchments — Monitoring and verification
Planting field and hedgerow trees, copses and woodland to buffer peak rainfall events. Planting buffer strips beside water courses to reduce nutrient leaching. (*Note: co-benefits from such action may also include shade for livestock and windbreaks for crops*)	Decrease flooding in downstream areas Sensitivity of livestock to increased temperatures	— Local community who benefit from reduced flood/erosion risk — Wider community who benefit from biodiversity habitat and global from carbon storage — Farmers who benefit from crop and livestock protection	— Local authorities — Water companies — Farmers	— Opportunity cost to land and resource managers	M	— Establishment of an intermediary — Mechanism for aggregating buyers — Flood risk modelling for specific catchments — Monitoring and verification — Could be undertaken by self-interested land and resource managers

Natural environment solution	Climate change aspects it can address	Beneficiaries	Potential buyers	Barriers	Priority	Examples of measures needed
Increase provision of urban green infrastructure	Urban heat island effect Flood risk Water scarcity Wild species diversity and resilience to climate change	— Local residents and businesses — Adjacent residents who benefit from amenity value of greenspace	— Local residents and businesses — Adjacent residents — Developers — Local authorities	— High opportunity cost, for e.g. if housing shortages further drive up the price of land, then the opportunity cost of using land for urban GI increases.	M	— Assessment of funding mechanisms (e.g. community levies, developer contributions)
Improving land management upstream in order to improve water quality downstream e.g. fencing river banks, reducing fertiliser/pesticide use, coppicing overshaded woodlands, scrub clearance, improved farming through intensive monitoring, advice, equipment calibration and financial support for winter cropping, improvements to slurry stores, and use of alternative chemicals	Water quality (during periods of drought improved water quality will support aquatic biodiversity and reduce water treatment)	— Water companies — Recreation users (e.g. anglers) — Downstream farmers — Environment agency	— Water companies	— Cost — Complexity of land ownership — Unwillingness of farmers to cooperate — Ethical issue of ‘rewarding the bad guys’	M	— Establishment of an intermediary — Mechanism for aggregating sellers — Monitoring and regulation

Natural environment solution	Climate change aspects it can address	Beneficiaries	Potential buyers	Barriers	Priority	Examples of measures needed
Restoring and preserving degraded peatlands. Specific activities include restoring blanket bogs by blocking drainage ditches, restoring areas of eroded and exposed peat, hay meadows and heather moorland, establishing clough woodland, providing new farm buildings for indoor wintering of livestock, new waste management facilities to reduce run-off pollution of water courses, and fencing to keep livestock away from areas such as river, streams, and special habitats	Flood risk Water quality Wild species diversity and resilience to climate change	— Downstream urban, agricultural, industry water users — Water utilities — Recreational users of watercourses and the area	— Water companies — Corporations (for the purposes of CSR) — Insurance companies — Environment agency — Tourists and visitors — Charitable organizations	— Complex land ownership — Opportunity cost (e.g. grouse moors) — Need for land management changes over a significant area to impact on flood risk	H	— Establishment of an intermediary — Flood risk modeling for specific catchments — Monitoring and verification — Metrics
Implementing measures to allow natural coast development and realignment of coastal flood defences to restore inter-tidal coastal habitats (e.g. salt marsh, floodplains, and dunes) and natural transition zones between coastal and terrestrial habitats	Coastal flood and erosion risk Wild species diversity and resilience to climate change Water quality	— Local and regional farmers, residents, businesses — Recreational users (e.g. bird watching) — Fishermen — Government (climate mitigation	— Local authorities — Environment Agency — Developers (compensatory habitat) — Fishery nurseries — Charitable organisations — Tourists and visitors	— Uncertainty of the impact of the measures — Social/public perception — Opportunity costs of land — Complex landownership	H	— Establishment of an intermediary — Mechanism for aggregating buyers — Flood risk modelling for specific catchments — Monitoring and verification

Natural environment solution	Climate change aspects it can address	Beneficiaries	Potential buyers	Barriers	Priority	Examples of measures needed
Increasing woodland cover and connectivity of existing cover	Fluvial and pluvial flood risk Wild species diversity and resilience to climate change	— Recreational users — Government (through supporting climate change mitigation targets) — Local residents and businesses	— Corporations (for the purposes of CSR) — Charitable organisations	— Opportunity cost — Uncertainty as to the magnitude of impact on flood risk — Potential water quality issues	M	— Establishment of an intermediary — Mechanism for aggregating buyers — Flood risk modeling for specific catchments — Monitoring and verification

6. BARRIERS AND CHALLENGES TO THE USE OF PES

It is clear therefore that there are a number of potential opportunities for PES schemes in the UK, and that PES could play an important role in supporting climate change adaptation through securing funds for investment in natural environment solutions. However, it is important to recognise that there are barriers and challenges to setting up and running successful PES schemes. The 2011 Defra report 'Barriers and Opportunities to the Use of Payments for Ecosystem Services'[155] identified a number of these issues. Using these general challenges as a starting point, this section assesses the particular barriers and challenges facing PES schemes in the context of climate change adaptation. Table 23 identifies challenges to adoption which are particularly relevant or significant in the context of climate change.

