The Economic Case for Investment in Natural Capital in England:

LAND USE APPENDIX

Final Report

For the Natural Capital Committee

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INVESTMENT CASE - UPLAND PEATLAND

SUMMARY

- The case for improving the condition of 140,000 ha or more of upland deep peatland in England can be made solely on carbon benefits, with a net present value around £500m over 40yrs. Additional biodiversity benefits might total hundreds of millions over 40yrs.
- Improving 20,000 ha or more upland peatland might deliver regulating services (water quantity) leading to flood risk mitigation benefits. There is some overlap between the locations of these improvements and the locations for highest carbon benefits.
- A rough approximation of the costs and benefit of upland peatland improvement shows benefits for water quality regulating services to be in the order of millions of pounds. Examples of partnerships between water companies and land-owning charities reinforce this.

Investment:
To improve the condition of 140,000 ha of degraded upland deep peatland areas to blanket bog in England.

Baseline:
The total area of upland deep peat is 350k ha, over 90% is thought to be degraded and between 20k and 60k ha may be undergoing improvement.

Threats:
There are multiple drivers of degradation of peatlands: drainage, overgrazing, afforestation, visitor pressure, burning and atmospheric deposition.

Monetised costs:
Natural England (2011) estimates of costs are used in the economic analysis. This captures CAPEX and opportunity costs for a range of actions: preventing overgrazing; re-seeding of bare peat; blocking grips; hagged/gully blocking; reduced intensity/cessation of moorland burning. Other CAPEX, OPEX and opportunity cost estimates from the literature are also presented.

Monetised benefits:
Natural England (2011) estimates of benefits are used (but are not identified separately from the NPV estimates below). These are associated with specified emissions factors and the associated avoided cost of CO_2 mitigation. Enhanced value of species diversity potentially amounts to an additional £304million over 40yrs. The total impact of water quality regulation is estimated to be in the order of millions of pounds a year.

Non-monetised costs:
None

Non-monetised benefits:
The estimated potential area of peatland most important for water quantity regulation services is 20,733ha based on interpretation of drivers of economic value and spatial datasets (via GIS). Landscape and recreational benefits are also likely provided but not possible to link to peatland improvement or express in monetary terms in this context.

NPV:
Two sets of spatial data were used to estimate NPVs:

1. NE (2010) spatial data on all peatland of all conditions considered the strongest investment case (with highest NPVs over 40yrs) is made for upland peatland that is currently under rotational burning (£470m/£3,266/ha); eroded/gullied (£310m/£5,920/ha), overgrazed (£160m/£3,624/ha) and/or gripped (£100m/£1,113/ha). These areas overlap to some extent so these values are not additional. Assuming complete overlap of categorisations, the smallest area of upland deep peat to improve is around 140,000ha.

2. Using the NE (2013) spatial data on upland deep peatland, an investment case is made for an area covering 140,737ha totalling NPV of £560m (over 40yrs). Of all peatland conditions to improve, the strongest case is made for hagged/gullied (£194m/£5,970/ha); under rotational burning (£167m/£3,266/ha); gripped and burnt (£97m/£4,379/ha), and hagged and burnt (£29m/£9,236/ha).

Time period:
40yrs, as this is the time period for the underlying analysis by Natural England, 2011.

Key assumptions/uncertainties:
The key assumptions are on the attribution of specific improvement actions across each peatland condition category. The NPVs are from the NE (2011) analysis and are based on average reduction in CO_2 multiplied by the non-traded price of carbon (DECC, 2009). In reality this will vary depending on the current condition and location of peatland. Comparison of the emissions factors used in the NE (2011) analysis (2.19 to 4.95 t/CO_2-e/ha/yr) with the pilot peatland code work (2.54 and 23.84 t/CO_2-e/ha/yr; Crichton Carbon Centre, forthcoming) suggests that the net carbon savings may be underestimated. Opportunity cost is measured using HLS payments. NE analysis (2011) assumes that CAPEX is incurred in year one, opportunity costs incurred and benefits delivered are consistent from years 1 to 40 years.

Additionality:
There are already significant peatland improvement projects underway in England, estimated to cover 60k ha. It is unclear how much of this improvement work is reflected in the GIS data used in the current analysis, but given the lag in recovery of peatlands to good condition, it is likely that the GIS analysis used here overestimates the area requiring action.

Synergies/conflicts:
Investments in catchment management and coordination actions will also help improve the condition of peat bogs, which in turn will improve its water regulating functions. There is an opportunity cost associated with improving land uses that currently provide some types of provisioning services (e.g. grouse shooting from upland areas). Further work is needed to assess the net impacts of improving peatland given these opportunity costs.

Scalability:
The benefits of avoiding loss of stored carbon and benefits of water regulation which are specific to individual catchments do not diminish over a large scale. The benefits to biodiversity could be expected to be constant across large scales, or even increase with scale as ecological networks are enhanced. However, we would expect the monetary value of these benefits to have diminishing returns to scale[1] over the large areas involved. Limitations of current capacity to implement investments may increase costs of carrying out actions on a very large scale too quickly (100,000 ha plus per year).

Impact on natural capital assets:
The specific natural capital assets associated with this investment are species (e.g. Spagnum moss), ecological communities (e.g. blanket bog, heath biomass/vegetation) and soils (e.g. organic matter). Crucially, the investment would improve the quality of these assets but also their extent and location relative to beneficiaries, for ecosystem service provision.

Distribution (over time):
The investment case assumes that carbon benefits begin in the first year after the commencement of capital works and remain the same each year over 40year period

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[1] i.e. the incremental benefit of an extra ha would decrease as the total area increases.

Distribution (over space):

Fig S1. Map of upland peat areas where investment case can be made for carbon benefits (using central shadow price of carbon. NE, 2010; 2011) (based on currently available information)

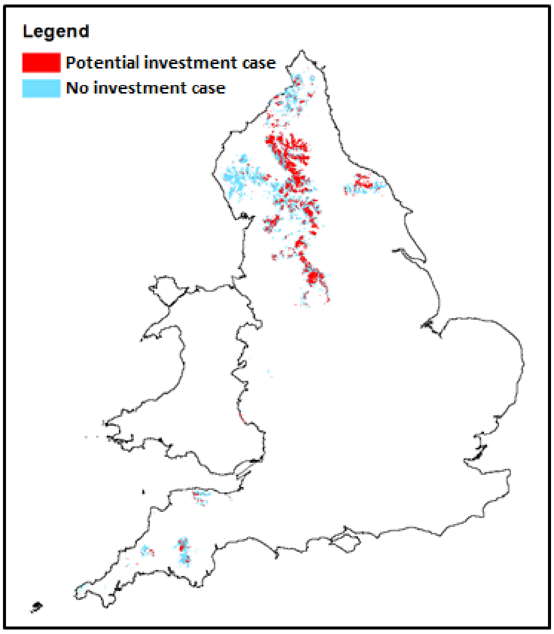
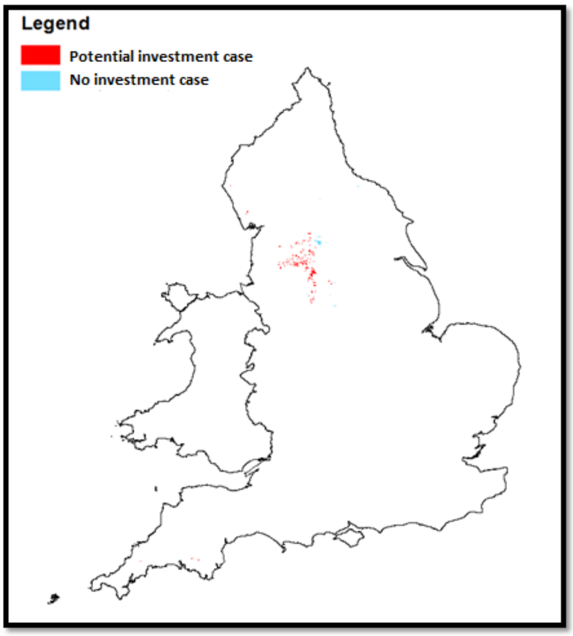


Fig S2. Map of peatland in upland areas, where investment case can be made for water quantity regulating benefits (NE, 2010; 2011)
(based on currently available information)



Note: 'No investment case' reflects the conclusions of this analysis, so is subject to the caveats and data limitations involved; conclusions are indicative of the spatial scale of the potential investment.

Case study example:

The Keighley catchment in Yorkshire covers an area of 4,369 ha. Farming and game hunting are the predominant land-use. 1,345ha is peatland, providing carbon storage and sequestration and water quality regulation ecosystem services. 37.5% of the catchment is designated SSSI (163 ha); which is crossed by the Pennine way. Farming is an important land use, and a significant part of the moorland is managed for grouse shooting. Benefits of improving habitats to increase levels of multiple ecosystem services were assessed.

Using Higher Level Stewardship (HLS) options to construct tailored measures for the catchment the cost is estimated to be approximately £3.2 million, of which over half are capital costs associated with blocking grips and gullies, re-seeding bare peat and woodland planting (i.e. not just related to peatland). The improvement included re-wetting 1,248ha of degraded peat bog. Valuation was approached in two ways: (i) Christie et al (2011) values for biodiversity which produced a net present value (NPV) over 25 years for 'improve' scenario of £1m with a benefit cost ratio range of1.31 and (ii) UKNEA (2011) values for biodiversity, Yorkshire Water estimates for water regulating benefits and also DECC (2009) values for carbon benefits which produced an NPV over 25 years for 'improve' scenario of £6.3m benefit cost ratio range of 2.96.

1. INTRODUCTION

This investment case focuses on the benefits that can be gained from improving the condition of upland deep peatland in England. The investment case finds the area and location (via the use of spatial data in GIS) of where upland peat is currently degraded and hence there is the potential for improvement based on the potential to deliver different ecosystem services. It uses NE spatial data on condition in 2010 (NE, 2010) and 2012 (NE, 2012) so that a range of NPV estimates can be produced acknowledging different condition categorisations used in each dataset.

The case then determines what actions can be undertaken to improve the peatland area identified and what the net economic impact is of these actions. For carbon, this is done through using NE (2011) information on the net present value of improving 140,000ha of peatland identified as having greatest potential carbon benefits. The biodiversity and landscape benefits of this area are estimated based on figures from Christie et al (2011).

For water quantity regulating benefits, economic valuation is not possible in this project but the area (20,733ha) over which the strongest investment case can be made is identified (via GIS) based on interpretation of economic drivers of value (i.e. areas upstream and in close proximity to population). Assuming overlap of this spatial area with the provision of water quality benefits, estimates of benefits of avoided treatment costs are taken from the Keighley Moor case study (NE, 2012b). A range of NPV estimates is produced based on assumptions regarding the overlap of the location of ecosystem service provision and therefore the sharing of costs. If it is assumed that water quality and carbon actions are taken in the same areas, the cost based is shared and benefits from avoided treatment cost are all additional. Where no overlap in the location of improvements is assumed the average costs from the NE (2011) analysis is used to produce (a lower) net benefit figure.

Following this introduction, Section 2 provides a definition of the natural capital asset, specifically the improvement of upland deep peatland to blanket bog. Section 3 outlines the current status and trend of the asset using a range of data sources. Whilst estimates of extent are consistently around 350,000ha, the estimates of the area under improvement vary as there is no systematic monitoring of condition. Section 4 explains the threats/drivers leading to degradation of the asset.

Section 5 describes possible improvement actions as described in the literature but focusing the investment case specifically on the improvement actions outlined in NE (2011). Section 6 presents the costs of improvement actions developed in the NE (2011) analysis and used in this investment case. Costs are broken down into capital costs (CAPEX), operational costs (OPEX) and opportunity costs where possible. A comparison of these figures with other total cost estimates from the literature is made.

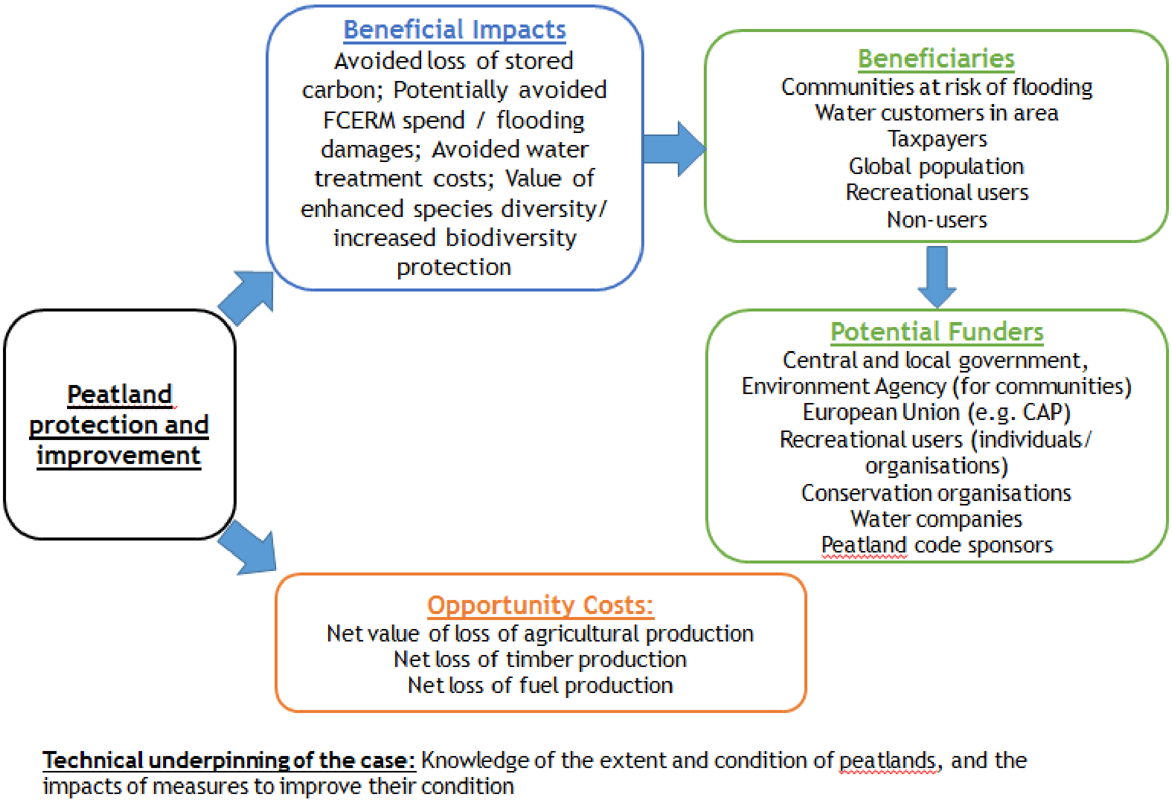
Section 7 provides a review of benefits information associated with peatland improvement for a range of ecosystem service benefits. This includes the specific per tCO_2e/ha/yr carbon values and per ha biodiversity values used in the investment case analysis. Comparison of the emissions factors used in the NE (2011) analysis with those in the pilot peatland code work from the Crichton Carbon Centre (forthcoming) suggests that the net carbon savings may be underestimated in this investment case.

Section 8 then provides the ‘investment case’ proper in that it sets out the estimated net present value of improving peatland areas in different conditions based on linking the NE (2010) and NE (2012a) spatial data on peatland condition and NE (2011) data on net present values of improving peatland. These are average NPVs and will vary depending on the current condition and location of peatland. Areas of peatland that are likely to have the highest NPVs for both carbon and water quantity regulating benefits are isolated from the total peatland area based on interpretation of drivers of economic value and GIS maps are produced illustrating these areas. It also describes the feasibility/uncertainty of these estimates.

Section 9 summarises the investment case through figures that link the ecological condition of peatland to economic outputs associated with improvement. Section 10 provides some more specific examples of peatland restoration in Yorkshire and Wales.

Figure 1.1 is a value chain which shows the links between peatland improvement actions and costs, changes to ecosystem service provision, the benefits produced and who might benefit as well as who might fund the improvement actions and what the likely opportunity costs of undertaking improvement action are.

Figure 1.1: Peatland value chain



2. ASSET DESCRIPTION

This section sets out the natural capital asset and ecosystem service of concern for improvement and how improvement is measured.

The starting point for this investment case was the potential to improve upland peatland areas to blanket bog in England. ‘Peatland’ is a term used to describe peat soils (>30-40cm peat), or peatland habitats (JNCC 2011) consisting of partially decomposed vegetable matter fed by rainwater.

This definition means that there are a number of broad habitats and sub-habitats associated with peatlands: blanket bog, heathlands, woodland, acid grassland and enclosed farmlands. There are also a number of different natural capital asset combinations including species poor Molinia dominated peat, calcium rich flushes, and there are peatlands in different conditions: degraded bog, areas of bare peat. This forms a complex mix of habitat types and natural capital assets within a landscape all associated with peatland, all of which could potentially lead to societal benefits if improved to blanket bog or to an improved state of blanket bog.

Blanket bogs are a priority habitat under the UK Biodiversity Action Plan consisting of ombrotrophic extensive bog communities or landscapes with poor surface drainage typically forming in upland areas with high rainfall. They are peat forming habitats, consisting of plants such as heather, sphagnum, cotton grasses and sundews.

The specific natural capital assets associated with this investment are species (e.g. Spagnum moss), ecological communities (e.g. blanket bog, heath biomass/vegetation) and soils (e.g. organic matter). These assets are important in determining the capacity of peatland to retain stored carbon, nutrient cycling/ availability / concentrations (TOC, nitrate, phosphate, ammonium), pollutant absorption, erosion, water holding capacity and water infiltration.

The measurement of improvement is through a metric reporting the integrity of functions (e.g. peat formation) and/or the quantity and quality of ecosystem service provision. Holden et al (2008) find that 50 out of 56 recent/current peatland improvement projects focused on the improvement of functionality through achieving favourable SSSI (Site of Special Scientific Interest) status. This may be a good surrogate for the success of improvement as intact blanket bog vegetation is likely to indicate integrity of functions. In the same way, much of the literature refers to improvement to ‘near natural’ peatland, on the premise that this will lead to a improvement of ecosystem functionality. Improved hydrological function is also used as a measure of improvement success: improving water quality (primarily discolouration of water but other parameters are also monitored for WFD compliance (Crouch et al., 2013)) and controlling water quantity (regulating flow and flood mitigation). Reducing carbon emissions and improving carbon sequestration are cited as reasons for carrying out improvement and have increased in importance in recent years.

3. BASELINE

This section sets out the current status and trend of the asset and ecosystem service provision.

3.1 Extent and condition of peatland

England's upland deep peatlands are distributed across the Pennines, Peak district, Dartmoor, Exmoor, North York moors.

Spatial data by Natural England (NE, 2010) on peatland condition was used as a starting point for the analysis. This dataset covered all peatland areas in England including upland and lowland, shallow and deep peatland. In order to focus on the area covered by upland peatland, the Moorland line was used, and to ensure only deep peatland (blanket bog) was covered, degraded states that are only found in uplands were included, specifically bare peat, rotational burning, eroded, gripped, Molinia dominated and overgrazed.

England's peatlands face degradation from a variety of land-uses; such as drainage for agriculture, forests and/or as a result of water and air pollution. Table 3.1 shows that at least 50% of what has previously been deep peat is no longer classed as 'bog', but has changed to another land use type (i.e. heath, grassland, woodland)(ASC, 2013) but potentially up to 89% being converted to another land use (NE, 2010). The classification of degradation differs across the literature, some simply report total degraded peatland area (NE, 2010), others report degraded area by prevailing land use (NE, 2010a; ASC, 2013) and others describe the amount of peatland under improvement or that has been improved (Holden et al, 2008; Worrall et al, 2011). Table 3.1 shows that the extent of upland deep peats that are, or were at some point, consistently estimated to be around 355,000ha.

There has been a decline in the extent and condition of England's blanket bog habitat over time. This investment case uses data from NE (2010) and NE (2012a) as shown in Table 3.1.