Table 23: Barriers and challenges to PES uptake in relation to climate change adaptation

Barriers	General challenges	Relevance to climate change adaptation
Informational	— Lack of awareness among beneficiaries and providers	— Lack of awareness amongst those affected by climate change of the potential for adaptation through investment in the natural environment — The attitudes of insurance companies and regulators and their acceptance of the potential opportunities for climate change adaptation through the use of natural environment solutions can present a barrier.

[155] Scott Wilson Ltd (2011) 'Barriers and Opportunities to the Use of Payments for Ecosystem Services'. Report for Defra

Barriers	General challenges	Relevance to climate change adaptation
Technical	— Scientific uncertainty	— Levels of uncertainty around climate change projections and their effects on ecosystems and associated services mean that PES schemes may not be able to deliver the expected level of benefits and that potential buyers have little confidence that land management activities taken now will be effective in addressing the future effects of climate change
	— Establishing baselines	— Monitoring of the benefits provided by PES schemes may be clouded by the effects of climate change (e.g. unless well designed, it may be difficult to assess the benefits of a scheme designed to alleviate flood risk when the risk of flooding is increasing over time). This highlights the importance of establishing baselines which consider the effects of climate change on ecosystem service delivery over the intended life of the PES scheme
	— Appropriate programme size — Diffuseness of beneficiaries/ suppliers	— The scale of intervention at which it is necessary to make an appreciable difference on climate change adaptation means that one seller is unlikely to able to make much difference on their own. Typically it is necessary to seek co-operation from a number of (often disparate) ecosystem service providers in order to achieve the desired outcome

Barriers	General challenges	Relevance to climate change adaptation
Spatial	— Spatial variability	— The OECD[156] has identified three factors in relation to ecosystem services which vary spatially: — the value of the benefits provided by ecosystem services; — the risk of loss or degradation; and — the opportunity cost. — The potential for a given site to generate ecosystem services is affected by a number of factors including biophysical characteristics (e.g. soils and topography), history (i.e. previous management), neighbouring sites (e.g. the presence of seed banks and habitats) and local managerial capacity (e.g. skills and access to capital). Such characteristics are highly variable, meaning that the marginal costs of delivering services also vary spatially. — This is compounded by the fact that the ecological systems that provide ecosystem services often operate at scale (e.g. landscape, river catchment) and with network linkages (e.g. hydrological connectivity, habitat mosaics) that span individual management units. — These factors are particularly pertinent in relation to PES schemes specifically designed to facilitate adaptation to a changing climate in that the vulnerability of ecosystems, their associated services and the beneficiaries of those services to the effects of a changing climate may vary across the landscape. This in turn suggests that, to be effective, PES schemes need to be targeted towards areas and populations where threats are most likely to emerge and, in some cases, intermediaries may be required to overcome collective action problems (see below).

[156] OECD (2010). Paying for biodiversity: enhancing the cost-effectiveness of payments for ecosystem services. OECD: Paris.

Barriers	General challenges	Relevance to climate change adaptation
Temporal	— Time lags and multiple time horizons — Permanence	— The time lags and multiple time horizons involved in climate change adaptation mean that investors sometimes cannot be sure they are benefitting from their investment in natural environment solutions. This is particularly relevant to establishing the business case for investment where the benefits may only be realised long after the costs have been incurred. — The OECD cautions that the long-term provision of ecosystem services may be compromised by unforeseen events such as fires and invasive species157, the risk of both of which is expected to increase in response to climate change. As such, they advise that the allocation of responsibility and risk needs to be specified in the PES contract. In cases where the risks of non-permanence are particularly high insurance payments can be considered158.
Financial	— Risk perception — High start-up costs and transaction costs	— Uncertainties around the exact nature of the benefits that might be achieved through land management activities may result in PES arrangements as being perceived to be high risk by potential buyers. — Potential buyers may also be discouraged by the high start-up costs (including high transaction costs associated with coordinating buyers with sellers).
Institutional	— Collective action problems — Perverse incentives — Complex policy environment	— For some PES schemes where there may be many willing buyers it can be difficult to organise payments from a large number of individuals (e.g. home-owners at increased risk of flooding) and negotiating voluntary collective action agreements amongst many participants can result in high transaction costs. In such cases public or private intermediaries or brokers may be required to overcome collective action problems. For example, a local authority may pay for flood control on behalf of its citizens or utilities may act on behalf of its customers.
Cultural	— Aversion to paying for ecosystem services	— There can be a degree of aversion to paying for ecosystem service provision, particularly when their effectiveness is unknown in light of uncertainty over the specific impacts of climate change.

[157] *Ibid.*
[158] *Ibid.*

Barriers	General challenges	Relevance to climate change adaptation
Equity considerations	— Perceived unfairness	— The time lag between actions taken now to improve climate change and future improvements may reduce willingness to pay for PES. For example, in many cases, the benefits of actions to adapt to climate change will not be experienced for decades or generations. In these cases, potential buyers of services now, may be discouraged from contributing because they may not see the benefits in their lifetime.