Table 3.1: Estimated extent and condition of upland deep peatland

Source	Upland deep peatland area		Condition of degraded upland deep peat (ha)
	Total (ha)	Degraded (ha)	
NE (2010)	-	-	**Bare peat: 4,209** **Rotational burning: 143,865** **Eroded (hagged / gullied): 51,721** **Gripped: 88,714** **Molinia (purple moor-grass) dominated: 5,364** **Overgrazed: 45,415**
NE (2012a)	320,570	-	**Peat with no category: 178,882** **Burnt only: 51,194** **Hagged/ Gullied only: 32,428** **Gripped only: 24,826** **Gripped and Burnt: 22,063** **Hagged, Bare, Burnt and/or Gripped: 9,155** **Peat cutting only: 1,065** **Peat cut and Gripped: 6** **Excluded areas: 951**
Natural England (2010)	Blanket bog ~355,300*	346,200	Various states of degradation: 346,200 Improved: 4,600 ha

Source	Upland deep peatland area		Condition of degraded upland deep peat (ha)
	Total (ha)	Degraded (ha)	
Holden et al (2008)	-	-	Bog under improvement: 15,700
Worrall et al (2011)	-	-	Drainage gripping: 11% ‘Actively eroding’ state: 7% Bog under improvement >20,000
Evans & Warburton (2007)			UK peatland upland area seriously eroding: 10-30%
UK BAP (JNCC, 2013)	Blanket Bog 244,536	46%	54% in a favourable condition
Adaptation Sub-Committee (2013)	~355,500	160,000ha under another land use; Acidification and heavy metal contamination in 98% of upland peat	Now more like heathland (from draining and burning): 98,000 Dominated by grassland (drainage and grazing): 32,000 Wooded (mainly plantations): 32,500 Drained: 75,000 Gullied: 50,000; Overgrazed: 30,000 Lost to development (mineral extraction, landfill, wind turbines): ~1,000

*(double the amount estimated by Countryside Survey (2007), a more floristically sample based estimate)

Moxey and Moran (2014) concluded that over 80% of UK peatland habitats are degraded and improvement should be undertaken to help meet climate change, water management (WFD) and biodiversity (BAP) targets. The area of active blanket bog (a key peat-forming habitat) was assessed as declining by <1% per annum across the UK for the period 1990-1998 (JNCC, 2007). More recently there have been many projects focused on improvement but the most conservative estimate is that 15,000 ha is under some form of improvement out of a total around 355 000 ha. Evans & Warburton (2007) estimated that 10-30% of the UK peatland upland area was subject to serious erosion. Peatland erosion is accentuated in known ‘hotspots’, where gullying erosion has taken hold (e.g. 34% of the Bleaklow plateau in the south Pennines (Evans & Lindsay, 2010)). Worrall *et al*. (2011) estimated that 11% of the upland peat area in England is subject to drainage gripping (35,262ha), with 7% (22,439ha) being in an ‘actively eroding’ state. There are differing estimates of the area under improvement but there is no systematic monitoring of improvement so these estimates are uncertain. It is estimated that about 60,000ha of upland peat has already been improved by partnerships among water companies and land-owning charities (RSPB, National Trust) between 2010 and 2015. Estimates of the area currently under improvement are between 15,700 ha and 20,000 ha (Worrall *et al*., 2011; Holden et al., 2008).

3.2 Carbon store (avoided emissions) and sequestration

There are estimated to be 138 million tonnes of carbon in England’s blanket bog peat soils (NE, 2010). Peatlands can act as either a natural sink or a net source of greenhouse gas (GHGs) depending on their condition and management (Moxey, 2011). NE (2010) states that less than 20,000 tonnes of carbon dioxide a year are sequestered by undamaged blanket bogs and that most of the peatlands in upland areas (where the majority of England’s peats lie) are sources of GHG, but some are still able to capture carbon.

Further work is needed to assess the expected changes in peatland condition over time due to the threats explained in the next section. The NE (2011) analysis does not factor in a deteriorating (or improving) baseline but assumes a constant baseline condition. Annex 1 sets out the carbon emissions factors used in this investment case as well as those developed in the work underpinning the pilot peatland code from the Crichton Carbon Centre (forthcoming).

3.3 Water quantity and quality regulation

Peatlands influence flood regulation (Bonn et al, 2010). Whilst undamaged peatlands are waterlogged and so have very little ability to store additional water during heavy rainfall events (Bain et al., 2011), the rate of runoff is influenced by peatland condition. The rate at which water leaves a peatland is accelerated by drainage channels and the loss of vegetation, where areas of bare peat can become so dry that water will no longer infiltrate (ASC, 2013).

Upland areas provide about 70% of the UK's total drinking water (Defra, 2011). There is evidence that damaged peatlands can negatively affect the delivery of water related ecosystem services and strong evidence for rapid ecological responses to peatland restoration related to reduced suspended sediment loads (Martin-Ortega et al, 2014). Degraded peatlands can lead to increased sediment and phosphate loadings into river catchments as well as dissolved organic carbon leading to water colouration, which results in higher treatment costs.

3.4 Biodiversity and landscape (amenity value)

Both upland and lowland peatlands can be rich in biodiversity and landscape values. These provide a range of non-market values and also underpin, directly or indirectly, a variety of commercial activities such as farming and tourism (Moxey, 2011; NE, 2011).

4. THREATS

This section sets out the nature of the threat/driver leading to the current degraded condition of natural capital.

There are multiple drivers of degradation of peatlands; drainage, grazing, afforestation (although it may increase carbon sequestration in some ways, it also lowers the water table and increases peat erosion), peat extraction, visitor pressure, burning (promotes vegetation closer to heathland than blanket bog) and atmospheric deposition (which can cause loss of key species particularly sphagnum). These may result in a loss of typical bog plants and increase in drier species, erosion of peat, increased carbon export and water colour, decreased methane emissions but increases in carbon dioxide emissions.

The different drivers interact with each other and will also interact with climate change. Clark *et al (*2010) examined the current topographic and climatic conditions in the areas where upland peats occur in the UK and noted that, under the most recent climate change projections, these conditions would become more restricted geographically in 50 or 100 years' time (JNCC 2011). The majority of upland peat is not in a sufficiently good condition for current assemblages of peat-forming vegetation to persist or for new peat-forming assemblages to colonise in the face of climate change (Adaption Sub-Committee, 2013).

5. IMPROVEMENT ACTIONS

This section sets out the potential improvement actions and the subsequent management regime.

The investment case focuses on improving the condition of degraded sites towards that of near natural peatlands, assuming that this is associated with a improvement in ecosystem functionality and service provision.

Improvement involves modifying or ceasing current damaging activities plus, in most cases, remedial actions to stabilise, re-wet and/or re-vegetate damaged sites. It typically involves (Moxey, 2011; NE, 2011; Moxey and Moran, 2014) raising the water table nearer to the surface and re-establishing peat forming fen or bog vegetation. Grip blocking and gully blocking are the most widely applied technique (blocking using peat turves, plastic piles, wooden dams, heather bales, straw bales and stone) (Cris et al., 2011, Holden et al. 2008, Shephard 2013, Genk et al.,) to re-wet the peat and increase water levels, other techniques may also be required e.g. peat bunding and sluiceways.

Other improvement actions include stabilisation (spreading heather brash, applying geojute), peat reprofiling (removing overhanging peat), re-vegetation (with heather, cotton grass or Sphagnum (Shepherd, 2013; Caporn, 2007)) possibly with the addition of lime or fertiliser (Shepherd, 2013), planting (where natural succession slow planting with plug plants of bilberry, crowberry, hare-tail, common cotton grass and cloudberry), vegetation removal (removal of undesirable species), mowing (to control rushes and Molinia) and reduction of grazing or stock exclusion (Holden et al 2008). Sites will vary according to whether a number of simultaneous actions are required or whether one action is sufficient. Projects also employ ongoing management techniques to improve/maintain good site condition and employ sustainable management practices including mowing, selecting the most appropriate grazing regime, burning or cessation of burning and scrub clearance (Holden et al., 2008).

This investment case focuses on the following peatland improvement options which have been identified from NE evidence (NE, 2011, 2010) as described and explained in Table 5.1.

Table 5.1: Upland deep peatland improvement action description and explanations

Description	Explanation
Preventing overgrazing	reduce stocking rates or complete removal of any grazing
Reseeding of bare peat	Seeding with dwarf shrub and nurse grass or Sphagnum. Possibly addition of lime or fertiliser, plug plants of bilberry, crowberry, hare-tail, common cotton grass and cloudberry, spreading of heather brash, application of geojute, reprofiling overhanging peat
Stabilisation of bare peat (hagged)	Re-seeding, spreading of heather brash, application of geojute, reprofiling overhanging peat
Blocking grips	Blocking of drainage ditches (grips) and gullies
Planting bare peat	Plug plants of bilberry, crowberry, hare-tail, common cotton grass and cloudberry
Gully blocking	blocking of erosion channels (Gullies) with plastic piling, peat, wood, stone bunding
Reduction of rotational burning	reducing the intensity and/or rotations of controlled burns or completely ceasing burning regimes all together

6. COSTS

This section sets out the cost of improvement action and subsequent management regime.

6.1 Capital costs (CAPEX)

Improvement incurs upfront expenditure on capital and there will be variation between sites as to whether a number of simultaneous improvement actions are required or whether one action is sufficient. For example, simple grip blocking may cost only a few hundred pounds per hectare, but scrub clearance and re-seeding can cost several thousand, even more for remote sites (Moxey and Moran, 2014). Illustrative range of £200/ha to £7,000/ha is indicated in the literature but without any accompanying baseline information on the level of degradation making a marginal change in functionality and ecosystem service (benefit) provision hard to identify.

Capital costs are likely to vary spatially, being relatively high for badly degraded sites and low for lightly degraded sites as well as by accessibility for improvement with more remote sites having higher costs. Therefore they vary according to baseline condition (extent of peatland and severity of degradation), location and by the choice of improvement activity. Capital costs provided by ASC (2013) for improvement activities are set out in Table 6.1 alongside those used in the calculations for this investment case from NE (2011). Costs for stabilising bare peat have not been available because it can be combined with other options

Table 6.1: Capital cost estimates of upland deep peatland improvement

Improvement Options	Capital Costs (£/ha)		
	ASC (2013)		NE (2011)
	Low	High	
Preventing overgrazing	0	3,000	**60**
Re-seeding of bare peat	200	7,000	**497.50**
Stabilisation of bare peat (hagged)	-	-	**1,700**
Blocking grips	150	600	**1,875**
Planting bare peat	-	-	**2,700**
Hagged/gully blocking	1,000	4,000	**2,500**
Reduction of moorland burning	0	300*	**164**

*high-end estimate of the capital cost is because reduced burning often occurs in tandem with grip blocking

Median improvement costs are estimated at around £1,500 per ha (PV of investment and maintenance over 30 years) (Moxey and Moran, 2014). However, although some extremely degraded bare peat sites and some lowland sites requiring land acquisitions can be even costlier, more typical grip blocking improvement may cost nearer to £240/ha (Moxey, 2011). Costs will also be impacted by other factors such as location – ease of access for improvement - remote uplands increases material delivery costs.

6.2 Operational expenditure (OPEX) and opportunity costs

The need for ongoing management/monitoring of the improvement process may well decline provided that the early stages of improvement management put the system on the path to recovery. **Table 6.5** shows ongoing costs provided by ASC (2013), although in some cases these include opportunity costs also, with a range of £25/ha to £200/ha. The lower end of this range reflects minimal monitoring costs with no management or opportunity costs and the upper end reflects high opportunity costs and/or high management and monitoring costs. The NE (2011) analysis used in this investment case did not consider ongoing costs but only opportunity costs based on income foregone from HLS payments and these seem to be broadly consistent with those set out by the ASC.

Opportunity costs for different sites will vary. Opportunity costs are typically higher in lowland peat where intensive and profitable land uses are generally more feasible, leading to the displacement of activities such as agriculture. The uplands support around 3 million sheep, which equates to roughly 45% of the national stock, they will typically have lower opportunity costs. However, grouse shooting is one of the major land uses in the uplands and is the most significant barrier to delivering widespread improvement (Thompson, D, pers comm, December 2014). The £150/ha to £200/ha in Table 6.2 is the ASC (2013) high-end estimate of the opportunity costs from changing land use from grouse shooting. The NE (2011) figures used in the calculations for this investment case are also set out. The opportunity costs identified in the NE (2011) analysis were HLS payments, that might not adequately reflect these costs associated with grouse shooting.

Table 6.2: Ongoing cost estimates of upland deep peatland improvement

Improvement Options	Ongoing costs* (£/ha/yr)		Opportunity costs (£/ha/yr)
	ASC (2013)		NE (2011)
	Low	High	
Preventing overgrazing	25	150**	**40**
Re-seeding of bare peat	25	100	**50**
Stabilisation of bare peat (hagged)	-	-	**50**
Blocking grips	25	200**	**50**
Planting bare peat	-	-	**50**
Hagged/gully blocking	25	100	**50**
Cessation of moorland burning	25	200**	**380**

*Costs exclude opportunity costs unless marked with ** which include opportunity costs (associated with grouse shooting).

Whilst current land use does increase cost (exclusion of livestock), the overall impact on current profitability and the degree of displacement by peatland improvement (e.g. can agriculture still operate) are uncertain.

7. BENEFITS

This section sets out the improvement in ecosystem service provision (benefit) associated with improvement and the change in the profile of these flows over time (qualitative, quantitative and monetary evidence).

Benefits associated with peatland improvement are highly variable as a result of heterogeneity across sites over time, and therefore subject to uncertainty (Moxey, 2011). In most cases, improving the integrity and functionality of blanket bogs results in the joint generation of ecosystem services, although linkages between these benefits are not always easy to describe or to ascribe monetary values to. For example, maintenance and improvement carried out primarily to reduce GHG emissions may provide other ancillary benefits in terms of water quality and biodiversity.

7.1 Climate regulation

Improvement of degraded sites should result in a reduction in CO_2 emissions (see below) and CO_2 sequestration by peat accumulation given the appropriate management, the maintenance of a near natural site will also avoid potential emissions that might occur and actively sequester additional carbon (Moxey, 2011). Illustrative figures from Moxey (2011) suggest that a near natural peat bog may sequester around 0.6t CO_2e per ha/year, but a degraded site may emit 2.9t CO_2e per ha/year. The difference is approximately 3.5t CO_2e per ha/year. Lightly degraded sites are generally associated with lower emissions and good ecosystem functionality and likely to result in modest CO_2 gains when improved. The latest work by Carbon Crichton Centre et al (forthcoming) for the Peatland Code estimates that a near natural peat may emit 1.08 t/CO_2e/ha/year and an actively eroding peatland may emit 23.84 t/CO_2e/ha/year. A comparison of these figures with the emissions factors used in the NE (2011) analysis is performed in Annex 1.

Peatland improvement is beneficial from a global warming perspective (NE, 2010). A study carried out by Pettinotti (2014) concludes that whilst degraded peatlands are more susceptible to climate change impacts (e.g. higher temperatures, drier conditions, increased wildfires, increased erosion from heavy rainfall events, increased CO_2 decomposition), improved, functioning peatlands are likely to be more resilient and to deliver durable benefits as they are able to adapt naturally to changing climatic conditions. The improvement of peatlands, therefore acts as both a mitigation and an adaptation response to climate change. This sends out a strong message that peatlands which are in a near natural / pristine condition should not be allowed to degrade; and those in a degraded state should be improved to near natural conditions sooner rather than later.

The work led by Natural England (NE, 2010) provides a net present value estimate for the list of peatland improvement options based on the estimated carbon benefits that are set out in Table 7.1. These figures are used in the calculations of the NPV of restoring peatland in different conditions under this investment case.

Table 7.1: Carbon benefits of upland peat improvement options

Improvement Options	Benefit ($tCO_2e/ha/yr$) NE (2011)
Preventing overgrazing	**2.49**
Re-seeding of bare peat	**2.45**
Stabilisation of bare peat (hagged)	**2.45**
Blocking grips	**2.19**
Planting bare peat	**2.45**
Hagged/gully blocking	**2.19**
Cessation of moorland burning	**4.95**

7.2 Water quantity

The benefit of water quantity regulating services by upland peatlands is experienced by downstream beneficiaries. Therefore peatlands in close proximity to beneficiary populations will have higher benefits from better regulation of water flows (e.g. reduced flood risk) (Moxey, 2011). Reduction in flood risk could also be estimated in terms of avoided investment in flood management infrastructure.

Improvement of peatland is likely to deliver co-benefits in terms of water quality and biodiversity. The improvement to near-natural peatlands may reduce the need for expensive treatment facilities for public water supply. Such services clearly have a value to society, but these co-benefits are hard to quantify and are not yet priced as explicitly or consistently as carbon.

However, water companies have this data and it will all be available when Ofwat publish their Final Determinations (FDs) of water company business plans for PR14. The FDs for those water companies who have significant upland catchments (i.e. Yorkshire Water, United Utilities, South West Water, Northumberland, etc.) can be reviewed to identify how much is being spent on treatment to reduce colour in raw water.

7.3 Biodiversity and landscape

Biodiversity and landscape benefits are approximated by using non-market valuation estimates derived from work by Christie et al (2011) in relation to worsening, maintaining or improving peatland condition under Biodiversity Action Plans. £94/ha/year is applied each year. This figure does not distinguish between improving different degrees of degradation, neglects geographical variation in valuations driven by beneficiaries' characteristics (e.g. population size, demographics, preferences). It does not assume increasing returns to scale of benefits to biodiversity that might be expected from improved connectivity of habitat (Lawton, 2011), nor allow for decreasing returns to scale of biodiversity values as more biodiversity is conserved. Nevertheless, it does provide a crude measure of Biodiversity and landscape benefits for use here. There is evidence in the literature to suggest that both biodiversity and landscape values can suffer if peat is degraded (Moxey, 2011).

7.4 Other ecosystem services

There are potentially less significant, mixed or uncertain impacts on other ecosystem services from improvement of peatlands, including hazard regulation by reduction of erosion. There is also evidence that there are potential improvements in food production from hill-farming (tick reduction) (Evans et al, 2014) but there is other evidence that there is little change to agricultural productivity from grip-blocking (Wilson 2011). Also recreation may be negatively affected because land is waterlogged for longer.

7.5 Timescale of benefit realisation

This section sets out the timescale for improvement – including whether change is linear (gradual) or non-linear (step-change or threshold).

7.5.1 Climate regulation

In terms of greenhouse gases, methane and carbon dioxide have opposing responses. As the bog is re-wetted peat decomposition is reduced due to the return of anaerobic conditions, and respiration slows, so DOC and carbon dioxide emission should reduce (Holden et al. 2008, Komilainen et al) with eventually the return to an active peat forming layer and carbon sequestration (Peacock et al 2013).

However, re-wetting is likely to lead to an increase in methane production (which is a more potent greenhouse gas than CO_2) and it is important to understand the scale and nature of this methane spike (NE, 2011; Waddington and Day 2007), it should only be a relatively short term response and be mitigated by the development of vegetation communities (particularly sphagnum) over time. Some evidence suggests that increased water tables produce less methane than fluctuating water levels (Green et al 2011). High methane emissions in the first years after improvement are likely, where standing vegetation becomes flooded, careful water control, removing plant residue and re-establishing sphagnum can help to mitigate these levels (NE, 2010). It has been suggested that in general, improved peatlands demonstrate emissions levels indicative of the improved state for the first 10 years and then pre-disturbance levels for the following 30 years (England’s peatlands (NE, 2011). However, Waddington et al (2010) estimated that substantial carbon sequestration benefits can be incurred as quickly as two years post restoration measures and Lindsay (2010) suggests a likely timeframe of 42 years before peatland restoration achieves net carbon gain. Therefore, the literature is unclear on the timescales of net carbon gains and it is likely that the development of abatement potential over time from any restoration project is heavily dependent on the starting condition. **The investment case assumes that carbon benefits begin in the first year after the commencement of capital works and remain the same each year over 40year period.**

7.5.2 Water quantity and quality regulation

There are different estimates for the timescales of the water quantity benefits. Holden et al (2008) states there likely to be improvements in hydrology in the first three years. Other estimates include: the water table may be similar to an undisturbed community in 1 year (Grant-Clement 2013), may take 6 years (Worral et al 2007) or may increase but not reach pre-disturbance levels (Shepherd et al 2013). Timescales and magnitudes of water quality changes are less well established (Martin-Ortega et al., 2014) and may vary for instances in relation to current and historic levels of atmospheric deposition. There is mixed evidence that grip-blocking reduces water colour and DOC export (Anderson et al 2011, Shepherd et al, 2013, Crouch and Walker, 2013) especially over short timescales.