It is evident from Table 23 that there are several barriers and challenges to the implementation of PES schemes specifically for the purposes of climate change adaptation. However, these are not necessarily insurmountable. As long as the challenges relevant to any particular PES scheme are identified and characterised early on, many of these can be overcome through careful design. For example:

- while it is difficult to be certain that a final service (i.e. climate change adaptation) will be provided in the long term, focusing instead on more tangible services or actions likely to give rise to those services (such as desynchronising river flows) can give confidence to buyers that they are getting what they paid for;
- buyers may be willing to invest in improving ecosystem services that indirectly relate to adaptation (e.g. increased recreation and health benefits from improved water quality);
- a lack of scientific certainty does not apply to all ecosystem services. There is good information, for example, on the potential for natural environment solutions to cool urban environments, re-connect fragmented landscapes, and secure water supplies;
- while pooling individual buyers can create additional costs, an alternative approach involves identifying larger organisations (such as insurance companies, water companies, or local authorities) who may be willing to pay for the service on behalf of their customers / citizens;
- measures to increase resilience can be specifically targeted (e.g. planting trees in gills and along gullies and integrating multi-functional green spaces into development proposals) and need not involve trade-offs with high quality agricultural land, and therefore can be more acceptable to sellers; and
- PES can represent a 'no (or low) regrets' option. For example, if the impacts of climate change are not as significant as predicted or take longer to be experienced, the natural environment solution may still contribute to beneficial outcomes such as recreation, air quality, noise regulation and habitat for wildlife.

6.1 Embedding climate change considerations into PES design

As well as the potential for initiating PES schemes to enhance climate change adaptation through changes to the natural environment, it is also important that existing and future PES schemes are designed to be resilient to the projected impacts of climate change and are aligned with broader adaptation planning and responses.

Using the phases set out in the Best Practice Guide for PES[159], it is possible to identify where or at what stage in the design, implementation and ongoing monitoring and evaluation of PES schemes the effects of climate change are best considered. The ways in which climate change considerations may be embedded into PES design at each stage is summarised below.

6.1.1 *Identify a saleable ecosystem service and prospective buyers and sellers*

The first phase in the design and implementation of a PES scheme involves determining the prospects for establishing a scheme in the first instance. This includes identifying the range of possible buyers and sellers of that service(s) and the prospects for trade between them.

Consideration of the potential impacts of climate change at this phase is important for the longer term success of the scheme. For example, by identifying those segments of the community (including businesses) that are more likely to be exposed to risk as a consequence of climate change. By identifying these populations, and by understanding the nature of the climate change risk that could be experienced, a more compelling case can be made for the need for adaptation action involving PES.

6.1.2 *Establish PES scheme and resolve technical issues*

The second phase in developing and implementing a PES scheme involves establishing the principles that will underpin the scheme and resolving key technical issues. Resolving key technical issues is potentially the most resource-intensive step in scheme development and involves a range of tasks including: determining the scheme's geographical coverage; establishing the baseline; undertaking opportunities and risk assessments; identifying appropriate interventions; determining the mode of payment; and establishing arrangements for monitoring, evaluation and review.

Consideration of climate change raises a number of technical issues in this phase. Establishing a baseline, against which the ecosystem-enhancing activities of the seller can be assessed, can be a challenging activity because of the complexity of the interactions within the natural environment. This is likely to become more challenging as the effects and pace of climate change become better understood in the area where the PES scheme is being considered. For example a PES designed to reduce the occurrence of floods based on current frequency, may risk being considered less effective if the baseline does not consider the potential for flood frequency to increase in some locations over time.

Climate change also has the potential to affect the degree to which certain ecosystem services are considered valuable. For example, as the climate becomes hotter and drier, urban heat island effect may be experienced to a great extent. Such conditions may result in greater demand for PES schemes that are designed to address such conditions. As a result, the willingness to pay for such schemes may increase over time.

In rural settings, climate change may result in areas that are currently less suited to agriculture becoming more suitable. In such situations, the opportunity cost of a land owner becoming involved in a PES scheme has the potential to increase and therefore the incentive payment that would be required to forego agricultural activity may also need to be higher.

6.1.3 *Negotiate and implement agreements*

The third phase in the process involves negotiating and implementing the PES agreement. Assuming that the appropriate interventions and the associated mode of payment for these

[159] Smith, S., Rowcroft, P., Everard, M., Couldrick, L., Reed, M., Rogers, H., Quick, T., Eves, C. and White, C. (2013). Payments for Ecosystem Services: A Best Practice Guide. Defra, London. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/200920/pb13932-pes-bestpractice-20130522.pdf (accessed 28/05/13).

have been established, the parties will need to negotiate and agree the nature, level and timing of payments and draw up the necessary contracts.

Given the uncertainty regarding how the natural environment and society will respond to the effects of climate change, establishing PES schemes that incorporate as much flexibility as possible will provide opportunities for adaptive management. Such flexibility may incorporate the use of flexible contracts in which, for example, payments are lower, but made more frequently to address buyer and seller concerns about uncertainty, efficacy and opportunity cost, respectively.

Flexibility may also be incorporated through the use of a reverse (or inverse) auction. This is a competitive bidding process whereby sellers nominate particular actions or services that they can provide and the price at which they are willing to sell them. The auction can therefore act as an effective mechanism for revealing information about the true cost of providing ecosystem services. Funding is allocated in the order of the bidders providing the greatest service provision at the lowest cost, with the selection of bidders continuing until the available funds run out. When considering climate change, reverse auctions can allow buyers of ecosystem services greater flexibility to select those projects that offer best value for money in achieving climate change adaptation objectives.

Climate change may also create additional incentive for the use of insurance schemes, which protect sellers. For example, a seller may wish to secure insurance to cover the risk of an extreme climatic event (such as a flood), which could undermine the provision of ecosystem services that they are contractually obliged to provide.

6.1.4 *Monitoring, evaluation and review implementation*

The fourth phase in the process involves monitoring, evaluating and reviewing the performance of the PES scheme in light of its original objectives. This is particularly relevant when considering climate change because of the potential difficulties associated with establishing the baseline. By establishing an agreed approach to implementing a schedule of monitoring, evaluation and review, buyers and sellers have the opportunity to address some of their concerns regarding uncertainty of the interactions between the natural environment, climate and the PES scheme. Sellers and buyers will also benefit from monitoring and evaluation when considering that the value of ecosystem services may change as the climate changes.

6.2 Ensuring PES schemes do not negatively impact adaptation

In addition to ensuring the design of any given PES scheme includes consideration of climate change, it is important to ensure that a scheme does not adversely affect climate change adaptation.

The majority of existing PES schemes seek to re-balance the ecosystem services provided by a particular habitat, often away from a focus on provisioning services to one more focussed on regulatory and cultural ecosystem services.

This change in focus is necessary if the trend towards ecosystem degradation is to be halted and possibly reversed. However, given the issue of food security and the vulnerability of crops and livestock to changes in climate, there is a need to create a balance when ecosystem services are in competition.

On the whole, PES schemes are likely to be synergistic with climate change adaptation. For example, projects set up with the objective of improving water quality within catchments are well aligned with climate change adaptation, especially in areas that are anticipated to experience drier conditions. Similarly, projects with the objective of reducing flood risk are also well aligned with the goals of climate change adaptation. However, projects set up to mitigate climate change through woodland creation may adversely affect adaptation if the project fails to adequately reconcile the possible trade-offs between fast-growing trees that sequester carbon and their potential impact on water quality and water scarcity. Further potential synergies and trade-offs are summarised in Table 24.

Table 24: PES schemes with climate change adaptation focus: potential synergies and trade-offs:

Type of PES scheme	Potential synergies with climate change adaptation	Potential trade-offs with climate change adaptation
Water quality	— Improvements in water quality and quantity achieved through PES schemes may assist in areas where climate change is predicted to result in water shortages.	— None identified
Carbon	— PES schemes with a revegetation focus (e.g. peatland restoration) may contribute to climate change adaptation by promoting enhanced water storage as well as mitigation through increasing carbon sequestration.	— Poorly cited woodland creation projects could exacerbate water scarcity and could lead to water quality issues — Depending on the type of land that trees are planted on it could lead to a trade off with agricultural production and therefore impact on food security
Biodiversity	— Schemes that are intended to increase biodiversity (e.g. through coastal realignment) may increase landscape connectivity and, hence, improve the potential for plant and animal species to adapt to climate change.	— PES schemes that are designed to increase biodiversity based on the current ecosystem in a given location may not result in these same ecosystems being able to adapt to future climate change. For example, revegetation actions may need to include drought-tolerant species, which, in turn, provide habitats for different animal species.
Flood risk regulation	— PES schemes such as those involving flood plain restorations may provide synergies with climate change adaptation because of the projected increase in extreme flooding events.	— None identified
Erosion management	— Schemes that are intended to restore vegetation on degraded slopes may reduce the effect of projected increases in extreme rainfall events.	— None identified

7. CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

The research findings suggest that PES could potentially play an important role in stimulating investment in the natural environment to contribute towards efforts to adapt to a changing climate. Overall, the most promising opportunities are likely to be those PES schemes that generate multiple benefits, including climate change adaptation, and/or which confer immediate adaptation benefits, for example significantly reduced flood risk.

Scotland's ClimateXChange identifies three categories of climate change adaptations: no-regret actions', 'low-regret actions' and 'win-win actions'[160] No regrets actions are considered as cost-effective now and under a range of future climate scenarios and do not involve hard trade-offs with other policy objectives, while low-regret actions are defined as relatively low cost while providing relatively large benefits under predicted future climates. Win-win actions contribute to adaptation whilst also having other social, economic and environmental policy benefits, including in relation to climate change mitigation.

Taking into account these definitions, the most promising opportunities are likely to be win-win actions which promote adaptation while yielding a range of other benefits. For example, peatland restoration can enhance water storage and so promote adaptation while generating a range of other potential benefits including carbon sequestration, improvements in water flow, enhanced biodiversity and greater potential for tourism and recreation. As a further example, the provision of green infrastructure could assist in promoting urban cooling and therefore adaptation while also providing a wide range of other benefits including cultural services and enhanced wellbeing, improved surface water management and biodiversity enhancements. Win-win actions implemented as part of PES schemes have an obvious advantage in that buyers may be interested in paying for other benefits and the climate change adaptation gains will be a positive, but incidental benefit.

Uncertainty regarding the precise nature and significance of climate change effects over the longer term and, in particular, uncertainty as to whether or not specific changes in land management practices today will deliver the resilience needed in future, is likely to render it very challenging in some cases to persuade would-be buyers of the benefits of paying for climate change adaptation-based interventions through PES schemes. This argument lends further weight to the need to promote win-win actions as part of scheme design.