7.5.3 Biodiversity

Colonisation by vegetation can happen in 18 months (Peacock et al 2013), however, improvement to the desired vegetation community type can take 10 years or more (Haaphetalo 2010) but it is still not likely to return to pre-disturbance levels. Other biodiversity may improve more rapidly, for example, stream invertebrates were shown to increase in number and diversity in 3-11 years (Ramchunder et al., 2009). One of the studies mentions that the quality of initial improvement activity is a strong determinant of subsequent success: for full benefits to be attained, initial activities need to be completed satisfactorily.

8. NET PRESENT VALUE

8.1 NPV with carbon benefits alone

Peatland mapping work led by Natural England (NE, 2011) provides a net present value estimate for the list of peatland improvement options based on the estimated carbon benefits, as set out in Table 8.1. Annex 1 sets out the emissions factors used in the NE (2011) analysis and in the calculations for this investment case, with the range of degraded states having emissions factors of between **2.19 to 4.95 t/CO_2-e/ha/yr**. It also sets out the emissions factors used in the work underpinning the pilot peatland code from the Crichton Carbon Centre (forthcoming) with the range of degraded states having emissions factors of between 2.54 and 23.84 t/CO_2-e/ha/yr. Comparing these sets of emissions factors suggests that the NE (2010) analysis used in this project underestimates the potential emissions savings associated with improving the condition of peatland.

The costs were assumed to be the initial capital cost of the improvement work and the opportunity cost from the land use change using the higher level stewardship income foregone payments. The benefit calculated was the reduction in average CO_2 multiplied by the non-traded price of carbon (DECC, 2009) discounted over a period of 40 years (the assumed time over which these improvement options would provide benefits) using HMT discount rates in line with the Green Book.

Table 8.1: Net present value estimate for a list of upland deep peatland improvement actions

	£/ha (Social Price of Carbon - SPC)		
Required actions	**Low**	**Central**	**High**
Preventing overgrazing	1,366	3,624	5,891
Reseeding of bare peat	695	2,917	5,147
Stabilisation of bare peat	-467	1,755	3,985
Blocking Grips	-873	1,113	3,107
Planting bare peat	-1,433	789	3,019
Gully Blocking	-1,477	509	2,503
Reduction in moorland burning	-3,246	3,266	10,035

Source (NE, 2011)

The baseline condition of peatland is not explicit in the study, it is just stated as being ‘degraded’ and average carbon reductions are applied.

In order to assess the potential to improve England’s upland deep peatlands, it has been necessary to make assumptions on the specific improvement activities that will be undertaken across the total degraded upland deep peat area. The study team has used the Moorland line (Moorland (Livestock Extensification) Regulations 1995) to ensure only upland areas are focused on and for each of the peatland condition categorisations in Table 8.1, the condition categories that are related to lowland and/or shallow peat soils have been excluded. This ensures that the focus of the analysis is on peatland areas where the carbon benefits are likely to be greatest. In addition, it is assumed that upland areas are generally associated with lower opportunity costs compared to lowland areas, even though grouse shooting might be a significant opportunity cost (further work is needed to include this in the analysis). Assuming lower opportunity costs in upland areas implies that the net benefits of taking the improvement actions in these areas will be higher (and so will the NPV) and the investment case will be stronger (*ceteris paribus*).

The condition categories where the investment case is 'Red' even when using the highest shadow price of carbon (i.e. improved grassland over deep peat and wasted peat) are scoped out from Figure 8.1. Peatland conditions for which we do not have any NPV information (no status, polluted, semi-natural vegetation, improved (hydrological only) and/or removed or developed) are also scoped out.

Following this scoping out, this gives the total area of upland deep peatland in England where a potential case might be made for peatland improvement based solely on the available evidence on net present value associated with restoring peatland for its carbon benefits. This is the peatland areas that have the strongest potential investment case based on improvement for the carbon benefits (using central SPC). This is shown by the red area in Figure 8.1 which totals approximately 250,000 ha and is associated with upland deep peatland with a potentially positive NPV.

For the remaining condition categories in Table 8.1, the study team has attributed the peatland improvement actions in Table 8.2 (NE, 2010) and calculated the associated net present value. This develops Table 8.1 because in some cases it has been assumed that multiple improvement actions are required (e.g. bare peat requires reseeding at a cost of £497.50 and NPV of £2,917, planting cost of £2,700 with NPV of £789 and stabilisation cost of £1,700 and NPV of £1,755), the NPVs and costs have been estimated based on a simple addition (i.e. total cost range between £497.50 and £4897.50 and central NPV is £5,461). There is an increased level of uncertainty associated with this because both marginal costs and benefits associated with each action are likely to be reduced as actions are combined. For example, the costs might be shared among the three activities (duplication of efforts and economies of scale), and therefore might be less costly. But also that the marginal benefit in terms of carbon associated with each action might be less as they save at least some the same carbon, which cannot be counted twice. If this is the case, the change in NPV is uncertain.

Table 8.3 shows the NPVs associated with improving upland peatland in different conditions for the net carbon benefits, based on central SPC (NE, 2011). The strongest investment case is made for peatland that is currently under rotational burning, that which is eroded/gullied, overgrazed and/or gripped with NPVs of £470m, £310m, £160m and £100m respectively over 40years. The figures in Table 8.2 have not been aggregated because the conditions of peatland are not mutually exclusive. There is a risk of double counting the benefits associated with peatland improvement if they are aggregated. Assuming complete overlap of categorisations, the lowest area of upland deep peat that can be improved is approximately 140,000ha (i.e. that associated with rotational burning).

Table 8.2: Matching of peatland condition to required actions and net present values for carbon

Condition of peat (NE, 2010)	Required action (from Table 7)	Costs (£/ha)	NPV for carbon (£/ha, over 40yrs)		
			Lower	Central*	Upper
Afforested	Scoped out as removing trees on deep peat leads to significant carbon losses				
Bare peat	Reseeding bare peat; Planting bare peat; Stabilisation bare peat	497.5 - 4897.5	-1,205	5,461	12,151
Rotational burning	Reduction of burning	164	-3,246	3,266	10,035
Cultivated	Scoped out as this is a lowland option				
Eroded (hagged / gullied)	Gully blocking; Reseeding bare peat; Planting bare peat; Stabilisation bare peat	497.5 - 7397.5	-2,682	5,970	14,654
Extracted	Scoped out as this is a lowland option				
Gripped	Blocking grips	1,875	-873	1,113	3,107
Improved grassland	Scoped out as lowland option and negative higher end NPV		9,540	-9,100	-8,659
Molinia (purple moor-grass) dominated	(Turf stripping, Mowing, flailing)**; Re-seeding; Grip blocking	497.5 - 1,875	-178	4,030	8,254
No status	Scoped out as no information				
Overgrazed	Preventing overgrazing	60	1,366	3,624	5,891
Peat cuttings					
Polluted	Scoped out as no net present value information				
Removed or Developed					
Improved (hydrological)					
Semi-natural non peat-forming vegetation					
Scrub					
Wasted peat	Scoped out as negative higher end NPV		-10,127	-5,093	-41
Wooded	Scoped out as removing trees on deep peat leads to significant carbon losses				

*: The NPV estimates include opportunity costs (Higher Level Stewardship payments) as well as costs set out in Table 6 (NE, 2011) and the benefits in terms of the shadow price of carbon. The range is based solely on the lower and upper SPC as set out in Table 7.

**: Potential actions to remove Molinia are not costed in NE (2011) report

Positive NPV cases are highlighted in green

Negative NPV cases are highlighted in red

Figure 8.1: Map of upland peat areas (250,000ha) with positive NPVs associated with improving for carbon benefits (using central SPC)

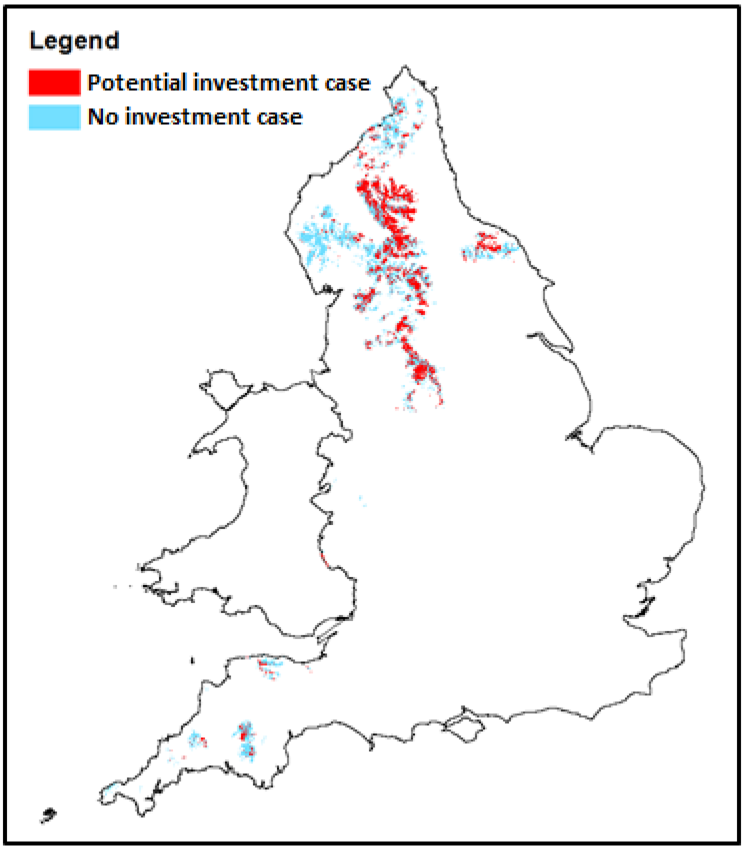


Table 8.3: Areas of upland peat with positive NPVs associated with improving for carbon benefits (using central SPC; NE, 2011).

Condition of peat	Upland area (ha)	Required action	NPV (£,over 40yrs, Central SPC)	
			per ha	Total
Bare peat	4,209	Reseeding bare peat, Planting bare peat, Stabilisation bare peat	5,461	22,990,000
Rotational burning	143,865	Cessation of burning	3,266	469,860,000
Eroded (hagged / gullied)	51,721	Gully blocking, Reseeding bare peat, Planting bare peat, Stabilisation bare peat	5,970	308,770,000
Gripped	88,714	Grip blocking	1,113	98,740,000
Molinia (purple moor-grass) dominated	5,364	(Turf stripping, Mowing, flailing)* Re-seeding, Grip blocking	4,030	21,620,000
Overgrazed	45,415	Preventing overgrazing	3,624	164,580,000

SPC: Social Price of Carbon

Note that whilst some of these areas will also include the condition categorisations that have been excluded because there is no NPV information, the peatland areas that have negative NPV's have been removed altogether. Therefore where improved grassland over deep peat and wasted peat are present at all, this peatland area has been removed. This was deemed to be appropriate because their NPVs are so negative (-£5,093/ha and £9,100/ha respectively under the central shadow price of carbon) that it is likely to not be outweighed by the positive NPVs of other actions.

In order to provide another estimate of the carbon value associated with improving upland deep peatland, NE (2012a) spatial data was used, which focuses solely on deep peat in upland areas and incorporates overlaps across condition categories (i.e. the categorisations are mutually exclusive), including different condition categories. Excluding the area of peatland with no category (178,882ha) the total area of degraded upland deep peat that could be improved is approximately 140,000ha. The condition categorisations, associated area and NPV are set out in Table 8.4. Figures 2.1 and 2.2 in Annex 2 show the extent and condition of upland deep peat in Northern and Southern England, respectively.

Table 8.4: Areas of upland deep peat with positive NPVs associated with improving for carbon benefits (using central SPC; NE, 2012a)

Condition of peat	Area (ha)	Required action	NPV (£,over 40yrs, Central SPC)	
			per ha	Total
Hagged/ Gullied only	32,428	Gully blocking; Reseeding bare peat; Planting bare peat; Stabilisation bare peat.	5,970	193,595,160
Burnt only	51,194	Cessation of burning/reduced intensity of burning	3,266	167,199,604
Gripped and Burnt	22,063	Grip blocking; Cessation of burning.	4,379	96,613,877
Hagged and Burnt	3,161	Gully blocking; Reseeding bare peat; Planting bare peat; Stabilisation bare peat; Cessation of burning.	9,236	29,194,996
Gripped only	24,826	Grip blocking	1,113	27,631,338
Hagged and Bare	3,682	Gully blocking; Reseeding bare peat; Planting bare peat; Stabilisation bare peat.	5,970	21,981,540
Hagged and Gripped	1,300	Gully blocking; Reseeding bare peat; Planting bare peat; Stabilisation bare peat; Grip blocking.	7,083	9,207,900
Peat cutting only	1,065	Reseeding bare peat; Planting bare peat; Stabilisation bare peat.	5,461	5,815,965
Hagged, Gripped and Burnt	507	Gully blocking; Reseeding bare peat; Planting bare peat; Stabilisation bare peat; Grip blocking; Cessation of burning.	10,349	5,246,943
Bare peat only	436	Reseeding bare peat; Planting bare peat; Stabilisation bare peat.	5,461	2,380,996
Bare peat, Hagged and Burnt	66	Reseeding bare peat; Planting bare peat; Stabilisation bare peat; Gully blocking; Cessation of burning.	9,840	649,440
Peat cut and Gripped	6	Reseeding bare peat; Planting bare peat; Stabilisation bare peat; Grip blocking.	6,574	39,444
Bare peat, Hagged and Gripped	3	Reseeding bare peat; Planting bare peat; Stabilisation bare peat; Gully blocking; Grip blocking.	7,083	21,249
Excluded areas	951	No associated action	-	-
Peat with no category	178,882	No associated action	-	-

SPC: Shadow Price of Carbon

Using the NE (2011) analysis of NPV's in combination with the NE (2012a) spatial data on condition (as opposed to the earlier analysis based on NE 2010 spatial data on condition), the strongest investment case is made for upland peat which is currently only hagged/gullied, only under rotational burning, that which is gripped and burnt, and that which is hagged and burnt with NPVs of £194m, £167m, £97m and £29m respectively over 40years.Given that these are additional (i.e. mutually exclusive categorisations) then the net present value of improving deep peat on upland soils is approximately £560m over 40years.

8.2 NPV with other ecosystem benefits

8.2.1 Water quantity (flooding)

The above estimates exclude other (than carbon) benefits associated with upland peatland improvements. As Section 7 suggests, there could be multiple and significant benefits. GIS analysis has been used to identify the peatland areas where the proposed improvement actions are expected to deliver greater net benefits, i.e. where there are lower opportunity costs and where these other (non-carbon) services have higher value.

To use GIS in this way to identify the areas with potentially highest water quantity regulation services results in peatland:

- In upland areas (with lower opportunity costs);
- That experience relatively high rainfall (>1,000mm), and
- Is in close proximity (within 10km) and upstream of an urban area with a large population (>10k people) (as a proxy for the importance of peatland for the provision of spatially sensitive ecosystem services such as recreation and water regulation).

These criteria resulted in identification of 20,733ha of peatland, the spatial distribution of which is shown in Figure 8.2. It is recognised that these criteria are a simple approximation of factors that will result in higher value of water regulation services. There are two reasons why the map does not show areas where there have been known investments in peatland improvement by water companies (e.g. south west England). First, because these areas are no longer degraded and so are not covered in the condition categories considered in this analysis. Second, they do not meet one (or more) of the criteria used to identify areas with potentially highest water quantity regulation services (i.e. they may not be in close proximity to large urban population).

Figure 8.2: Map of peatland in upland areas, upstream of large urban populations with different levels of rainfall

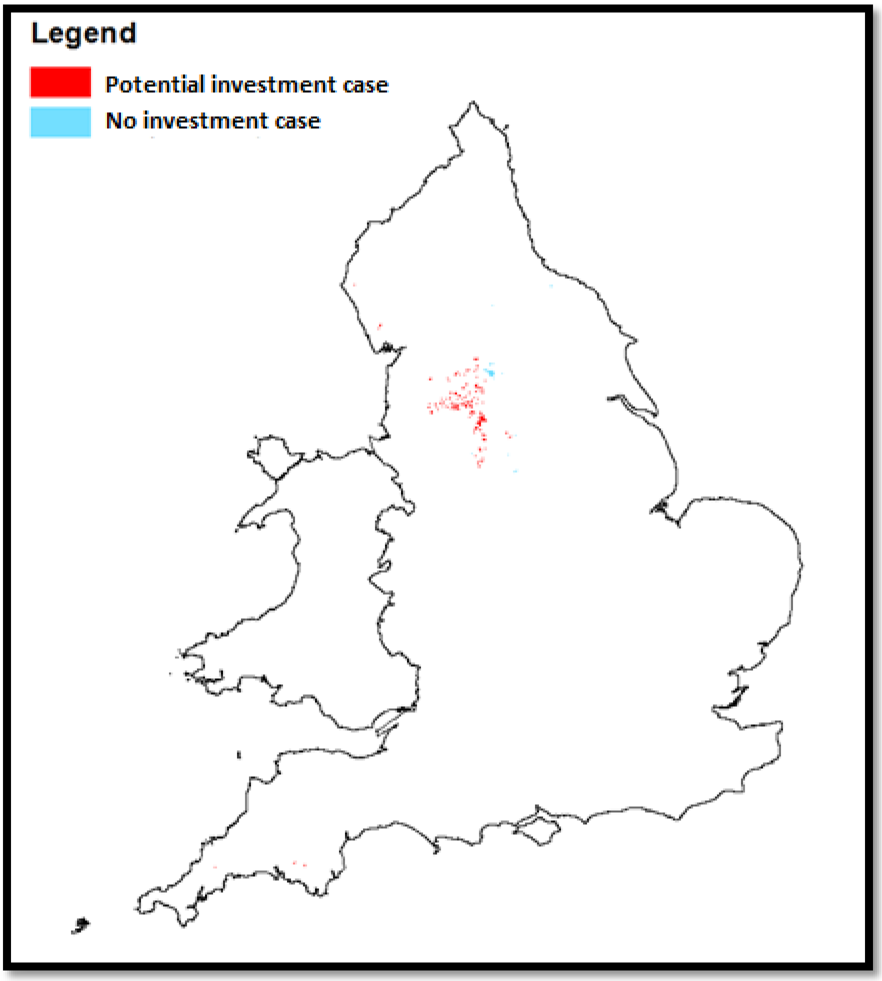


Table 8.5 reports the area of peatland associated with close proximity to a large population (proximity is); the area that is close to people and upstream of them, and the area within this that has high rainfall (both important for water regulating benefits). **This area of 20,733ha has the potential to provide high level of water regulating services.** Further analysis is required to investigate the condition of this peatland and to quantify the associated improvement costs and benefits.

Table 8.5: Area peatland potentially providing high water regulating services

Peatland	Area (ha)
Upland peat with > 10,000 people within 10 km	63,011
Upland peat with > 10,000 people within 10 km and upstream of urban	24,220
Upland peat with >10k people within 10 km, upstream of urban, and >1,000 mm annual precipitation.	20,733

8.2.2 Water quality

Further analysis to identify the area of peatland with potentially highest water quality regulation services could be undertaken using GIS to identify the Water Resource Zones (WRZs) with high areas of deep peat and the condition of those areas in order to identify areas at risk of high DOC/raw water colour. Using WRZs will give the number of customers reliant on those catchments for drinking water. A rough calculation can be made based on benefits estimates from Keighley Moor example (NE, 2012b). Water quality regulating services and the benefits in terms of reduced water treatment costs in this case are approximately £97/ha/yr (this is the equivalent annual cost of £1,700/ha in PV terms over 25years, taken from section 10.1 on Keighley Moor, 2.2million avoided water treatment costs over 1,345ha). Using this unit benefit across the same 20,000ha as for water quantity benefits (based on upland areas (with lower opportunity costs, that experience relatively high rainfall (>1,000mm), and is in close proximity (within 10km) and upstream of an urban area with a large population (>10k people)) suggests a benefit value of £1.9m/yr. This estimate assumes complete overlap of the 20,000ha with the area improved for carbon benefits would mean a sharing of the cost base so that the benefits are all additional.

Based on these assumptions (using the Keighley Moor example) the potential water quality regulating benefits may be in the order of millions of pounds a year.

8.2.3 Biodiversity and landscape

Assuming that improvements of peatland for both carbon (Table 8.2) and water regulation (Table 8.5) deliver biodiversity benefits, the Christie et al (2011) figure of £94/ha/year can be used as an indication of the order of magnitude of these benefits. If we assume there is complete overlap in condition categorisations in Table 8.3 such that the total area improved is equivalent to the area of rotational burning (144,314ha) and that there is also complete overlap with water quantity regulation then the biodiversity benefits associated with this area are estimated to be £304million (PV over 40yrs). These can assumed to be attributed to the same cost base as the carbon and water quantity investment and so are net benefits.