In some cases, however, it may be possible to persuade buyers of the merits of paying for no-regrets or low-regrets actions if they are specifically interested in promoting climate change adaptation and if these actions are likely to yield significant short- to medium-term benefits in terms of adaptation, for example in relation to flood risk. For example, downstream communities subject to flood risk may be very willing to contribute to a PES scheme focused on floodplain restoration where the benefits in terms of flood risk management are clearly apparent. Similarly, local residents may be content to fund sustainable drainage systems if the flood management benefits are evident.

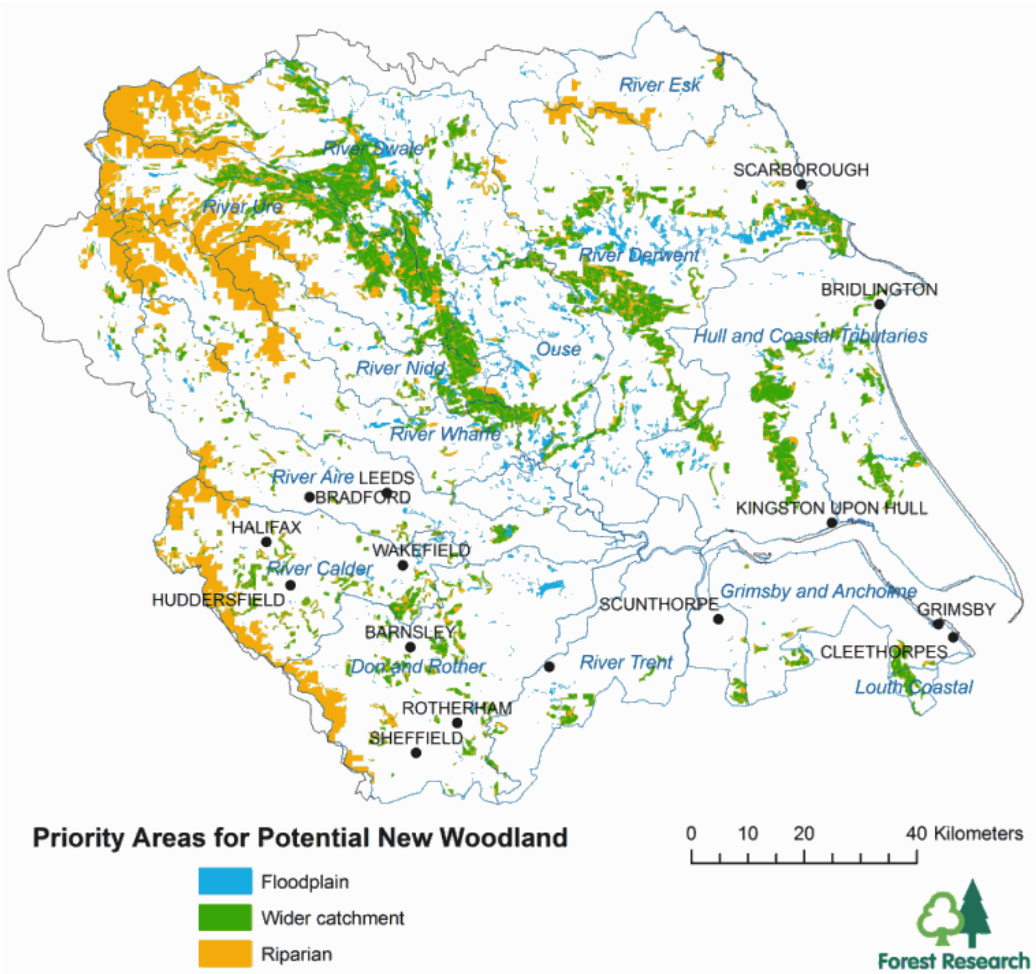
In these cases, the nature of the climate risk may be well understood with the impacts already being felt; the benefits of investing in the natural environment could therefore clearly outweigh the future costs of inaction. Communities might also be willing to pay for interventions where the evidence around cause-and-effect is less clear cut but the costs are nonetheless likely to be reasonably low, for example paying for woodland planting in strategic upstream locations to help manage flood risk (For example, Figure 4 indicates high priority areas with the greatest potential for woodland planting to reduce downstream flooding in the Yorkshire and the Humber region). However, as Defra acknowledge, "A barrier to using PES for flood risk

[160] Martin, S. (2012). Examples of 'no-regret', 'low-regret' and 'win-win' adaptation actions [online] available at: www.climatexchange.org.uk/adapting-to-climate-change/examples-no-regret-low-regret-and-win-win-adaptation-actions/ (accessed 15 August 2013).

management is that the benefits on the ground may not be particularly visible or tangible, leading to scepticism around the benefits and a lack of demand from beneficiaries".[161]

Aside from schemes predicated on reducing flood risk, on the basis of the research undertaken, it appears that there are relatively few interventions that might solely promote adaptation without generating other benefits, many of which are more likely to be more attractive to would-be buyers. For example, Forest Research is investigating those areas in Greater London where new greenspaces could help combat the Urban Heat Island (UHI) effect.[162] However, in all likelihood, would-be buyers of ecosystem services would be more interested in paying for the other services generated by additional greenspace (for example, equality and wellbeing benefits, noise attenuation, biodiversity benefits and townscape improvements).

Figure 4: High priority areas with the greatest potential for woodland planting to reduce downstream flooding in the Yorkshire and the Humber region[163]



[161] Defra (2013). Developing the potential for Payments for Ecosystem Services: an Action Plan [online] available at: www.gov.uk/government/uploads/system/uploads/attachment_data/file/200889/pb13918-pes-actionplan-20130522.pdf (accessed 15 August 2013).
[162] Forest Research (2012). Using green infrastructure to relieve urban heat-related stress [online] available at: www.forestry.gov.uk/fr/INFD-8ZBDHC (accessed 15 August 2013).
[163] Forest Research (2013). Opportunity mapping for trees and floods [online] available at: www.forestry.gov.uk/fr/INFD-7T9JRD (accessed 15 August 2013).

The specific opportunities for PES are summarised in the Table 25.

Table 25: Natural environment solutions and priorities for PES development

Natural environment solution	Priority for PES development	Potential funding sources
Incorporate sustainable drainage systems (SuDs), which include permeable pavements, trees and vegetation, green roofs, stormwater retention ponds, and wetlands and swales	High	— Developers — Local residents — Local businesses — Local authorities — Environment Agency — Water companies
Making space for natural flooding by restoring natural flows and particularly floodplain meadows (wetlands)	High	— Local and regional farmers, residents, businesses — Recreational users of the area — Insurers — Environment Agency — Developers
Slowing the flow of surface water in flood risk areas by low-level flood storage bunds, woodland creation, large woody debris (LWD) dams, and blocking drains	Medium	— Water companies — Insurance companies — Environment Agency — Developers
Planting field and hedgerow trees, copses, and woodland to provide shade for livestock and windbreaks for crops, also buffering peak rainfall events, slowing water runoff. Buffer strips besides water courses can reduce nutrient leaching	Medium	— Farmers — Local authorities — Water companies
Increase urban green infrastructure	Medium	— Local residents — Local businesses — Developers — Local authorities
Improving land management upstream in order to improve water quality downstream e.g. fencing river banks, reducing fertiliser/pesticide use, coppicing overshaded woodlands, scrub clearance, improved farming through intensive monitoring, advice, equipment calibration and financial support for winter cropping, improvements to slurry stores, and use of alternative chemicals	Medium	— Water companies

Natural environment solution	Priority for PES development	Potential funding sources
Restoring and preserving degraded peatlands. Specific activities include restoring blanket bogs by blocking drainage ditches, restoring areas of eroded and exposed peat, hay meadows and heather moorland, establishing clough woodland, providing new farm buildings for indoor wintering of livestock, new waste management facilities to reduce run-off pollution of water courses, and fencing to keep livestock away from areas such as river, streams, and special habitats	Medium	— Water companies — Corporations (for the purposes of CSR) — Insurance companies — Environment Agency — Tourists and visitors — Charitable organisations
Implementing measures to allow natural coast development and realignment of coastal flood defences to restore inter-tidal coastal habitats (e.g. salt marsh, floodplains, and dunes) and natural transition zones between coastal and terrestrial habitats	High	— Local authorities — Environment Agency — Developers (compensatory habitat) — Tourists and visitors — Charitable organisations — Capture fishery and aquaculture enterprises
Increasing woodland cover and connectivity of existing cover	M	— Corporations (for the purposes of CSR) — Charitable organisations

The research also identified a number of challenges to the implementation of PES in the context of climate change adaptation. These include:

1. Lack of evidence to inform the business case

A common barrier to the uptake of PES schemes is convincing evidence to demonstrate both the links between changes in land management practices and the actual climate benefits these are meant to confer, and the cost-effectiveness of such schemes in relation to hard engineering solutions ('grey' infrastructure). This highlights the need to focus, at least initially, win-win or no or low regrets options and to establish a sound baseline against which changes can be measured.

A recent European Commission-funded project compared information on the costs and benefits of natural environment solutions for addressing climate change against more traditional engineering solutions across Europe[164]. The study concluded that most of the natural environment projects could be considered economically beneficial, especially when the long-term social and environmental benefits are considered. However, because of a lack of quantitative information, the authors could not definitively comment on the relative cost-effectiveness of the projects.

Examples such as this reflect the need for evidence of relative costs and benefits of natural environment solutions over a time frame that is long enough to allow benefits to be realised.

[164] Naumann, S., G. Anzaldua, P. Berry, S. Burch, McKenna, D., A. Frelih-Larsen, H. Gerdes and M. Sanders (2011) Assessment of the potential of ecosystem-based approaches to climate change adaptation and mitigation in Europe. Final report to the European Commission, DG Environment, Contract no. 070307/2010/580412/SER/B2, Ecologic institute and Environmental Change Institute, Oxford University Centre for the Environment [online] available at http://ec.europa.eu/environment/nature/climatechange/pdf/EbA_EBM_CC_FinalReport.pdf (last accessed 30/04/2013)

They also reflect the potential disconnect between ecosystem timeframes and those of potential beneficiaries and buyers of ecosystem services.