8.3 Additionality

As set out in Section 3, there has been a decline in the extent and condition of England's blanket bog habitat over time. At least 50% of what has previously been deep peat is no longer classed as 'bog' having changed to another land use type (i.e. heath, grassland, woodland).

Over the last 10 years a lot of effort has been put into improving one-third of upland peat in order to meet the 95% target to get SSSIs into a favourable, or 'unfavourable recovering' position. In order to reach this target, there have been several mechanisms for delivering improvement, which have, in part, driven the improvement activity including:

1. **Environmental Stewardship scheme:** £27 million paid to farmers and land owners who have taken up moorland improvement options under the Higher Level Stewardship (HLS) since 2007. The main type of improvement supported by HLS is a reduction in grazing, and some payments have been made for grip blocking.
2. **Catchment scale improvement:** £45 million will be invested by water companies in partnership with land-owning charities (RSPB, National Trust) between 2010 and 2015. With projects such as SCAMP (5,500 ha), Yorkshire peatland partnership (over 10,000 ha), Border Mires (2,850ha), Exmoor Mires, Moors for the Future (2012) and similar projects estimated to have improved between 20,000ha and 60,000ha of upland peat, with more work ongoing. Many have also accessed HLS funding to reduce grazing pressures.
3. **Peatland code** - pilot research project exploring use of payments for ecosystem services. It provides a code designed to support markets that could pay for the improvement and rewetting of degraded peatlands across the UK through resolving technical issues, providing advice and developing markets.

4. **EU LIFE – Nature programme funding** (e.g. Wales Lake Vrnwy); £2.9 million in total, 55% of the final costs were spent on the practical work. Of this, the project spent £1.3 million on drain blocking, for which costs varied depending on the technique used. MoorLIFE; £5.5 million project for Moors for the future. MoorLIFE protects Active Blanket Bog by improving bare and eroding peat in the South Pennines Special Area of Conservation (SAC) and Special Protection Area (SPA).

There are overlaps in the above list. For example, payments under the environmental stewardship scheme and the EU LIFE – nature programme funding are likely to be funding, or at least contributing to catchment scale improvement. The investment case needs to account for the existing suite of investments, to identify where the use of existing funds is justified and where additional funds are needed.

8.4 Feasibility of estimates/uncertainty

This section sets out the factors affecting the feasibility of estimates developed in this investment case to improve peatland nationally

The required improvement actions for each of the peatland conditions considered are assumed based on expert judgement and might not be fully reflective of the specific actions required at a specific site.

As noted previously, for the analysis that uses the NE (2010) spatial data, where improvement requires multiple actions, the NPV is uncertain due to lack of information on whether costs and benefits are additional or overlapping. For example, the costs might be shared among the three activities (duplication of efforts and economies of scale), and therefore might be less costly. But also that the marginal benefit in terms of carbon associated with each action might be less (i.e. they save at least some the same carbon, which cannot be counted twice). Whilst this issue is lessened by the fact that many of the conditions are assumed to require single improvement actions, this is based on expert judgement as to which actions are required to improve peatland.

Moreover, the conditions of peatland are not mutually exclusive meaning that multiple actions might be required on the same peatland area (ha) to deal with different conditions. Based on the NE (2013) spatial data used, there are 546 combinations of peatland condition across the 256,208ha of upland peatland. Table 8.6 shows the top ten combinations by area and then the top 5 with no overlap.

Table 8.6: Peatland area with different combinations of conditions using NE (2010) spatial data

Peatland condition	Area (ha)
Rotational Burning, Polluted and Semi-natural non peat-forming vegetation	38,457
Rotational Burning, Semi-natural non peat-forming vegetation	17,911
Rotational Burning, Polluted	16,321
Eroded (hagged and gullied), Polluted	16,274
Rotational Burning, Gripped, Polluted	15,385
Eroded (hagged and gullied), Polluted, Semi-natural non peat-forming vegetation	15,112
Rotational Burning, Gripped, Polluted, Semi-natural non peat-forming vegetation	13,642
Rotational Burning	2,000
Gripped	1,809
Overgrazed	439

Comparing the total area of peatland under different combinations of conditions (top five are between 38,457ha and 15,385ha) with the area that has no overlap (top one is 2,000ha) in Table 8.6. It can be seen that most peatland conditions overlap with another condition category. This means that the analysis based on NPVs for single improvement activities is highly uncertain as for the majority of upland peat areas, multiple actions to deal with different conditions are required (and the costs and benefits are likely to change where multiple actions are needed).

Moreover, we don't have NPVs for polluted or semi-natural non peat-forming vegetation condition categories which feature heavily in the top 10 peatland categorisations by area. If the costs of actions required to improve peatland under these categorisations outweigh the benefits, and these actions are needed to improve peatland condition to a state where improved ecosystem service provision is delivered, then the NPVs will be reduced and could potentially be zero or even negative.

The specific actions costed in the NE (2011) analysis should be considered further, as the NPVs are strongly dependent upon the original analysis done by NE (2011). For example, the carbon estimates are based on average reductions in carbon, with no explicit linking to a baseline condition or differentiation between shallow peat and deep peat soil[2] and across different states of degradation (e.g. lightly degraded, severely degraded). Also the assumptions on payments foregone under agri-environment schemes may not be the most relevant counterfactual for the uplands where grouse shooting can be a significant barrier to land use change. The opportunity cost figures used in the NPV figures developed by NE (2011) did not include the opportunities for grouse shooting, instead only using HLF payment rates as a proxy.

The second analysis that focuses on upland deep peat, might be considered more robust as it avoids many issues set out above. However, it may also underestimate the potential investment case for upland peatland as there are fewer peatland condition categories.

It is recognised that the shadow price of carbon figures (DECC, 2009) have been developed to assess the relative cost-effectiveness of different mitigation options and programmes and is designed to reflect the long-term social and political drivers for the transition to a low carbon economy. These figures are not the same as actual trading values, which for the voluntary market are significantly lower around £4-5 / tCO_2e (NE, 2010). The use of the SPC has, however, indicated that the majority of peatland improvement options can be deemed a cost effective means of carbon mitigation.

The identification of areas of peatland that has the potential to provide high water regulating benefits is based on the proximity to a large population. However, proximity is only a proxy for the importance of peatland for the provision of spatially sensitive ecosystem services such as water regulation. A peatland near a reservoir could be important for water regulation despite having a small population nearby. But in general the further a peatland is from large numbers of people, the smaller its likely importance to water regulation within the total area of the catchment serving them.

In reality, there are a number of interrelating factors that may affect the costs and benefits of improvement. For example, it has been suggested that re-vegetation without improving hydrological function, will probably not reverse net loss of carbon (Worrall *et al*, 2011).

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[2] These function differently, are subject to different land-use pressures, and would be expected to have different GHG fluxes so standard emission factors cannot be applied across both.

Understanding a potentially complex hydrological system is important, including the underlying substrate, adjacent land and the network of drainage channels and streams (Holden et al 2008). For the realisation of biodiversity benefits the potential for species dispersal and connectivity is an important factor to take into account (Grant Clement 2013). Evans et al. (2014) examine the relationships between pressures (anthropogenic activity) and ecosystem functions response and demonstrates the complex sometimes conflicting or interactive effects of multiple ecosystem functions showed that ecological responses to multiple pressures can be complex and sometimes counteractive. For example acid deposition is thought to have reduced water colour in the past, whereas peat drainage may have increased it.

The cost benefit ratio of a specific improvement activity(-ies) also varies with a number of site-specific factors that are not picked up in the analysis including historic management impacts and site conditions e.g. current ecological condition, volume of peatland, slope, size of drain, peat-pipes (Evans et al 2013, Life project), geographic location (location of beneficiaries, access to the site, Holden et al 2008), current land use at sites (opportunity cost) and current and future climatic conditions (Glenk, Hinde et al 2010). The need for ongoing management to improve/maintain good site condition and employ sustainable management practices also vary between sites (Holden et al. 2008).

Political aspects such as governance and involvement of stakeholders in the improvement and management might also be important. Policy targets (e.g. meeting 95% target to get SSSIs into a favourable, or ‘unfavourable recovering’ status) will also contribute to the decision as to which type of improvement occurs where. All of these factors will affect the number and types of actions that need to be implemented at a site and will affect the cost: benefit ratios.

9. SUMMARY

Table 9.1 sets out a summary of the investment case for peatland. This links the baseline condition of peatland based on the NE (2010) spatial data to the assumed improvement actions, the change in functionality and ecosystem service provision as well as the associated costs and benefits and NPV of each improvement activity.

Table 9.2 does the same but uses baseline condition of peatland from the NE (2012) spatial data.

Table 9.1: Summary of peatland investment case based on NE (2010) spatial data and NE (2011) NPV analysis

Ecology → **Economics**

Condition of peat	Upland area (ha)	Improvement action	Improved Functions	Ecosystem Services	Total Cost [3] (£/ha)	Benefits	NPV for carbon (£, over 40yrs, Central SPC[4])	
							per ha	Total
Bare peat	4,209	Reseeding bare peat, Planting bare peat, Stabilisation bare peat	Raises water levels and re-establishing bog vegetation (e.g. sphagnum species) The following relationships describe the natural capital (and man-made capital) assets that underpin the functionality of blanket bog. The condition of each of these assets will determine the capacity of blanket bog to deliver a range of benefits. Therefore, in improving blanket bog habitat from peatland in various conditions, the actions undertaken are improving the condition of these underlying assets in a way that increases the capacity to produce ecosystem services. The notes accompanying this table explain which natural capital assets are important determinants of the capacity of peatland to provide equable climate*,water**, flooding risk**** and soil erosion*****	Carbon regulation (sequestration and storage/ avoided emissions) Water quantity regulation (flood water storage); Water quality regulation; Biodiversity and landscape	497.50 - 4897.5	Avoid cost CO_2 mitigation – shadow price of carbon, see NPV (DECC, 2009) Avoid FCERM spend (requires modelling to quantify), damages potentially across 20,733ha of peatland; Avoid some of the annual water treatment cost Enhanced value of species diversity potentially £21.6m/yr associated with case for peatland improvement for carbon (144k ha) and water regulation (86k ha) (Christie et al, 2011)	5,461	22,990,000
Rotational burning	143,865	Cessation of burning			164		3,266	469,860,000
Eroded (hagged / gullied)	51,721	Gully blocking, Reseeding bare peat, Planting bare peat, Stabilisation bare peat			497.5 - 7397.5		5,970	308,770,000
Gripped	88,714	Grip blocking			1,875		1,113	98,740,000
Molinia (purple moor-grass) dominated	5,364	(Turf stripping, Mowing, flailing)* Re-seeding, Grip blocking			497.5 - 1,875		4,030	21,620,000
Overgrazed	45,415	Preventing overgrazing			60		3,624	164,580,000

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[3] Include CAPEX, OPEX and opportunity costs as identified in NE (2010)

[4] Shadow price of carbon

Table 9.2: Summary of investment case for peatland based on NE (2011) spatial data and NE (2011) NPV analysis

Condition of peat	Upland area (ha)	Improvement action	Improved Functions	Ecosystem Services	Total Cost (£/ha)	Benefits	NPV for carbon (£, PV over 40yrs, Central SPC)	
							per ha	Total
Burnt only	51,194	Cessation of burning	Raises water levels and re-establishing bog vegetation (e.g. sphagnum species) The following relationships describe the natural capital (and man-made capital) assets that underpin the functionality of blanket bog. The condition of each of these assets will determine the capacity of blanket bog to deliver a range of benefits. Therefore, in improving blanket bog habitat from peatland in various conditions, the actions undertaken are improving the condition of these underlying assets in a way that increases the capacity to produce ecosystem services. The notes accompanying this table explain which natural capital assets are important determinants of the capacity of peatland to provide equable climate*,clean water**, flooding risk**** and soil erosion*****	Carbon regulation (sequestration and storage/ avoided emissions) Water quantity regulation (flood water storage); Water quality regulation; Biodiversity and landscape	164	Avoid cost CO$_2$ mitigation – shadow price of carbon, see NPV (DECC, 2009) Avoid FCERM spend, damages potentially across 20,733ha of peatland; Avoid some of the annual water treatment cost Enhanced value of species diversity potentially amounting to £21.6m/yr associated with case for peatland improvement for carbon (144k ha) and water regulation (86k ha) (Christie et al, 2011)	3,266	167,200,000
Hagged/ Gullied only	32,428	Gully blocking; Reseeding bare peat; Planting bare peat; Stabilisation bare peat.			7,398		5,970	193,600,000
Gripped only	24,826	Grip blocking			1,875		1,113	27,630,000
Gripped and Burnt	22,063	Grip blocking; Cessation of burning.			2,039		4,379	96,610,000
Hagged and Bare	3,682	Gully blocking; Reseeding bare peat; Planting bare peat; Stabilisation bare peat.			7,398		5,970	21,980,000
Hagged and Burnt	3,161	Gully blocking; Reseeding bare peat; Planting bare peat; Stabilisation bare peat; Cessation of burning.			7,562		9,236	29,190,000
Hagged and Gripped	1,300	Gully blocking; Reseeding bare peat; Planting bare peat; Stabilisation bare peat; Grip blocking.			9,273		7,083	9,210,000
Peat cutting only	1,065	Reseeding bare peat; Planting bare peat; Stabilisation bare peat.			4,898		5,461	5,820,000
Hagged, Gripped and Burnt	507	Gully blocking; Reseeding bare peat; Planting bare peat; Stabilisation bare peat; Grip blocking; Cessation of burning.			9,437		10,349	5,250,000
Bare peat only	436	Reseeding bare peat; Planting bare peat; Stabilisation bare peat.			4,898		5,461	2,380,000
Bare peat, Hagged and Burnt	66	Reseeding bare peat; Planting bare peat; Stabilisation bare peat; Gully blocking; Cessation of burning.			7,562		9,840	650,000
Peat cut and Gripped	6	Reseeding bare peat; Planting bare peat; Stabilisation bare peat; Grip blocking.			6,773		6,574	40,000
Bare peat, Hagged and Gripped	3	Reseeding bare peat; Planting bare peat; Stabilisation bare peat; Gully blocking; Grip blocking.			9,273		7,083	20,000

a. Based on carbon benefits based on central estimate of the non-traded shadow price of carbon. Differences between these rates were scaled over the areas mapped, to estimate the potential benefits of peatland restoration show in Table 6. The costs considered were the initial capital cost and the income foregone (‘opportunity costs’) from the land use change

* Blanket bog for equable climate = f [species (sphagnum moss etc); ecological communities (photosynthesis and carbon locking); soils (high acidity, organic matter and water holding capacity, nutrient availability); atmosphere (temperatures, rainfall, CO_2, N); freshwater (high water table); land (low gradient); material capital (extraction methods, land management - burning and grazing regimes)]

** Blanket bog for clean water = f [ecological communities (vegetation - nutrient cycling, pollutant absorption), soils (pH, nutrient concentrations (TOC, nitrate, phosphate, ammonium), erosion, infiltration), freshwater (high water table) land (altitude, gradient), atmosphere (temperature and rainfall); pressures (management practices e.g. low intensity grazing, low drainage gripping, limit burning)]

*** Blanket bog for flooding risk = f [ecologi cal communities; soils (pH, nutrient concentrations (TOC, nitrate, phosphate, ammonium), erosion, infiltration); freshwater (water table); land (gradient), atmosphere (rainfall); pressures (management practices e.g. drainage gripping, burning)]

****Blanket bog for wildlife risk = f [ecological communities (heath biomass, blanket bog); soils (eroding); freshwater (low water table); atmosphere (temperature, rainfall); pressures (management practices e.g. burning regime)]

***** Blanket bog for soil erosion = f [ecological communities; soils (pH, nutrient concentrations (TOC, nitrate, phosphate, ammonium), erosion, infiltration), freshwater (water table) land (gradient), atmosphere (temperature, rainfall and wind); pressures (management practices e.g. grazing, drainage gripping, burning)]

10. CASE STUDY EXAMPLES

10.1 Keighley moor, Yorkshire

10.1.1 Background[5]

The Keighley catchment in Yorkshire covers an area of 4,369 ha. Farming and game hunting are the predominant land-use. 1,345ha is peatland, providing carbon storage and sequestration and water quality regulation ecosystem services. 163ha is SSSI with significant wildlife interest and value. Pennine way runs through the catchment and grouse shooting is prevalent providing recreational benefits. An ex-ante assessment of 2 scenarios was performed. Table 10.1 shows that intervention under the 'improved' scenario is expected to result in 1,244ha of degraded bog and bare peat improved to favourable conditions through re-wetting. Under the 'decline' scenario, 'intact' blanket bog is likely to become degraded and degraded bog is likely to become bare peat. This suggests that current levels of investment in peatlands are avoiding degradation but that there is scope for further investment to improve degraded and bare peat (NE, 2012b).

Table 10.1: Peatland habitat area (ha) under the different scenarios

Habitat type	Baseline	Improve scenario	Decline scenario
Deep peat intact	43	1,287	0
Degrade bog	1,220	0	1,056
Bare peat (severe burn)	24	0	231
Flush and Mire	57	57	57

10.1.2 Improvement actions and costs

Capital costs, operating costs and opportunity costs are considered. Costs are based on Environmental Stewardship payments rates and the England Woodland Grant Scheme. Using HLS options to construct tailored measures for the catchment the cost is estimated to be approximately £3.2 million, of which over half are capital costs associated with blocking grips and gullies, re-seeding bare peat and woodland planting (i.e. not just related to peatland). The costs for the decline scenario (which will effectively be savings i.e. money not spent on Environmental Stewardship schemes) are estimated at around £1.61 million (in PV terms), as set out in Table 10.2 (NE, 2012b).

Table 10.2: Costs of improved and decline scenario

	Costs (PV over 25yrs)	
Approach	Improve scenario	Decline scenario
HLS payment rates	£3,204,000	-
Current spend in catchment	-	£1,614,000

10.1.3 Quantifying ecosystem services and beneficiaries

This case study involves improvement of the catchment which includes peatland as well as heathland and woodland. Changes in soil carbon were estimated using a model developed by

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[5] http://publications.naturalengland.org.uk/publication/1287625

Natural England (based on earlier work by Couwenberg et al, 2008). Possible changes in water quality were assessed by Yorkshire Water. Changes in woodland carbon were estimated using the Forestry Commission Carbon Lookup Tables and assumptions about species planted, spacing, yield class, management and growth period. Yorkshire water serves around ~1.9 million households in the region who might benefit from improved water quality as a result of catchment improvement, including as a result of peatland improvement. Biodiversity improvements might be directly enjoyed by some of the estimated 15,000 people within the Keighley Catchment and 6 million within a 50km radius. The beneficiary for carbon regulation is the global population (NE, 2012b)..

10.1.4 Valuing ecosystem services

The value of improvements in the catchment was estimated through two approaches. The first was through using per ha figures on biodiversity and landscape value from Christie et al (2011) using value transfer. Table 10.3, provides estimates of the PV for change in service provision using this approach. Note that this is for improvements to peatland but also woodland and heathland.

Table 10.3: Estimated present value (PV) benefits of scenarios for peat habitats (25 years[6])

Scenario	Value (£)	Area (ha)	Value/year	PV benefits (25 years)
Improve	£94	1,244	£116,936	£1,448,268
Decline	-£170	168	-£28,560	-£353,724

The second approach was to value the physical flows estimated using DECC carbon values (2009), Brander et al (2008) for biodiversity used in UKNEA (2011), a treatment cost approach was adopted by Yorkshire Water to value possible changes in water quality from the catchment. Table 10.4 provides estimates of the PV for change in service provision using this approach. The carbon benefits are attributable to just peatland improvement, whilst the biodiversity and water quality benefits are attributable to woodland and heathland also.