One of the specific areas of action identified by Defra in the PES Action Plan is to evaluate ongoing efforts to develop PES schemes in England. This includes piloting, building capacity, fostering innovation and demonstrating good practice through, amongst other things, learning networks, formal evaluations of PES pilot research projects. This will go a long way to generating the evidence needed to provide confidence to buyers and sellers and to support the business case for investment. This is important in the context of climate change because of the complex interplay of spatial and temporal factors that influence the efficacy of measures to address climate change.

2. Establishing longer planning horizons to address long term climate changes

While some beneficiaries, for example communities at risk from flooding, may be willing to enter into PES schemes if the climate change adaptation benefits are apparent in the short- to medium-term, they are less likely to pay into schemes where the returns will only be apparent in the longer-term and, moreover, subject to increased uncertainty. Depending on the realities of future climate change, a more significant step change in investment in natural environment solutions may be necessary; however, PES has currently conceived and implemented is unlikely to assist in adapting to the long-term impacts of climate change.

Climate change is projected to result in changes in long-term climatic averages. It is also projected to result in increased frequency of extreme weather events such as droughts and floods. Natural environment solutions are typically not well-suited to addressing the projected increased frequency of extreme weather events, because they usually involve longer timeframes before benefits are realised. Generally, hard infrastructure solutions will be better-suited for addressing extreme weather events as they can be implemented relatively quickly and provide comfort to the community that the threat to life and property will be reduced promptly (e.g. flood defence mechanisms). However, natural environment solutions are arguably better-suited for addressing changes in long term averages because they are relatively low cost and typically low-regrets, with the potential to provide multiple benefits.

Despite these advantages, it can still be difficult to create a compelling business case for investments because of the disconnect between ecosystem timeframes, which are typically longer term and those of potential beneficiaries and buyers of ecosystem services, which are typically shorter-term. To overcome this challenge, we are likely to need to develop new approaches to representing the business case for investment in natural environment solutions. The Ecosystem Markets Task Force has highlighted concerns over the time horizons for water resources planning: *"Investments in ecosystem restoration to manage water supplies might be more attractive options if appraised over a longer timescale, as large scale catchment management programmes can take long periods to implement, and may also be more likely to achieve the necessary ecosystem changes. A longer time horizon would more realistically reflect the lifetimes of built capital assets, and the sustainability of returns from ecosystems"*.[165]

3. Finding new means to aggregate buyers and facilitate collective action

Assuming that the case for establishing PES schemes premised on flood risk management through natural environment solutions can be increasingly made, the question of arises of how best to aggregate the beneficiaries and transform them into buyers in order to make schemes a reality. In the case of a PES scheme focused on restoring a natural floodplain, the beneficiaries may be households and businesses spread over a reasonably wide area and it is currently difficult to envisage the mechanism(s) through which they might be brought together. In order to overcome these so-called collective action problems, a supporting institutional

[165] Ecosystem Markets Task Force (2013). Realising nature's value: The Final Report of the Ecosystem Markets Task Force [online] available at: www.defra.gov.uk/ecosystem-markets/files/Ecosystem-Markets-Task-Force-Final-Report-.pdf (accessed 15 August 2013).

environment is needed.[166] Moreover, the Committee on Climate Change's Adaptation Sub-Committee's 2012 progress report on flooding suggested that *"In principle individual households and businesses should be willing to cover the costs of property-level flood protection because they receive the benefits. However, the upfront costs and uncertain benefits mean that households and businesses may not be willing to invest in these measures on a significant scale"*.[167] In the case of flood risk, there is a movement towards a PES approach in this area, with the new Partnership Funding arrangements in England seeking to increase contributions from local beneficiaries.[168] The emergence of intermediaries or brokers able to bring together local households and businesses and persuade them of the merits of collectively investing in natural environment-based solutions will be critical.

With respect to PES schemes which feature interventions with climate change adaptation benefits such as new green infrastructure in urban areas, it will also be necessary to develop new means to aggregate beneficiaries. When it comes to funding a major piece of urban green infrastructure, it is again difficult to envisage the mechanism(s) through which beneficiaries will be effectively brought together and transformed into willing buyers. Again, intermediaries or brokers will be necessary in order to facilitate households and businesses coming together and contributing to green infrastructure provision. Furthermore, whereas the beneficiaries within a catchment may be identified with relative ease, the beneficiaries of green infrastructure will be more difficult to identify with confidence. For example, if the green infrastructure is of more than local significance, should users from further afield be encouraged to contribute financially to its upkeep? One approach would be to establish a spatial boundary with regards to the presumed beneficiaries; for example, a scheme for conserving the Wimbledon and Putney Commons involves an annual levy on all those living within ¾ of a mile of the commons who are assumed to benefit from the services they provide.[169]

4. Implementing monitoring and evaluation to understand efficacy

Related to the preceding recommendations, workshop participants reinforced the need for the development and implementation of monitoring and evaluation plans that allow the efficacy (or otherwise) of the scheme to be established. The Defra Best Practice Guide on Payments for Ecosystem Services[170] defines effective monitoring as monitoring that is: cost-effective; accurate, bias free; replicable; and timely. Importantly, the monitoring programme should also be designed to take into account effects on other ecosystem services not included within the scheme.

A key component of effective monitoring is the establishment of a baseline for the ecosystem service that is being marketed and, where possible, any other key ecosystem services linked to it. This is particularly important in schemes that are designed to enhance climate change adaptation because the evidence between the contributions made by natural environment solutions to improvements in climate change resilience is the subject of on-going research.

[166] Food and Agricultural Organization of the United Nations (2007). The State of Food and Agriculture 2007: Paying Farmers for Environmental Services [online] available at: ftp://ftp.fao.org/docrep/fao/010/a1200e/a1200e00.pdf (accessed 15 August 2013).
[167] Adaptation Sub-Committee (2012). Climate change – is the UK preparing for flooding and water scarcity? (Adaptation Sub-Committee progress report 2012) [online] available at: www.theccc.org.uk/publication/climate-change-is-the-uk-preparing-for-flooding-and-water-scarcity-3rd-progress-report-2012/ (accessed 15 August 2013).
[168] Defra (2013). Developing the potential for Payments for Ecosystem Services: an Action Plan [online] available at: www.gov.uk/government/uploads/system/uploads/attachment_data/file/200889/pb13918-pes-actionplan-20130522.pdf (accessed 15 August 2013).
[169] Since 1st April 1991, the Commons have been largely financed by means of a levy on the Boroughs of Wandsworth, Merton and Kingston in a proportion relevant to the number of "D" Band properties in each Borough within 3/4 mile of the Commons or in the old Parish of Putney. The Boroughs pass on this levy by way of an addition to the Council Tax on properties in the area. For further information see www.wpcc.org.uk/commons.html.
[170] Smith, S., Rowcroft, P., Everard, M., Couldrick, L., Reed, M., Rogers, H., Quick, T., Eves, C. and White, C. (2013). Payments for Ecosystem Services: A Best Practice Guide. Defra, London. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/200920/pb13932-pes-bestpractice-20130522.pdf (last accessed 28/05/2013).

5. **Pilot studies to inform the feasibility of natural environment solutions**

There is a lack of evidence from which to draw experience and lessons learned from the practical application of PES in the context of seeking to enhance climate change adaptation. More information is required about, for example, how the insurance sector could play a larger role in the market for ecosystem services; or how local planning authorities could be encouraged to contribute to flood risk insurance.

A series of pilot studies (or at least an evaluation of existing PES schemes) designed specifically to explore the efficacy and feasibility of different models of mobilising both public and private sector engagement in PES is considered to be a key step towards understanding how PES can be used to enhance efforts to adapt to a changing climate. This may include, for example, developing a clearer understanding of the drivers for climate action amongst different groups of buyers, the scale(s) at which they operate and the potential for public-private partnerships.

7.2 Further research

In addition to the opportunities and challenges already discussed, the following list of questions arose throughout the project for which resolutions were not immediately available. It is considered that further research into these questions could help to advance not just the consideration of the role of PES in facilitating adaptation to climate change, but also PES scheme design more generally.

7. ***What do climate-friendly natural environment solutions look like?*** How can climate change be incorporated within such solutions? For example, will new urban green spaces have to be planted with drought-resistant species?

8. ***Issues of scale:*** Could a number of small scale PES schemes, geographically dispersed, achieve the same results as fewer, larger schemes, in terms of enhancing adaptation to climate change? For example, could small reforestation projects scattered across a catchment achieve the same as a single, large scale reforestation project?

9. ***Beneficiary identification:*** Who are the beneficiaries of specific natural environment solutions for climate change adaptation? Can they be readily identified? How can free-riders be encouraged to contribute?

10. ***Buyer identification:*** Who are the buyers of the ecosystem services? How do we address the differing spatial catchment of buyers? For example office workers that have direct access to an urban green space relative to those that have to travel further to enjoy the benefits. How can a PES scheme designed to enhance climate change adaptation through the provision of urban green spaces be designed to account for different buyers?

11. ***Financial mechanisms:*** What mechanisms are available to fund natural environment solutions? If different degrees of benefit are obtained by different beneficiaries, how should payment/funding be arranged? Should payment be flat-based or should it vary depending on level of benefit derived by the buyer?

    Can new buyers and instruments be introduced to the market? For example, can local planning authorities pay insurance on behalf of citizens? Can the Environmental Stewardship component of the Rural Development Programme for England be utilised as a vehicle for greater consideration of natural environment solutions to enhance climate change adaptation?

    Are buyers more likely to respond to payment structures that include only maintenance costs, which are likely to be relatively small, periodic payments and offer greater flexibility for mobile populations? Or can they be induced to cover capital costs, which are likely to once-off, larger payments?

12. ***Monitoring/measurement:*** Which organisations will undertake monitoring / measurement / verification of the benefits? What are the necessary pre-requisites of such organisations to engender trust from buyers and sellers? Will they be in operation long enough to keep step with the time period over which climate change adaptation is likely to be experienced?

    If direct measures of climate change adaptation cannot be identified, what are suitable proxies? For example, a measure may be designed to reduce the probability of a 1:100 year flood, but how can this be confirmed without being able to measure the new flood return interval?

APPENDIX A WORKSHOP PARTICIPANTS

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9	Lili	**Pechey**	URS (Project Team)
10	Mike	**Render**	Forestry Commission England
11	Petrina	**Rowcroft**	URS (Project Team)
12	Colin	**Smith**	Defra
13	Steven	**Smith**	URS (Project Team)
14	Sarah	**Taylor**	Natural England
15	Chris	**White**	URS (Project Team)