Table 10.4: Estimated PV benefits of scenarios for peat habitats (25 years[8])

Ecosystem Service	Benefits (PV over 25yrs)	
	Improved scenario	Decline scenario
Biodiversity (non-use)	£2,342,000	-£2,297,000
Carbon change (woodland)	£1,599,000	-
Carbon change (bog)	£3,285,000	-£3,188,815
Carbon change (heathland)	£49,310	-£121,000
Water quality (reduced treatment costs)	£2,200,000	-£2,510,000
Total*	£9,475,000	-£8,400,000

*Does not include PV for benefits associated with other ecosystems such as carbon change for woodlands

10.1.5 Cost benefit ratios

Table 10.5 presents net present values (NPV) over 25 years and benefit/cost ratios for the improved and decline scenarios using both the UKNEA/DECC values and the Christie et al values. The NPV (over 25yrs) for improved scenario ranges from £1m to £6.3m and the benefit cost ratio range from 1.31 to 2.96 meaning that for every £1 spent in the catchment, society benefits by £2.96 (NE, 2012b).

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[6] using HMT discount rate of 3% in line with the Green Book

Table 10.5: Net present value and benefit cost ratios (25 years, 3.5%)

Scenario	PV benefits	PV Costs	NPV	B:C ratio
NEA & DECC Values				
Improved	£9,475,000	-£3,204,000	£6,271,000	2.96
Decline	-£8,400,000	£1,614,000	-£6,786,000	-5.20
Christie et al. values				
Improved	£4,206,404	-£3,204,000	£1,002,404	1.31
Decline	£3,270,860	£1,614,000	-£1,656,860	-2.03

10.2 Pumlumon, Wales

10.2.1 Background

The Pumlumon Project (PP) is a Payments for Ecosystem Services (PES) project over a watershed area of 40,000ha in the Cambrian Mountains, Wales. It has brought over 652ha into active habitat management which has had an effect over 1,136ha of the catchment helping to secure and enhance the supporting services provided by this land. Table 10.6 shows the physical outputs being addressed in 2012.

Table 10.6: Pumlumon Project Annual Outputs in 2012

Physical Outputs:	Amount	Units
Area of active habitat management	652	hectares
Area of catchment affected by management actions	1,136	hectares
Area of blanket bog managed	309	hectares
Volume of peat managed	5	m cubic metres

Montgomeryshire Wildlife Trust acts as a broker for land managers to provide multiple ecosystem services funded through various private and public finance streams (including RDP and Glastir). In most examples private funding is generally not linked to an established market.

10.2.2 Improvement actions and costs

Although several habitats were included under the improvement plan, the practical mechanisms used to improve the peatland habitats were Ditch blocking, using scrapes and bunds to create dams with long battered edges (to reduce the angle of slope) across gullies to re-wet and increase the water absorbency, water quality and biodiversity of the peatland habitats on the mountain tops.

Table 10.7 shows the project costs related to project development, land management, staff costs and overheads from 2009 – 2012.

Table 10.7: Costs for the Pumlumon Welsh PES Project

	Action	Costs
Project Development (one-off)	Habitat evaluation	£20,000
	Strategic development	£70,000
Land Management	Ditch blocking	£71,128
	Livestock grazing	£1,350
	Fencing	£4,082
	Habitat improvement	£2,700
	Survey & monitoring	£1,000
Staff costs	Senior Ecologist (P/T)	£22,500
	Grazing Ecologist (P/T)	£14,130
	Farm Liaison Officer	£6,110
	Project Economist	£3,000
	Project Manager	£3,000
Overheads	Admin/office	£10,000
	Vehicles and travel	£2,000
Total		**£230,000**
Total (excluding one-off costs)		**£140,000**

10.2.3 Quantifying and valuing ecosystem services and beneficiaries

The whole project area is home to 15,000 people. The watershed supplies water to 4 million people in England. This study estimates that the project delivered additional value of over £250k in 2012 from carbon sequestration (£128,808) and increased water storage capacity (£53,339) which are related to the peatland improvement as well as food provision (£98,595). The £250,000 is considered to be additional and the management actions to deliver the physical outputs would not have happened without the PES project in Pumlumon.

It is estimated that only 10% of the land in the project area is being improved and it is believed that this figure would rise substantially if more of the peatlands in the project area could be brought into the improvement (PES) scheme. The values expressed for this project and the outputs achieve through landscape management can be up-scaled to get a value for the whole of the Project area and for peatlands in Wales. These are shown below in Table 10.8.

Table 10.8: Value of potential benefits (£/yr) for whole of project area and Wales

Ecosystem Service	Peatlands in current area (309ha) £/yr	Peatlands in whole Project area (3,732ha) £/yr	All peatlands in Wales (71,800ha) £/yr
Livestock sales	£98,595	£102,000	unknown
Carbon benefits	£128,808	£1,131,692	£21,772,632
Water benefits	£53,339	£279,900	£5,385,000
Total annual benefits	**£280,742**	**£1,513,592**	**£27,157,632**

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ANNEX 1. COMPARISON OF EMISSIONS FACTORS

Table 1.1 sets out the emissions factors used in the NE (2011) study, with the range of degraded states having emissions factors of between 2.19 to 4.95 t/CO_2-e/ha/yr. Table 1.2 sets out the emissions factors used in the work underpinning the pilot peatland code from the Crichton Carbon Centre (forthcoming) - the range of degraded states having emissions factors of between 2.54 and 23.84 t/CO_2-e/ha/yr. Comparing these sets of emissions factors suggests that the NE (2010) analysis used in this project underestimates the potential emissions savings associated with improving the condition of peatland.

Table 1.3 provides the estimates of the net effect on emissions from improving the state of peatland from the under the Crichton analysis. It suggests that improving actively eroding to modified peatland provides net emissions savings of 21.3 t/CO_2e/ha/yr.

Table 1.1: Emissions factors used by Natural England to estimate greenhouse gas flux from England's peatlands under a range of improvement actions. Units are tonnes CO_2e/ha/yr

Condition Categories	Improvement action	Estimated annual C benefit from activity ($tCO_2e/ha/yr$)	Source	Notes
Gripped	Blocking grips*	2.19	Byrne et al median figures	Does not include particulate losses
Bare	Reseeding bare peat**	2.45	Durham Carbon Model	Assuming 40% conversion of POC to CO_2 and reduction of this to 0 following restoration does not include gaseous losses, which may be high associated with liming and N fertiliser
	Planting bare peat**			
	Stabilising bare peat**			
Hagged/ gullied	Gully Blocking	2.19		
Overgrazed	Preventing overgrazing	2.49		
Burnt	Reduction in moorland burning	4.95		

* Also assumed in this analysis to be a relevant improvement action for Molinia (purple moor grass) dominated peatland

** Also assumed in this analysis to be relevant improvement action for hagged/gullied peatland

Table 1.2: Emission Factors for each Condition Category after statistical analysis (tCO_2e/ha/yr) using IPCC default values for DOC and relevant literature for POC. See footnotes for details on how POC and DOC values were derived

Peatland Code Condition Category	Descriptive Statistic	CH_4	CO_2	N_2O	DOC	POC	Emission Factor*
Near Natural	Mean (±StE)	3.2(1.2)	-3.0(0.7)	0.00(0.0)	0.88[7]	0	**1.08**
	Median	1.5	-2.3	0.0			
Modified	Mean (±StE)	1.0(0.6)	-0.1(2.3)	0.5(0.3)	1.14[8]	0	**2.54**
	Median	0.2	0.1	0.5			
Drained	Mean (±StE)	2.0(0.8)	1.4(1.8)	0.00(0.00)	1.14[9]	0	**4.54**
	Median	1.0	-0.9	0.0			
Actively Eroding	Mean (±StE)	0.8(0.4)	2.6(2.0)	0.0(0.0)	1.14[10]	19.3 (average of 14.67[11] and 23.94[12])	**23.84**
	Median	0.1	0.4	0.0			

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[7] Calculated as the mean value of reported values in UK studies given in Table 2A.2 of the 2013 Supplement to the 2006 Guidelines for National Greenhouse Gas Inventories: Wetlands (Wetlands Supplement) http://www.ipcc-nggip.iges.or.jp/home/wetlands.html

[8] IPCC Tier 1 default value for drained peatland (best estimate for modified condition)

[9] IPCC Tier 1 default value

[10] IPCC Tier 1 default value for drained peatland (best estimated for actively eroding condition)

[11] Estimated from UK blanket bogs (in Goulsbra, C., Evans, M. & Allott, T. (2013) Towards the estimation of CO_2 emissions associated with POC fluxes from drained and eroding peatlands. In: Emissions of greenhouse gases associated with peatland drainage waters. Report to Defra under project SP1205: Greenhouse gas emissions associated with non-gaseous losses of carbon from peatlands – fate of particulate and dissolved carbon. Report to the Department of Environment, Food and Rural Affairs, UK)

Standard error rates for CH4 seem high partly because methane is often emitted in bubbles.

* The data underpinning these Consolidated Emission Factors should be updated by the JHI as new science is published. Annual updates might be useful, until error margins reduce.

[12] Value from Birnie and Smyth (2013) unpublished, but recalculated to reflect that 70% of POC derived carbon assumed to be reaching the atmosphere with remaining 30% assumed redeposited (Chris Evans *pers. comm*).

Table 1.3: Net effect on emissions resulting from improvement and changing Condition Categories calculated using the Emission Factors given in Table 1.2 (in $tCO_2e/ha/yr$)

Restoring from Modified to Near Natural	Saves 1.46
Restoring from Drained to Near Natural	Saves 3.46
Restoring from Drained to Modified	Saves 2.00
Restoring Actively Eroding to Modified	Saves 21.30
Restoring Actively Eroding to Drained	Saves 19.3
Allowing Drained to develop into Actively Eroding	Loses 19.3

ANNEX 2. NATURAL ENGLAND (2013) SPATIAL MAPS OF PEATLAND CONDITION

From Natural England (2013) project on mapping upland peat Figure 2.1 illustrates the extent and condition of deep peat in the Northern uplands of England and Figure 2.2 for the Southern uplands of England.

Figure 2.1. Extent and condition of peatland in Northern England

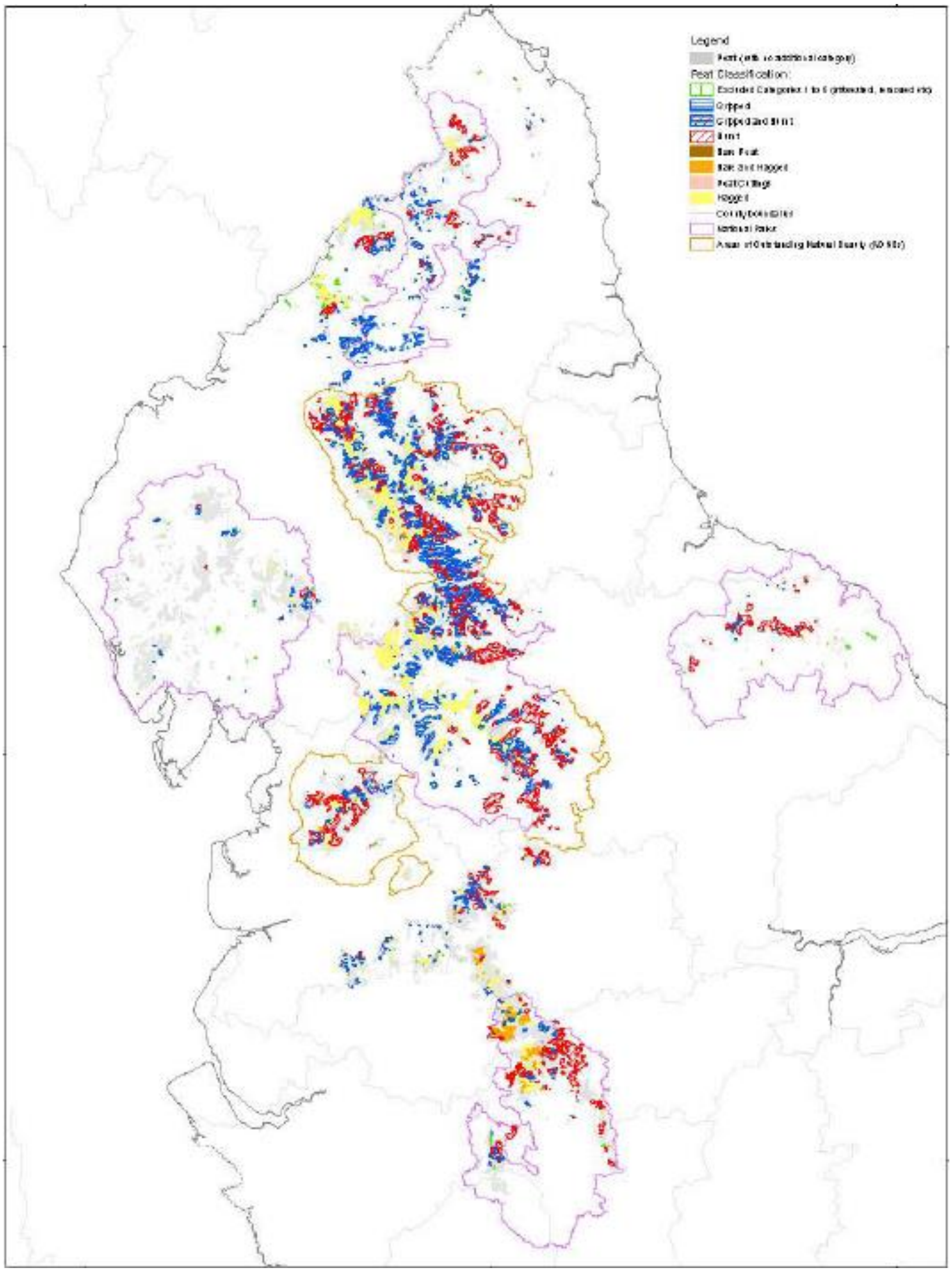
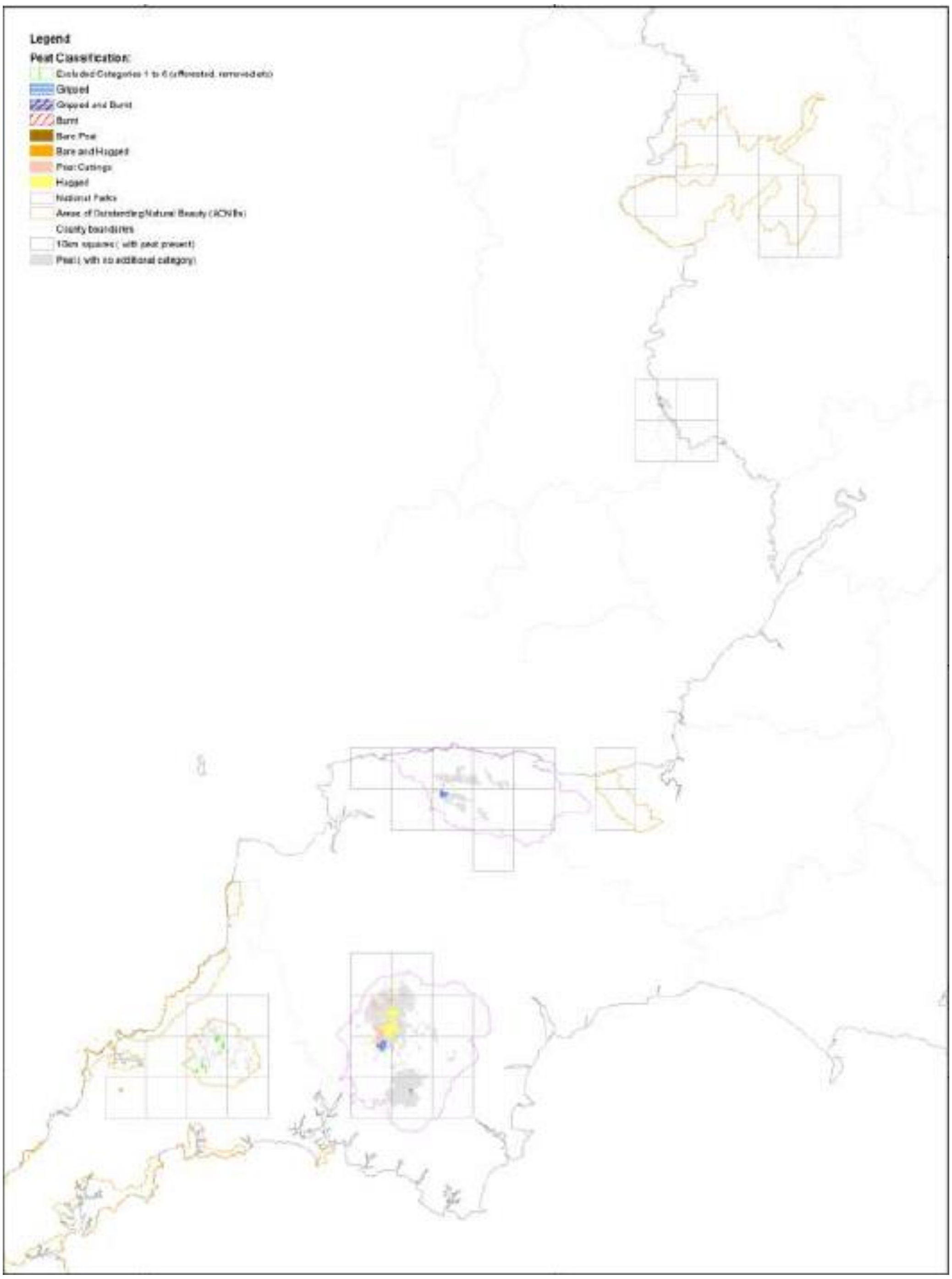


Figure 2.2. Extent and condition of peatland in Southern England



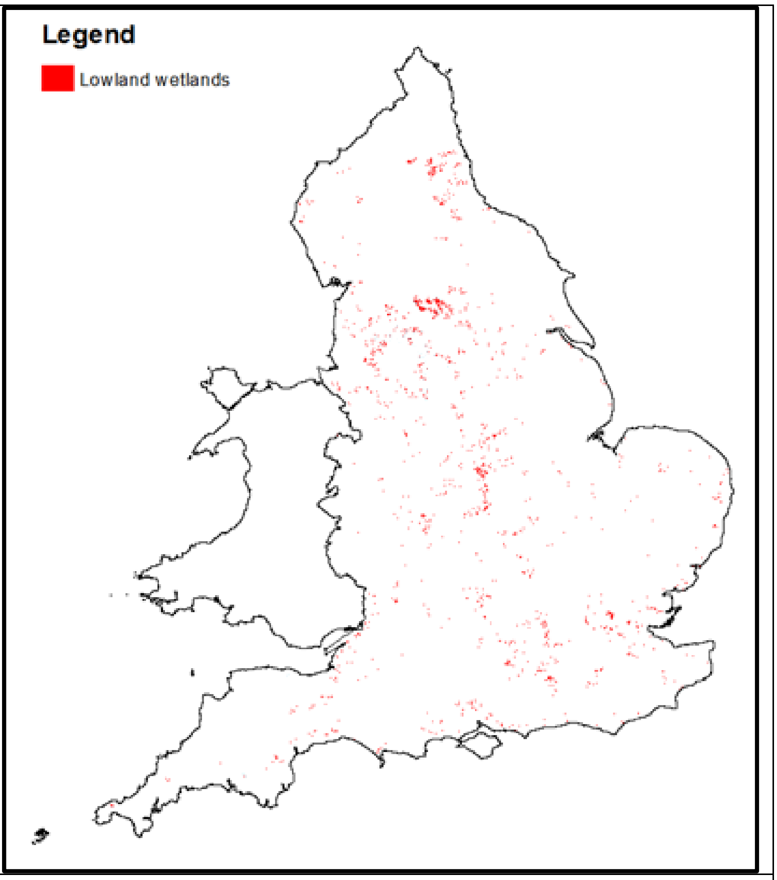
INVESTMENT CASE: FRESHWATER WETLANDS

SUMMARY

- *The total area of existing wetland with strongest investment case for improvement is approximately 10,000 ha. This very small area illustrates that only a small fraction (around 1%) of existing wetlands are optimally placed to deliver multiple ecosystem services.*
- *An investment case is defined for the creation of freshwater wetlands in a way that maximises ecosystem services values (upstream of and close to towns or cities) and minimises costs (on lower grade agricultural land). GIS is used to identify potential for approx. 100,000ha of such wetland creation.*
- *Data on costs and benefits can be compared, and in some circumstances costs outweigh benefits. However, positive returns can be obtained from investments in sites with an average size of 100ha, that are located in areas where economic returns are likely to be highest (such as in close proximity to large populations).*

<table>
<tr><td colspan="2">Investment:
Create 100,000 ha of new wetland in locations deemed feasible in the Wetland Vision and prioritised to where ecosystem service provision is likely to be maximised.</td></tr>
<tr><td colspan="2">Baseline:
45% loss of wetland habitat area in the last 75 years and a general downward trend in the status and condition of wetlands in the past 60-70 years.</td></tr>
<tr><td>PV of costs:
Total costs of creating 100,000 ha in England between £345m to £2,366m (PV over 50yrs).</td><td>PV of benefits:
Total benefit of wetland creation across 100k ha in England is £924m to £3,800m (PV over 50yrs), depending on average site size.</td></tr>
<tr><td>Monetised costs:
CAPEX and OPEX of wetland creation and ongoing management, land purchase assumed to reflect opportunity costs.</td><td>Monetised benefits:
Flood control; drinking water supply and quality; recreation; enjoyment of aesthetics/landscape; biodiversity.</td></tr>
<tr><td colspan="2">Non-monetised impacts:
GHG emissions are not considered, therefore benefits could be underestimated. No estimate for the wider opportunity costs to other ecosystem services, leading to potential overestimation of net benefits.</td></tr>
<tr><td>NPV:
Between £634m and £2,750m, and the BCR between 1.3 and 9, for restoring up to 100,000ha of wetland built up from sites of an average size of 100ha.</td><td>Time period:
Results of interventions realised after 10 yrs. PVs over 50yrs at HMT discount rate.</td></tr>
<tr><td colspan="2">Key assumptions:
Wetland creation can be targeted to deliver ecosystem services based on being upstream of and within close proximity to large populations. Opportunity costs of food provision lowest on low quality agricultural land. Costs taken from example 20ha and 500ha sites and literature. Benefits estimated based on Brander et al (2008) meta-analysis function.</td></tr>
<tr><td colspan="2">Scale of impacts:
Up to 100,000ha of wetland creation across England, assumed to be in sites of a mixture of sizes and an average size of approx. 100ha, so there are limited diminishing returns (i.e. where the incremental benefit of an extra ha would decrease as the total area increases). Some risk of diminishing returns to recreational services, as these could also be provided by investment in saltmarsh (other wetlands within 50km) and possibly other habitats (e.g. woodland).</td></tr>
</table>

Distribution (over space): Figure S1: Map of possible wetland sites with potentially high ecosystem service provision and low opportunity costs.



Additionality:
Habitats legislation tends to be focused on the status of individual sites. This investment case goes beyond current levels of wetland habitat creation and also considers connectivity and creation of a resilient ecological network in response to historical fragmentation.

Synergies/conflicts:
Synergy with catchment management investments.

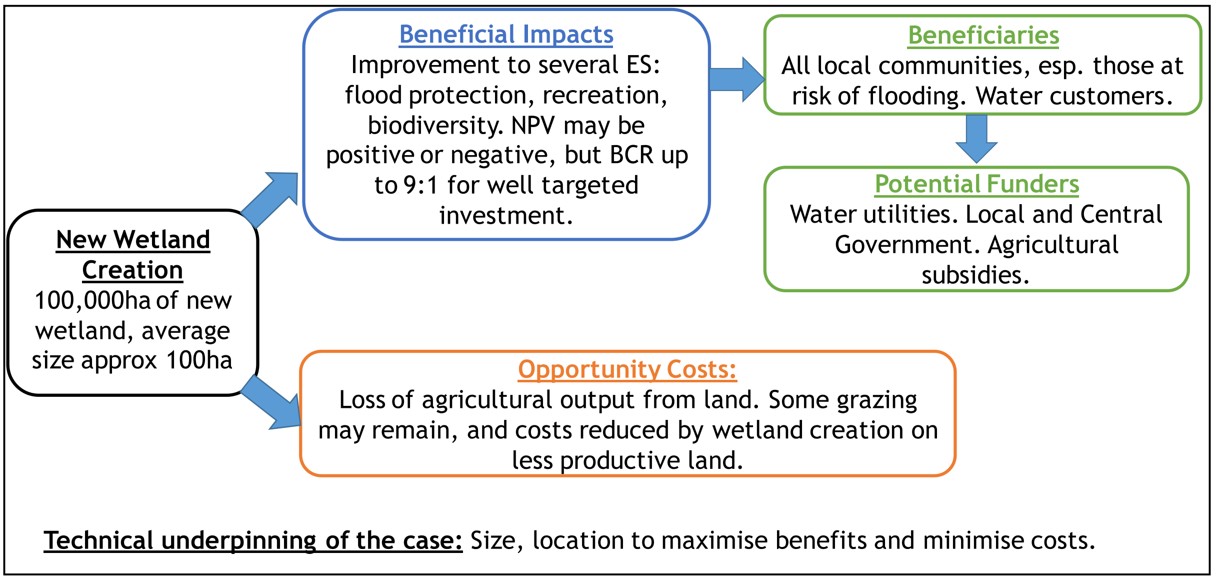
Impact on natural capital assets:
Improved condition of soil and improvement to ecological communities in wetlands. Improvement to freshwater resources.

Uncertainties:
Reliability of the meta-analysis function used; the potential for specific areas to deliver high ecosystem services; trade-offs and interactions between services; constraints on scaling up; climate change.

1. INTRODUCTION

Figure 1.1 is a value chain which provides a simple illustration of the links between wetland improvement actions and costs, changes to ecosystem service provision, the benefits produced and who might benefit as well as who might fund the improvement actions and what the likely opportunity costs of undertaking improvement action are.

Figure 1.1: Wetland value chain



New Wetland Creation
100,000ha of new wetland, average size approx 100ha

Beneficial Impacts
Improvement to several ES: flood protection, recreation, biodiversity. NPV may be positive or negative, but BCR up to 9:1 for well targeted investment.

Beneficiaries
All local communities, esp. those at risk of flooding. Water customers.

Potential Funders
Water utilities. Local and Central Government. Agricultural subsidies.

Opportunity Costs:
Loss of agricultural output from land. Some grazing may remain, and costs reduced by wetland creation on less productive land.

Technical underpinning of the case: Size, location to maximise benefits and minimise costs.

Following this introduction, Section 2 provides a definition of the natural capital asset, specifically freshwater wetland habitat and associated ecological communities. Section 3 outlines the current status and trend of the asset and ecosystem service provision using a range of data sources. Ecosystem services considered are flood control, drinking water supply and quality, recreation; enjoyment of aesthetics/landscape and biodiversity. The Wetland Vision is used as a basis for the analysis and this estimates current freshwater wetland to be around 300,000ha. Wetland habitat loss in the UK is estimated to be 45% loss of area in the last 75 years (WWT, 2011). Section 4 explains the threats/drivers leading to degradation of the asset including land drainage, flood defences, abstraction, pollution, invasive species, climate change and habitat degradation.

Section 5 describes possible improvement actions as described in the literature. It also sets out total area (10,200 ha) of existing wetland with strongest investment case for improvement given known drivers of economic value. The potential area (114,000 ha) with greatest net benefits given these same drivers is also estimated. The geographic location of both areas is illustrated using GIS. Section 6 presents the evidence on costs of wetland creation actions including capital costs (CAPEX), operational costs (OPEX) and opportunity costs where possible. The total costs (CAPEX and OPEX) of creating 100k ha in England are £345m to £2,366m (PV over 50yrs).

Section 7 provides a review of benefits information associated with wetland creation for a range of ecosystem service benefits. It introduces the Brander et al meta-analysis function which provides a bundled value estimation for wetland creation, i.e. all relevant services valued simultaneously. This function is then used to estimate the benefits associated with wetland creation in England and sensitivity analysis is performed. Total benefit of wetland creation across 100k ha in England is £924m to £3,800m (PV over 50years).

There is a strong argument for restoring 100,000ha of wetlands built up from smaller sites of an average size of 100ha and targeted to maximise ecosystem service value and minimise opportunity costs. Here the net present value of creating new wetland is between £634m and £2,750m, and the benefit:cost ratio between 1.3:1 (£3,000m:£2,366m) and 9:1 (£3,100m:£345m).

Section 8 then provides an overview of the likely timescale of benefits realisation and explains the feasibility/uncertainty of the estimates. Section 9 summarises the main knowledge gaps/research needs. Section 10 provides detailed case studies in Gwen Finch in Worcestershire and Wicken Fen in Cambridgeshire.

2. ASSET DESCRIPTION

The established definition for wetlands is provided by the Convention on Wetlands of International Importance (the Ramsar Convention): “areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing".

The natural capital asset under consideration in this investment case is freshwater wetland habitat and associated ecological communities (thenceforth ‘wetlands’ where not stated otherwise). More specifically the investment case relates to the priority habitat types wet woodland, fen, lowland raised bog, reedbeds, ponds and a sub selection of open water habitats (Hume, 2008). Upland priority habitats (upland peatlands and purple moor grass rush pasture) are not included in this investment case. They provide many similar services to lowland wetland habitats, however, the context is quite different. They are more remote from populations, important for carbon and water, but less so agricultural production and have different patterns of visitor use. Upland wetlands are generally peat bogs and are considered under the peatland case.

Historically wetland habitat improvement has been focused on individual sites. More recently projects have aimed at restoration of wetlands system at a landscape scale (Grootjans, 1995). The Wetland Vision (Hume, 2008) was a multi-organisation project concerned with the development of ecological networks and resilience of wetland functions, particularly to climate change. It focuses on restoring benefits associated with biodiversity and the historic environment as the primary final ecosystem services, which incorporates the non-use (existence) value of wildlife and the supporting services of biodiversity in terms of ecosystem functionality. However, the varied nature of wetlands means that the range of ecosystem services and associated final goods is also highly diverse (see Table 2.1). The literature gives numerous typologies of benefits based on ecosystem services-type frameworks (see for example Barbier et al. 1999; Turner et al. 2008; de Groot et al., 2009; Maltby et al., 2011; Jones et al. 2011).

Provision of ecosystem services is determined by topography, hydrology, soil type and the specific function and condition of the natural assets of a given wetland (e.g. species, ecological communities), and the interactive effects between these factors that combine to produce specific benefits. The benefits that are realised are also dependent on both water and land management and other exogenous factors. For example recreation benefits cannot be derived without access to a site, whilst the scale of flood protection benefits is dependent on the proximity of the wetland to at risk settlements and the population of those settlements.

Targets for restored wetland are likely to be based on the EC Habitats Directive and the Water Framework Directive. Habitats legislation tends to be focused on the status of individual sites. This investment case goes beyond that and also considers connectivity and creation of a resilient ecological network in response to historical fragmentation.

Table 2.1: Wetland ecosystem services and goods

Final good	Examples
Provisioning services	
Food: crop and livestock products	Management of wetland grasses for grazing, silage and hay Intensive agriculture on floodplains Commercial fisheries dependent on spawning habitats
Biomass: fibre and energy materials, including peat	Lowland bogs provide peat for horticultural industry Reed and willow for building materials
Health products	Flora and fauna with medicinal uses
Regulating services	
Carbon regulation	Management of wetlands to sequester and store carbon in vegetation and soils
Water flow and flood regulation	Flood risk reduction from capacity for water storage
Water quality regulation	Breakdown of waste, removal of pollutants and detoxification of freshwater
Cultural services	
Recreation and tourism	Formal (paid for) and informal recreation (fishing, bird watching)
Science and education	Preservation of archaeological artefacts Scientific research on ecosystems
Human health and wellbeing	Enhancement of physical and mental health through physical activity
Sense of place and history	Sites of local/regional/national cultural and historical significance

Sources: Jones et al. (2011); Maltby et al. (2011); Morris and Camino (2011).

3. BASELINE

This section sets out the current status and trends in the freshwater wetland assets and the ecosystem services they provide.

3.1 Extent and condition of freshwater wetlands

The baseline data used for the GIS assessment has been taken from the Wetland Vision[13] of where current wetlands can be restored and where new wetlands could be created. The total area of current wetlands is 932,396 ha as set out in Figure 3.1 (N.B. this includes 175,576 ha of upland blanket bogs estimated based on the extent of Moorland SSSIs).

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[13] We are grateful to RSPB for providing the GIS data layers associated with the study (Hume, 2008).

Figure 3.1: Current area of wetland in England (including blanket bog)

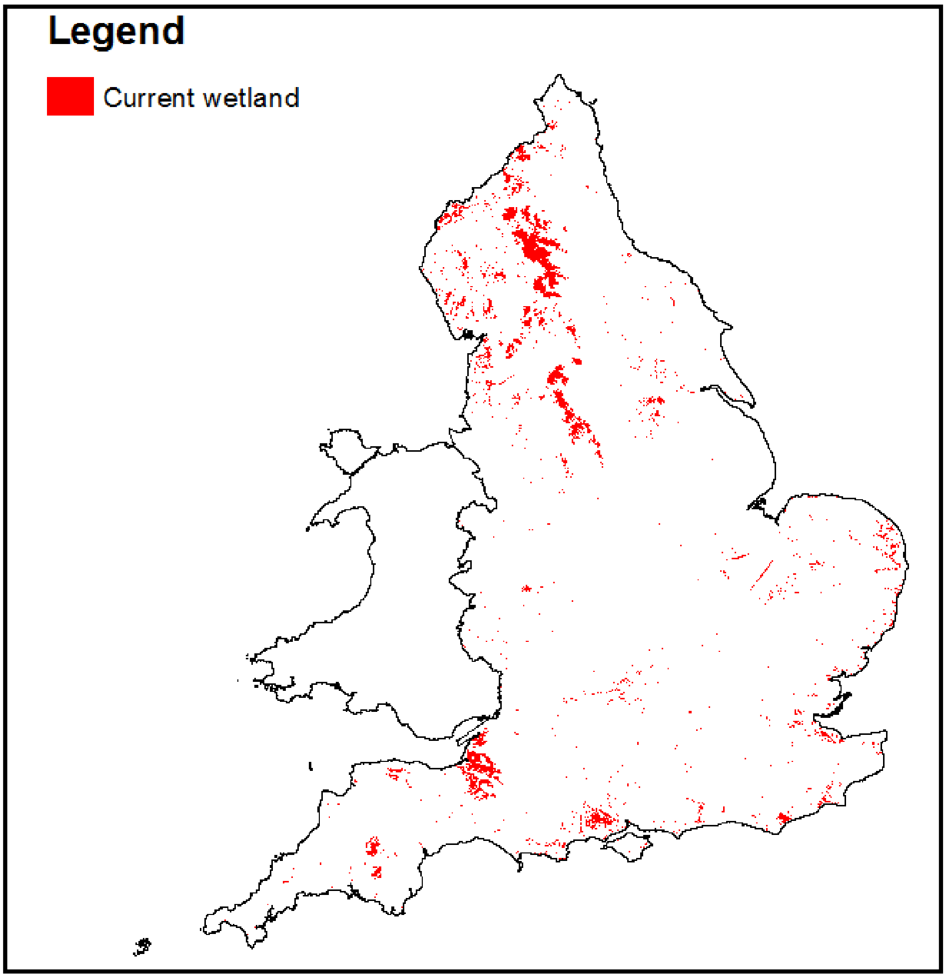


Table 3.1 sets out estimates of current extent of the lowland freshwater wetland priority habitats. They were taken from the Natural England single habitats layer final report which supports the GIS files provided as part of the habitat inventory.

Table 3.1: Estimated extent of wetland

Source	Total
Coastal and floodplain grazing marsh	218,171ha
Lowland Fen	22,180ha
Lowland raised bogs	9,690 ha
Reedbed	7,014ha
Wet woodland**	50,000ha to 70, 000ha
Ponds	183ha per km^2 or 234 000 ponds***
Total	307,055ha to 327,055ha

Source: Single Habitats layer final report (NE, 2013)
** BAP reporting (2008) not in single habitats layer report
***Countryside Survey (2007)

The wetland habitat loss in the UK is estimated to be 45% loss of area in the last 75 years (WWT, 2011). The UK National Ecosystem Assessment (UK NEA, 2011) also reports a general downward trend in the status and condition of wetlands in the past 60-70 years. 13% of floodplains are degraded or completely disconnected from river channels and the area of lowland raised bog retaining a largely undisturbed surface has declined by 94% (UK NEA, 2011).

More than a quarter of the total wetland area in England is designated as SSSI (Maltby and Ormerod 2011). By area, 21% (52,308 ha) of SSSI wetland is in favourable and 48% (118,671 ha) is recovering condition (not including blanket bog) (Natural England 2008). Over 80% of reedbed is in favourable or recovering condition compared with 60% raised bog or lowland fen.

3.2 Ecosystem services

3.2.1 Recreation/landscape/amenity

Wetlands provide unique opportunities for recreation (boating and fishing) and tourism (often wildlife focused). Sites such as RSPB reserves (e.g. Titchwell, Minsmere, Leighton Moss) are locally important for wildlife tourism (Rayment & Dickie, 2002). They are also important historically with the habitat capable of preserving artefacts and palaeo-environmental data in the form of pollen, small beetles etc. (Hume 2008, Maltby et al 2011). They are also often valued waterscapes (aesthetic/landscape value) providing a sense of place, religious significance, folklore and mythology, these cultural services are thought to be deteriorating slightly presumably from fragmentation, drainage and disconnect between people and place.

3.2.2 Climate regulation

Wetland vegetation and soils can also be important stores of carbon (or sources of carbon emissions). Natural England (2010) estimated that the remaining lowland fen in English peatlands stored 1,004 to 2,576 tonnes of carbon/ha, and raised bog peats stored 1,575 to 1,629 tonnes of carbon/ha. Maltby and Ormerod (2011) showed that this ecosystem service was either declining or stable.

3.2.3 Water quantity and quality regulation

Wetlands, particularly reedbeds, can lead to improvements in water quality through trapping particulates, nutrient cycling and the potential to dilute, store and detoxify pollutants/waste products, thereby benefiting water quality in river catchments (Maltby 2009; Maltby et al., 2011). Wetlands can also regulate water flow thereby reducing downstream flooding risk (Bullock and Acreman 2003, Acreman et al 2003, Maltby et al., 2011). Maltby and Ormerod (2011) showed that the management of flood plains is improving.

3.2.4 Provisioning services

Grazing (livestock agriculture output) is an important provisioning service, particularly in managed floodplains and grazing marsh. This service is improving on managed floodplains, but deteriorating in other habitats (Maltby et al. 2011). The services also conflicts with other services at higher livestock intensities, but can provide synergies at lower levels.

Wetlands provide habitat for wild game, but this is another area where decline has occurred.

They can also be harvested for various materials (sedges, willows, reeds, peat, Sphagnum for hanging baskets), even though this has often happened unsustainably and led to habitat degradation reducing wetlands productivity these goods.

3.2.5 Other ecosystem services

Wetlands also provide an important ‘supporting service’ or natural capital input to the freshwater system providing spawning grounds for fish, this function has also deteriorated slightly.

3.3 Biodiversity

Wetlands can be important habitats for fish (e.g. spawning), native and migratory bird species, aquatic plants, amphibians other invertebrates. For example, at Wicken Fen, 8,000 species have been recorded, including 121 red data book invertebrates (Acreman et al 2011). This is recognised in the proportion of wetlands (more than a quarter) that are designated for landscape and nature conservation purposes (as mentioned above for SSSI designation).

The JNCC Biodiversity-in-your-pocket (BIYP) indicators show that between 1975 and 2011 water and wetland birds have declined, but the most recent data (2013) showed that there had been no change in the short term. Wintering water birds have increased over the longer term but decreased in the latest indicator. This is not solely a reflection of the condition of UK habitats.

4. THREATS

This section sets out the nature of the threat/driver leading to the current degraded condition of natural capital. Wetlands are very sensitive to subtle changes in water supply and quality, including acidity, nutrient levels and water table fluctuations (Wheeler & Shaw 2001, UK NEA, pg 332).

Key pressures leading to wetland degradation have included land drainage particularly for agriculture, modification of water bodies for flood defences, water abstraction, diffuse and point source pollution, invasive species, climate change (increased sediments from more severe storm events) and water quantity (more extreme floods and droughts, increased likelihood of summer flooding) and habitat degradation, fragmentation and loss.

With regards to pollution: a wetlands natural capital asset check case study in Dickie et al, (2014) identified different thresholds relation to eutrophication. Firstly, raised nutrient levels reduce species diversity and associated biodiversity and recreational benefits (e.g. nature-watching). Secondly, at higher levels eutrophication can lead to toxic algal blooms, preventing all water-contact recreation activities. Recovery from any of the above threats may be non-linear. For instance accumulation of pollutants, once a threshold value has been passed more effort, cost and time may be required for recovery.

5. INVESTING IN FRESHWATER WETLANDS

Investments should target increasing the area and improving the condition of wetlands. In doing so, they should be planned to enhance wetland systems rather than focusing on individual sites. Establishing a matrix of functioning wetlands in the landscape will not only increase the area, but also benefit the existing wetlands (with benefits such as provision of buffers from pollutants, dispersal of species, and resilience to changing climatic conditions). To successfully restore a system requires the location of new wetland areas to be chosen based on consideration of the landscape context including the use and quality of surrounding land.

5.1 Likely actions to improve freshwater wetlands

Relevant investments include the creation of new and extension of wetlands to combat habitat fragmentation and to improve the condition of existing wetlands. Specific restoration actions include (den Uyl 2013, Great fen project website, Hardman 2010):

- Reducing fertility of vegetation and soil (e.g. removal of vegetation);
- Restoring the hydrological regime of existing and new wetland;
- Controlling water levels; may be by diverting ditches, manipulating water levels, re-profiling ditches;
- Introducing appropriate grazing regimes;
- Other management including invasive species control; and
- Creation or extension of other wetland habitats such as reedbeds, ponds.

The size of sites created is a sensitive issue for both the costs and benefits involved:

- Ecologically, there are minimum sizes of area for the habitat to function effectively for different conservation objectives. For example, lowland wet grassland sites need to be large >200ha in order to deliver multiple benefits, whilst reedbeds need to be greater than 20ha (Ward 1995). Current conservation projects vary in size. For example, the Great Fen project aims to restore 3,700ha of land, while Wicken Fen project created an additional area of approximately 479ha.
- Economic benefits are, overall, higher at smaller sites of 50ha or less. At larger sites of around 500ha, nature conservation values can be maximised, but other values, such as for recreation, could be lower per ha due to diminishing returns (see Section 7.2). Actual benefits are dependent on local conditions – for example, flood risk alleviation is dependent on the current management of a catchment.
- Economic costs can be reduced by realising economies of scale in larger sites up to at least 500 ha (see Final Report Section 2.4.3). The assumption is that the range of costs used in this analysis reflects the economies of scale that can be achieved by spreading the cost base over a larger area.

In practice, it is assumed that the size of sites will vary between approximately 50 and 500 ha, and that there could be some targeting of investments to ensure a mixture of site sizes is delivered.

Delivery can be through a number of mechanisms, but most wetland creation in the UK has been funded by CAP agri-environment schemes and/or fundraising by environmental NGOs/agencies from a range of sources (e.g. from members or grants such as from Heritage Lottery Fund and the Landfill Tax Credit Scheme). In either case it is important to provide landscape level planning and co-ordination. For example some of the Nature Improvement Areas (e.g. Morecambe Bay limestone and wetlands) aim to restore lowland raised bog and create wet grassland by providing bespoke advice to farmers to assist with submission of Higher Level stewardship.

5.2 Opportunities for creating new wetlands

The Wetland Vision identified the total land area ‘with potential for new wetland creation’ as 1,583,500 ha, which includes blanket bogs. Based on this, it set various targets for wetlands, beginning with the BAP targets, but accepting that they have limitations in describing a vision for wetlands in 50 years’ time. This is partly because they are short term targets that do not take into account ecosystem functionality or interactions between habitats (Hume, 2008).

The Wetland Vision screened out areas where wetland creation would conflict with major built developments (e.g. transport infrastructure) where opportunity costs of wetland creation would be highest. It is therefore assumed that the vast majority of this wetland creation would be on undeveloped land, which, in lowland England, effectively means on farmland.

For example, BAP targets include increasing the population of 50 booming male Bitterns (*Botaurus stellaris*) to 500 in 50 years' time. To support this population, the current extent of reedbeds, ponds and grazing marsh would need to double to approximately 14,000 ha, 360ha per km^2 and 450,000 ha, respectively. The Wetland Vision also suggests that approximately 1.1% (UK wide about 143,000 ha) of land for wetlands (lowland) is needed to deliver sustainable populations of all birds considered in a calculation by the RSPB (Hume 2008). If this 143,000 ha was provided using nature reserves, then half as much area again would be required for water storage.

Creating 1.5 million ha of wetland is difficult considering other demands that our land resource needs to meet, so there is a need to identify a subset of the area of potential wetland from the Wetland Vision where it is most beneficial for society to invest in wetland creation. The areas that are prioritised as being important in providing ecosystem services are those that:

- Are in the lowlands, due to both different ecosystem services produced and because upland peatland improvement is considered in a separate investment case;
- Close to human settlements, and therefore providing recreational opportunities and other services (e.g. water quality regulation) to larger populations;
- Have an urban area downstream of it, as a proxy for water regulating services, in particular flood hazard regulation, and
- Have lower opportunity cost. Therefore opportunity costs are further distinguished by excluding agricultural land classified as grade 1 or 2.

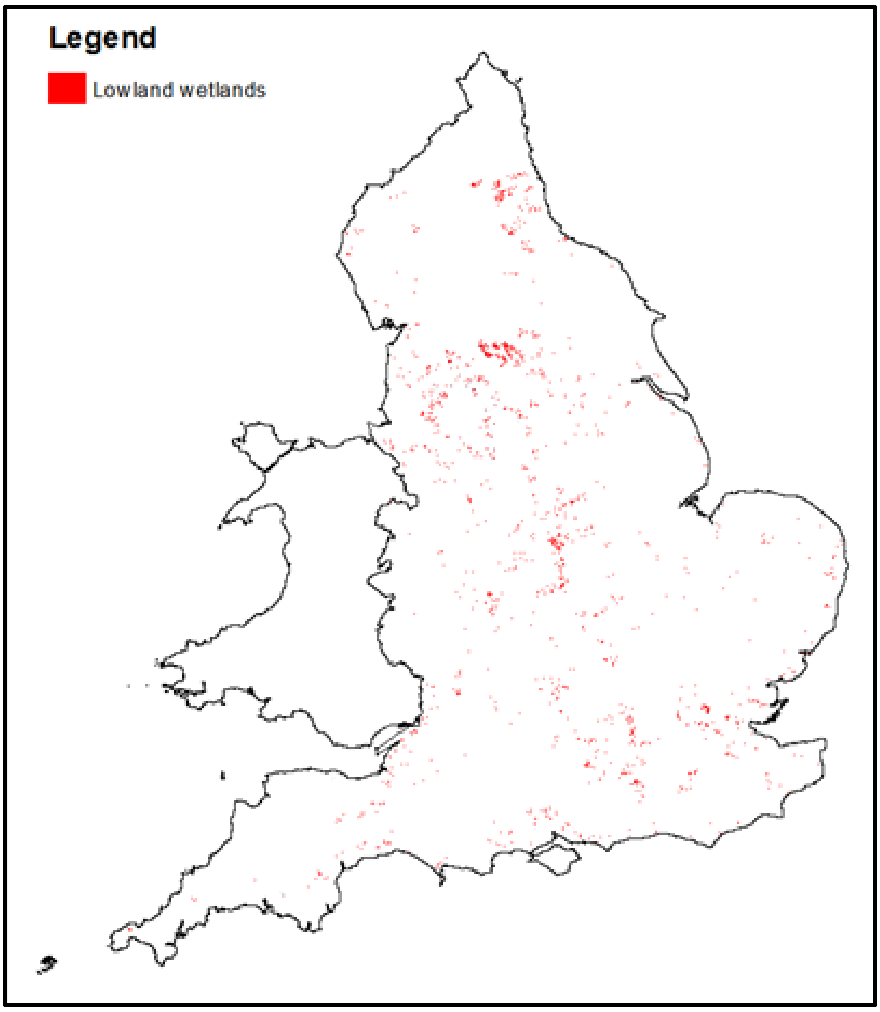
These filters were applied to the 1.5 million ha of areas potentially available for wetland creation in England (as set out under the Wetland Vision) using GIS, to identify the area with the strongest investment case (i.e. areas that are likely to generate the maximum ecosystem service benefits at lowest cost). This results in a **total potential estimated area for wetland creation with potential for greatest net benefits given criteria above of 114,000 ha.** The distribution of this area is shown in Figure 5.1.

However, for each new wetland, the case will be influenced by local factors, such as:

- The costs of actions required to deliver this improvement, which will vary by site and show economies of scale (see Final Report, Section 2.4), and
- Levels of ecosystem services benefits, which in addition to the factors above will be influenced by many local factors, such as the availability of substitutes for the services, i.e. other assets that could provide the same service.

These need to be assessed on a case by case basis.

Figure 5.1: Map of possible wetland sites with potentially high ecosystem service provision



5.3 Opportunities for improving existing wetlands

The Wetland Vision areas can also be used to identify where existing wetland could be most beneficially improved. The same filters as described in Section 4.2 were applied to the 930,000 ha of existing wetland (upland and lowland), to identify where improvement would likely provide the most significant ecosystem service benefits. The extent to which these benefits are currently being realised is unclear. If it is assumed that at least some proportion of this wetland area is in a state of degradation that results in sub-optimal ecosystem service provision, then there is a potential case for investment in improvement. The case will rely on the costs of actions required, which have to be assessed on a case by case basis.

The total area of existing wetland with strongest investment case for improvement is estimated at 10,200 ha. This very small area illustrates that only a small fraction (around 1%) of existing wetlands are optimally placed to deliver multiple ecosystem services. Of the 930k ha, only 250k ha is situated in areas where 10k people live within 10km, only 37k ha of this is situated upstream of urban land cover and only 10,200 of this is situated on low opportunity cost land in the lowlands.

5.4 Wetland Investment Area

As the area for wetland improvement is too small to make a significant difference to the national freshwater wetland area, the remainder of this investment case examines how to devote resources on wetland creation. This is not to say that investment in wetland improvement is not cost effective. In fact, ensuring good condition of existing habitat is usually an essential first step before environmental enhancements. Given the available data, we are unable to say much about the costs of improving current wetlands, nor the extent to which this would enhance ecosystem services, and therefore cannot comment on the net benefits of such actions.

This analysis of a wetland investment plan is therefore based on new wetland creation. The area analysed could be based on the 143,000 ha estimated by Hume (2008) necessary to conserve wetland birds. However, a more conservative approach is adopted here based on the land area identified as optimal for wetland creation (114,000 ha).

It should be recognised that wetland creation on exactly this spatial area as identified in Figure 5.1 at the lowest opportunity costs is unlikely to be feasible for a variety of reasons. Efficient wetland creation boundaries are dictated by hydrology (As reflected by the Wetland Vision), and these may not correspond to the boundaries of the optimal land identified in Section 4.2. There will also be significant local factors that influence wetland creation opportunities. Therefore, **the 25 year wetland investment case is based on creation of 100,000 ha** – of which the majority is assumed to be on land with lower opportunity costs.

The following sections identify the costs and benefits of such an investment. This is based on national wetland creation economic data, and supported by analysis of two examples of wetland creation.

6. COSTS

This section sets out the costs of wetland improvement actions and subsequent management regime in terms of capital (capex) and operating (opex) expenditures.

6.1 Capital costs (CAPEX)

There is a wide range of evidence on the capital costs of wetland creation. For example, capital costs of over £78,000 are associated with the creation of a ‘habitat mosaic’ (IEEP, 2013) was based on example from a 1.5 ha site created in Pinkhill Meadow, Oxfordshire (The River Restoration Centre, 2002) and included creating deep water ponds, shallow-water areas and edges, temporary ponds and pools, wader scrapes, gravel islands and margins, mudflats and islands, undulating wet grassland and reedbeds. This very small site is not considered representative of scalable wetland creation, so this cost data is ignored.

Capital costs of wetland creation at two other example projects are shown in Table 6.1. They are the capital costs associated with the following actions: (i) converting drained and intensively farmed arable land to wetland habitat mosaic across 479ha for the Wicken Fen NNR in Cambridgeshire (Peh et al, 2014) and (ii) wetland creation from intensive agricultural grassland across a smaller 20ha[14] site to produce the Gwen Finch wetland reserve, Worcestershire (Hölzinger and Dench, 2011). The data suggests that the greatest cost associated with wetland creation is land purchase (£1,500/ha - £12,000/ha).

The high end estimates of CAPEX reflect high land purchase costs at Gwen Finch - a reserve of 20ha and earth works, associated structures and sluices, wind pump purchases, reeds and willows, fencing, tools and machinery as well as staff costs. The costs for Gwen Finch are likely to reflect diseconomies of scale being from a small site. However, they are kept as a high-end assumption in developing the model. The lower end estimates are for the Wicken Fen NNR of 479ha including land purchase, fencing and some re-engineering of ditches. The assumption is that the range of costs reflects the economies of scale that can be achieved by spreading the cost base over a larger area (see Final Report, Section 2.4).

The conclusion is that the **indicative costs for wetland creation (one-off CAPEX) are £1,450/ha to £24,269/ha.**

Table 6.1: Wetland creation capital cost estimates

Improvement Options	***Source***	**CAPEX (£/ha)** Central estimates
Land purchase, fencing and some re-engineering of ditches	*Peh et al, 2014*	£1,450
Land purchase costs	*Hölzinger and Dench, 2011*	£12,333
Earth works, associated structures, sluices		£7,132
Wind pump purchase		£892
Reeds and willows		£1,783
Fencing		£396
Tools and machinery		£198
Staff costs		£1,535
Floodplain scrapes	*IEEP, 2013*	£1,050
Wetland habitat mosaic through re-profiling		> £78,000
Reed bed		£2,500
Creation of reedbeds	*NE (2008)*	£380
Creation of fen		£380

6.2 Operating costs (OPEX)

The ongoing maintenance cost associated with the two example projects (creation of the Wicken Fen NNR in Cambridgeshire (Peh et al, 2014) and the Gwen Finch wetland reserve, Worcestershire (Hölzinger and Dench, 2011)) are shown in Table 6.2 and are relatively low £40 to £116/ha/yr. **Indicative costs for wetland creation (ongoing OPEX): £40/ha/yr to £116/ha/yr.**

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[14] 20.19ha comprising of 1 ha (300m) of ditches, 6 ha of reedbeds, 11 ha of wet grassland and 2 ha of wet woodland.

Table 6.2: Wetland creation, ongoing cost estimates

Improvement Options	*Source*	OPEX (£/ha/yr) Central estimates
Salaries, equipment, veterinary fees, and fence maintenance	*Peh et al, 2014*	£116 *
Pump servicing, infrastructure repairs and improvements, staff costs	*Hölzinger and Dench, 2011*	£168

*although a net gain when compared to arable land of $1325/ha/yr.

This analysis assumes there will be adequate water available to maintain the wetlands created. This may be a restriction in establishing wetlands, but they are assumed to contribute to (and can be designed for) summer water storage, so is not regarded as a long term constraint.

6.3 Opportunity costs

Opportunity costs refer to the lost benefits from land that could have been use for other purposes than being converted to wetland. For wetland creation, the main land use lost is arable land, the opportunity cost lost is arable production. The cost of land purchase under wetland creation is assumed to include the opportunity cost of land, as the potential to use the land for agricultural production is already capitalised into the price of that land (i.e. sellers of land are willing to forgo the potential value of land for agriculture at the market price of that land).

For wetland creation, grazing may increase with change of land use from arable to wetland. There are trade-offs/opportunity costs between increased grazing and the provision of other services: increased soil compaction may increase runoff and N_2O emissions; reduced water quality by increased deposition of nutrients and faecal bacteria; increased GHG (CH_4) from grazing of animals; and higher water levels on grazing marshes may lead to reduced hay production and reduced live-weight of livestock (Acreman et al. 2011). Whilst the opportunity cost of food provision is considered by concentrating wetland creation on lower agricultural classed land, there is no estimate for these wider trade-offs/opportunity costs in the calculations and therefore the net benefits of creating new wetlands may be overestimated.

Improvements to condition of existing wetland may require setting lower stocking densities. Therefore, for wetland improvements, changing in grazing practices and the benefits from food provision are the main opportunity costs.

6.4 Total costs of improvement in England (PV over 50yrs)

The indicative one-off CAPEX of between £1,450/ha to £24,269/ha and ongoing OPEX of £116/ha to £168/ha are applied across the investment area identified (i.e. 100,000ha). This gives an estimated present value of CAPEX between £122m and £2,043m and OPEX of £223m to £322m (PV over 50yrs). It is assumed that capital costs are incurred from year 1 to year 10. For ease of analysis, all capital costs are assumed to be incurred in year 5 and discounted into PV terms. Operational costs are assumed to be incurred from year 6 to year 50. **The total costs (CAPEX and OPEX) of creating 100,000 ha in England = £345m to £2,366m (PV over 50yrs).**

7. BENEFITS

This section presents the ecosystem service benefits of creating 100,000 ha of wetlands, including the change in the profile of these flows over time based on qualitative, quantitative and monetary evidence.

7.1 Ecosystem services

7.1.1. Biodiversity

Different components of biodiversity are likely to respond to wetland creation at different rates (see below) for some species heterogeneity of habitats will be important (e.g. birds). Biodiversity levels are likely to be higher in areas adjacent to existing high biodiversity areas and there needs to be provision for connectivity and dispersal.

7.1.2. Recreation/landscape/amenity

Nature-based recreation provides value to those living locally, but it has also been shown that people are willing to travel to particular sites e.g. to see birds. The best wetland nature reserves attract over 100,000 visitors per year (Rayment and Dickie, 2002).

7.1.3. Climate regulation

Wetlands will be impacted by and help to adapt to the effects of climate change. Climate change may result in decreases in summer rainfall and increase in winter rainfall or decreased rainfall overall (Hume, 2008). Wetlands can help to moderate extreme events and to regulate water flow, they also affect local climate with higher humidity and lower temperatures (Acreman et al 2003).

In the short term, wetland creation may increase CH_4 emissions due to raising water levels and N_2O due to soil compaction by grazing animals introduced to previously arable land. In the long term, these emissions should reduce with improvement of wetland function (Couwenberg et al 2011). A study in the Somerset levels looked at the impact of agri-environment scheme (tier 3) management, at prescribed water levels, carbon loss should have reduced as respiration reduced but increased methanotrophic bacteria lead to increased methane production (which is 33 times more potent a GHG than CO_2). This study suggested a critical water level 10cm below the surface, and potential for soil water level management to control the soil methane budget. In addition to the water levels introduction of livestock will increase methane emissions.

7.1.4. Water quantity and quality regulation

The EA has proposed a series of projects using natural processes to reduce flood risks including the use of wetlands. Wetland (with the aim of regulating flow) will need to be optimally positioned in relation to the population they are protecting. Although wetlands are useful for flood mitigation, where the water table is brought close to the surface, there may be less capacity for water storage than currently so there are potential tradeoffs with biodiversity (Fisher et al, 2011). Some biodiversity will require high water tables, but it may be necessary to plan some deeper pools for heterogeneity of habitats with other less wet areas to allow for flood mitigation capacity.

Water quality may improve after wetland creation as wetlands, particularly reedbeds, have the ability to filter and process nutrients, also conversion of arable land to wetland may reduce nitrogen and phosphorous downstream (Peh 2014, Evans et al 2007). However there may be an initial release of phosphorus where surface layers are decomposed peat (Zak et al 2010), managed fluctuations in water levels or floodwaters may also drawdown water from agricultural land with release of nutrients (Niedermeyer 2009, Surridge et al 2012). For a more biologically diverse and valuable site good water quality may be required and highly polluted eutrophied sites may take more time or money to improve, or restrict what improvement can take place, this is a tradeoff that needs to be considered (Hume, 2008).

7.1.5. Other ecosystem services

There are provisioning services associated with wetlands including traditional practices that benefit the local population (e.g. harvesting of willow (Acreman et al. 2011)). These should increase with improvements in the quality of wetland. There are also potential dis-benefits of wetland creation, some associations with disease, mosquitos and avian flu.

7.2 Total benefits of Wetland Creation in England (PV over 50yrs)

The valuation of wetland and intertidal habitat creation in terms of improved ecosystem service provision has been estimated using the Brander et al. (2008; EEA 2010) meta-analysis function[15]. Using this function provides a bundled value estimation of wetland creation, which considers the study characteristics (e.g. the study method, such as contingent valuation or travel cost); wetland characteristics (e.g. the type of wetland being valued); and context characteristics (e.g. GDP per capita, population density, and wetland size).

The Brander et al. function examines how observed wetlands values vary with these characteristics. **Error! Reference source not found.**1 outlines the variables from the Brander et al. (2008) function included in the analysis:

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[15] The function specification and parameters applied are as reported in Brander et al. (2008; EEA 2010).

Table 7.1: Value function for wetland[16]

Variable	Coefficient value	Value of explanatory variable used for this valuation	
Constant	-3.078	1	-
Wetland Type: Inland Marsh	0.114	1	It is assumed that 100% of the habitat created will be inland marsh.
Wetland Size	-0.294	*In*[a] 100,000	100,000 ha of wetland are created in blocks of different average sizes (see Table 7.2 below).
Flood control	1.102	1	Assumed ecosystem service provision: flood control; surface and groundwater supply; water quality improvement; non-consumptive recreation; amenity and aesthetic services; and biodiversity.
Surface and groundwater supply	0.009	1	
Water quality improvement	0.893	1	
Non-consumptive recreation	0.34	1	
Amenity and aesthetic services	0.452	1	
Biodiversity	0.917	1	
GDP per capita (2003US$)	0.468	*In* 31,981	UK GDP per capita is taken from Eurostat (in euros) in 2003, converted into US dollars ($) using PPP in 2003 as $31,981 (Eurostat, 2014; OECD 2014) and uprated for inflation to 2013 prices (ONS, 2013).
Population density per km^2 within 50km	0.579	*In* 353	The population density within 50 km has been approximated from the average population density England (excluding London) of 353 people per km^2 (ONS, 2013).
Wetland area within 50km	-0.023	*In* 3,000 (5,000)	Assumed to be 3,000 ha within 50 km radius of each wetland site, based on the WWT estimates for Gwen Finch, which was considered generous. Sensitivity analysis is performed using a figure of 30,000ha.
Source: Brander et al. (2008; 2011)			

[a] ln represents the natural logarithm of a number

Factors controlled for in the meta-analysis function include:

- **Wetland size (in hectares):** (size of wetland created in terms of this case study). The coefficient estimate is negative (and statistically significant), implying the unit value for

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[16] This is a truncated version of the full Brander et al. (2008) function, only including variables that were used in estimation of wetland values in this report. Parameters that were set to zero (e.g. peat bog, saltmarsh, intertidal mudflat) are not reported.

wetland (£/ha) decreases as the size of the wetland increases (all else equal); i.e. indicating decreasing returns to scale.

- **Flood control service:** The coefficient estimate is positive (and statistically significant), indicating that wetlands that provide flood control and/or storm buffering are associated with higher values than those that do not. Note that in this case study flood control benefits of freshwater habitat creation are valued only through application of the Brander et al. function. Other appraisal guidance (e.g. the Environment Agency FCERM guidance) has not been applied.
- **Water quality improvement:** The coefficient estimate is positive (and statistically significant), indicating that wetlands that contribute to water quality improvements are associated with higher values than those that do not.
- **Biodiversity:** The coefficient estimate is positive (and statistically significant), indicating that wetlands associated with enhanced biodiversity outcomes are associated with higher values than those that do not.
- **Income of the population in the vicinity (or users) of the wetland.** The coefficient estimate is positive (and statistically significant), indicating that higher wetland values are observed in regions with higher levels of GDP per capita.
- **The population within 50 km of the freshwater wetland habitat.** The coefficient estimate is positive (and statistically significant) indicating that the unit value for wetland increases with the size of the population within 50km.

Table 7.2 reports the estimated value per hectare for freshwater wetland habitat based on the application of the Brander et al. function as described in Table 7.1, along with the corresponding PV over 50 years. The present value estimates are based on 100,000ha being created over 10 years. Estimates are reported for alternative initial habitat sizes for sites being 50ha, 100ha, 200, or 5,000ha, along with alternative assumptions for the area of substitute wetlands (3,000 and 30,000ha).

Table 7.2: Value of wetland habitat creation

Initial wetland size (ha)	Wetland within 50km (ha) (Substitute)	Value (2012)	
		per ha/yr	Total (PV over 50yrs)
50	3,000	£2,379	£3,800m
100		£1,936	£3,100m
500		£1,200	£1,900m
5,000		£606	£975m
50	30,000	£2,256	£3,600m
100		£1,836	£3,000m
500		£1,138	£1,800m
5,000		£575	£924m

The decreasing value per hectare is attributed to the diminishing returns to scale and availability of substitute wetland as illustrated in the Brander et al. function.

The range of values demonstrate that the size of individual wetland sites is a key determinant of the scale of benefits obtained from investing in wetlands. In reality, wetland creation would happen across a variety of sites with a range of different sizes. The range of 50 – 500ha is thought to encompass the size of the majority of sites where wetland creation is likely. It is noted that the value for a 100ha site (£1,936/1,836 per ha), are similar than the average of the 50ha and 500ha values (£1,790/1,697) per ha, which are approx 7.5% lower. Therefore, an assumption that the wetland creation is on sites of 100ha is representative of the average benefits likely to be obtained across a range of sites of different sizes.

The total benefit of wetland creation across 100,000 ha in England is £924m to £3,800m (PV over 50 years). The 'central case' benefits, based on an average wetland size of 100ha, is £3,100m (PV over 50 years).

7.3 Case studies

At Gwen Finch wetland reserve, Worcestershire the change in service provision was estimated by Hölzinger and Dench, 2011 using the Brander meta-analysis function (Brander et al, 2008) as shown in Table 7.3.

Table 7.3: Annual value of Gwen Finch wetland site

	Annual value (£/ha/yr)		
	Low	Central	High
Flood control	£160	£742	£1,100
Surface and ground water supply	£2	£10	£15
Water quality improvement	£142	£656	£973
Non-consumptive recreation	-	£320	£475
Amenity and aesthetic services	-	£587	£871
Biodiversity	£144	£667	£989
Total	£448	£2,983	£4,423

For the Wicken Fen, Cambridgeshire, the change in service provision was estimated using TESSA (Toolkit for Ecosystem Service Site-based Assessment) to estimate marginal change in biophysical and monetary values (Peh et al, 2014). This result is shown in Table 7.4.

Table 7.4.: Annual value of Wicken Fen wetland site

	Annual value of the Wicken Fen wetland site (£/ha/yr)
	Central
Flood control	£30
Recreation	£420
Agriculture (grazing)	£75
GHG emissions*	£45
Total	£570

*(relative to agricultural baseline)

Tables 7.3 and 7.4 suggest that the indicative benefits from wetland creation are between £570/ha/yr and £2,983/ha/yr. This difference may in part reflect the diminishing returns that might be expected from larger sites associated with ecosystem services such as flood control and recreation, as smaller areas provide proportionately greater benefits per ha. However, it might also reflect the different values associated with different sites due to their biophysical and geographical (e.g. located upstream of settlements with high flood risk) and socio-economic (e.g. availability of substitute sites for recreation) characteristics. Brander et al (2008) estimates larger per ha values despite taking into account substitute availability (by the variable of ha of wetland within 50 km radius), which suggests that this may be the case. The differences are also, at least in part, due to methodological differences.

7.4 Net present value

The total cost (CAPEX and OPEX) of creating 100,000 ha in England is between £345m and £2,366m (PV over 50yrs). Total benefit of this wetland creation across 100k ha in England is £924m to £3,800m (PV over 50years).

Therefore the estimated net present value of creating new wetland sites could be between -£1.4bn and £3.5bn. On the benefits side the key variation is the size of wetland created. More work needs to be done to refine the range of costs and benefits based on assumptions about the sizes of sites. There is a strong argument for restoring 100,000ha wetland built up from a range of sites with an average size of 100ha and targeted to maximise ecosystem service value and minimise opportunity costs. Under these assumptions the net present value of creating new wetland is between £634m and £2,750m, and the benefit:cost ratio between 1.3:1 (£3,000m:£2,366m) and 9:1 (£3,100m:£345m).

8. TIMESCALE OF BENEFIT REALISATION

The returns on investment in wetlands are dependent on how quickly wetlands ecosystem can be created and start to provide benefits. Different ecosystem services benefits can have very different restoration timescales, as demonstrated in the evidence below. Overall, the investment case assumes a timescale of 10 years before wetland benefits are realised.

8.1 Ecosystem services

8.1.1. Biodiversity

In the short term the diversity of the plant community is not likely to increase (Mountford 2001-wet grassland). For example, when water levels were raised through agri-environment scheme funding in the Somerset levels the diversity of plant species in ditches and farmed wet grassland increased but not those on fen or carr (Acreman et al 2011). Some beneficial changes to vegetation may be observed in 10 years, but not to pre-disturbance community (Large 2007- fen). Sites that had still not been restored to the original community composition were found even after 60 years (Stroh et al 2012- fen). Open water habitats such as reedbed can be restored more quickly. The diversity of bird communities particularly open water habitats may improve in a few years (Van Rees-Siewart 1996; Ward 1996). Species diversity of invertebrate communities was found to be restored in 10 years, even though abundance was not (Hardman 2010) and rare species were still not restored after 60 years (Martay 2011).

8.1.2. Recreation/landscape/amenity

Restoration of existing wetland and expansion of wetland habitat should provide benefits for recreation, landscape and amenity in a relatively short space of time. Bird populations particularly on open water and reedbed habitats can be restored quite quickly and these are often the key attraction for visitors to an area. Landscape level changes can be quite rapid in terms of restoring hydrological function, which may have cultural benefits.

8.1.3. Climate regulation

It is expected that emissions of carbon dioxide will decrease from re-creation or restoration of wetland habitat, however it is likely that methane levels will increase at least in the short term (e.g. Holden et al. 2008). It has been suggested that in general restored peatlands demonstrate emissions levels indicative of the restored state for the first ten years and then pre-disturbance levels for the following 30 years (England's peatlands (NE257), Waddington et al 6-10 years to become a sink).

8.1.4. Feasibility of estimates/uncertainty

This section sets out the factors affecting the selection and success of restoration actions and the feasibility of undertaking natural capital restoration nationally, by transferring actions from exemplar sites to larger and/or more sites. Results from application of the Brander et al (2008) function are relatively sensitive to the assumptions that are applied, as has been shown in Table 7.2.

Whilst it is assumed that around 90% of total wetland that is of highest potential value for wetland creation will be taken up (100k ha out of potential 114k ha), it might be expected that two thirds of this wetland will be 'high-grade' wetland delivering the full range of ecosystems services and one third 'low grade' delivering fewer/lower quality services. Therefore, it might be expected that the estimates from Brander et al (2008) overestimates ecosystem service delivery across the entire 100,000ha. Furthermore, the identification of areas of peatland that has the potential to provide high water regulating benefits is based on the proximity to a large population. However, proximity is only a rough proxy for the importance of peatland for the provision of spatially sensitive ecosystem services such as water regulation. A peatland near a reservoir could be important for water regulation despite having a small population nearby. But in general the further a peatland is from large numbers of people, the smaller its likely importance to water regulation within the total area of the catchment serving them.

In addition, there is also consideration of the reliability of the meta-analysis. The Brander et al. function provides overall a reasonably good fit to the data, given the nature of the analysis (r^2 = 0.43). This is comparable to fit to data observed in other meta-analysis studies (Brander et al. 2006; Woodward and Wui, 2001). However whilst there can be some confidence in the overall explanatory power of the model, the results indicate that distinctions between individual wetland and ecosystem service characteristics are somewhat weak (based on the statistical significance of estimated coefficients). Therefore the results do not necessarily give strong empirical justification for distinctions that can be made in the application of the function between habitat types, ecosystem service provision, size of wetland and availability of substitutes. As a result there is, to some degree, a risk of giving a false sense of 'precision' in the estimation of wetland ecosystem service values by applying the function to the letter.

The use of the Brander et al (2008) function means that the full range of final ecosystem services and goods that may be associated with wetlands are not necessarily captured. The most notable exclusion from the function is climate regulation in terms of carbon sequestration and storage, but also agricultural outputs. The change in GHG emissions as a result of new wetland creation could be estimated and added to the estimates in Table 7.2. The identification of the 100,000ha is based on sites where high flood control, water quality and recreational services are likely to be produced. These values suggest that the £924m figure identified from Table 7.2 is conservative.

The Brander et al function also does not pick up the trade-off between the benefits of large blocks/clustering the creation of new wetland areas to deliver benefits to wildlife of habitat connectivity (Lawton, 2010) and cost reductions associated with economies of scale, versus spreading new wetland areas out to deliver greater recreational value. This adds to the uncertainty of the benefits estimates.

There are constraints on scaling up these actions to 100,000 ha that have not been identified in this analysis (e.g. environmental, such as soil type/hydrology; or socio-economic, such as existing land uses). Eutrophication and pollution of the site prior to restoration will have an impact on the restoration action and the outcome, it may limit the capacity to create wetlands of high conservation importance (Hume, 2008), the actions required for restoration and the timescale. Peat depth will impact on valuation, both for restoration costs and for agricultural value (opportunity cost)- wasted peat has a low value and it is difficult to restore, but also on the benefits delivered (i.e. carbon). Climate change is another important consideration for the location and development of wetlands, in some areas climate change predictions are that water shortages will be a factor combined with increased evapotranspiration from restored/created wetlands the feasibility of restoration success may be reduced. There may also be increased winter rainfall causing more rapid runoff when water levels are already high which will also need to be factored in. Climate change and subsequent stresses can exacerbate and magnify existing issues such as pollution and invasive species (Pointer 2005). It will be necessary to consider whether the wetland will still be viable if climate change leads to less rainfall.

There are also interactions between the ecosystem services that may not be picked up in the analysis and which will vary on a site by site basis. For example, planting reedbeds can increase evapotranspiration rates (Fisher et al., Acreman et al 2003) as can creation of wet woodland and other wetland habitats so there could be less water available, particularly impacting downstream (Bullock and Acreman 2003).

9. KNOWLEDGE GAPS

Knowledge gaps/Research needs:

- Analysis to estimate the change in carbon storage and sequestration associated with wetland creation;
- Quantitative understanding of links between the structure and function of Wetland natural capital and provision of ecosystem services and economic and non-economic valuation;
- Identify factors that maintain resilience and resistance to external pressures, and
- Identify robust measureable indicators of ecosystem change (Maltby and Ormerod 2011).

10. CASE STUDY EXAMPLES

10.1 Gwen Finch wetland reserve

10.1.1. Introduction

The Gwen Finch wetland reserve was created by the Worcestershire Wildlife Trust (WWT) in 2001 adjacent to the River Avon. Prior to the restoration, this 20 hectare wetland area was semi-improved rye grassland which was managed for grazing and problems were experienced through regular flooding of the site. Within 2 years of the restoration work, otters were using the reserve, with the pools and marshes attracting hundreds of birds; dragonflies and damselflies. A large variety of flora have also developed and become established. This study values the benefits to human wellbeing provided by the Gwen Finch Wetland Reserve.

Main aim for the wetland creation was to provide a habitat for a range of species including; breeding waders and otters. The creation of the reedbeds contributed 10 % of the Local Biodiversity Action Plan (LBAP) target for this habitat. The area contains about 1 ha (300m) of ditches, 6 ha of reedbeds, 11 ha of wet grassland and 2 ha of wet woodland. Two wind pumps were installed to pump water from the adjoining River Avon into the ditches.

Source: Wendy Carter, Worcestershire Wildlife Trust

10.1.2. Results

The total one-off creation costs, or investments, into the Wetland reserve are shown below in Table 10.1. The WWT estimated that these costs, which included land purchase costs, totalled £490,000 in 2000.

Table 10.1: One-off creation costs for Gwen Finch Wetland Reserve (nominal values)

Asset	Costs (£)
Land purchase costs	249,000
Earth works, associated structures, sluices	144,000
Wind pump purchase	18,000
Reeds and willows	36,000
Fencing	8,000
Tools and machinery	4,000
Staff costs	31,000
Total	**490,000**

This total cost was inflated by the WWT using the ONS figures to calculate the 2010 value of the investment (total cost) and was estimated to be £602,632. In addition to one-off cost, the annual average running, or maintenance costs need to be taken into consideration. These are shown below in Table 10.2.

Table 10.2: Annual average running costs for Gwen Finch Wetland Reserve

Asset	Costs (£)
Pump servicing	1,400
Infrastructure repairs and improvements	800
Staff costs	1,200
Total	**3,400**

The real costs are estimated to be constant over time in prices 2010; therefore an inflation adjustment is not necessary. Only the technical progress has been taken into account by applying a discount rate (1.5% for the best guess). Therefore the capitalised running costs add up to £178,157 over a time period of 100 years. As a result of uncertainties associated with forecasts for a range for annual costs from £3,200 to £3,600.

To value the ecosystem services provided by the restored wetland, a value transfer function was applied for different ecosystem services. Applying PPP exchange rate again and conversion to GB£ (2010 prices) they calculate an annual value per ha of £2,983. Multiplied with the attributable area of 20.19 ha (restored area) this gives an annual value of £60,234 (best guess estimate in Table **10.3** for the valued ecosystem services provided by Gwen Finch Wetland Reserve. This results in £3,156,197 capitalised value over the next 100 years (discount rate of 1.5 percent). The value of the space for grazing cattle is not included as the WWT not charge for grazing.

The attributable value for each ecosystem service can be approximated as an estimation can be made about the attributable value for each benefit. Following this approach amounts of about 24.9% for flood protection, 0.3% for surface and ground water supply, 22.0% for water quality improvement, 10.7% for recreation, 19.7% for amenity and aesthetical services as well as 22.7% for biodiversity or habitat for species, are produced. A summary of the findings can be found in Table **10.3**.

Table 10.3: Valued ecosystem services provided by Gwen Finch Wetland Reserve (£, 2010)

	Low	Best guess	High
Annual value of the wetland site	**9,043**	**60,234**	**89,295**
Flood control	3,233	14,984	22,214
Surface and ground water supply	43	201	298
Water quality improvement	2,859	13,251	19,645
Non-consumptive recreation	-	6,467	9,588
Amenity and aesthetic services	-	11,860	17,583
Biodiversity	2,906	13,469	19,968
Capitalised value of the site over 100 years	**269,587**	**3,156,197**	**8,929,543**
Flood control	96,395	785,157	2,221,373
Surface and ground water supply	1,293	10,534	29,804
Water quality improvement	85,249	694,366	1,964,507
Non-consumptive recreation	-	338,885	958,777
Amenity and aesthetic services	-	621,473	1,758,278
Biodiversity	86,650	705,782	1,996,804

The benefit:cost ratio of 4.17 has been calculated for this project. This ratio above shows that the investment in Gwen Finch Wetland Reserve is rewarding. Note that this calculation is for the capitalised values over 100 years beginning in 2010. Underlying assumption is that the one-off investment is written off over the total time period over 104 years (4 years in the past and 100 years from 2010 on). This includes costs of £35,178 that are already written off from 2006 till 2009. This explains the lower one-off costs than stated before. Additionally, future costs as well as future benefits have been discounted to actual values, applying the discount rate of 1.5%.

The capitalised net benefits provided by Gwen Finch Wetland Reserve add up to £2,398,587; considering all costs and benefits. The annual net benefit of the site is £51,039. A sensitivity analysis was undertaken to produce a worst case and a best case scenario. The worst case scenario calculates with lowest estimates for the benefits and highest estimates for the costs and vice versa for the best case. Only in the very unlikely worst case scenario an unfavourable BCR of 0.62 would occur. This would lead to net costs of £289,019 over a 100 year period. For the best case scenario a BCR of 6.26 has been valued.

Table 10.4 below summarise the findings of the restoration of 20 hectares of rye grassland to a mosaic of wetland habitats for the Gwen Finch wetland reserve.

Table 10.4: Summary of findings for Gwen Finch Wetland Reserve

Annual Costs and Benefits	Low	Best guess	High
Annual Costs	**9,395**	**9,195**	**8,995**
Annual management costs of wetland site	3,600	3,400	3,200
One-off creation costs	5,795	5,795	5,795
Annual Benefits	**9,043**	**60,234**	**89,295**
Flood control	3,233	14,984	22,214
Surface and ground water supply	43	201	298
Water quality improvement	2,859	13,251	19,645
Non-consumptive recreation	-	6,467	9,588
Amenity and aesthetic services	-	11,860	17,583
Biodiversity	2,906	13,469	19,968
Annual Net benefits	**-352**	**51,039**	**80,301**
Annual Net benefits per ha	-17	2,815	4,264
Capitalised Costs and Benefits	**Low**	**Best guess**	**High**
Total costs over next 100 years	**768,090**	**757,610**	**747,130**
Management costs	188,637	178,157	167,677
(Non-written off) One-off creation costs	579,453	579,453	579,453
Capitalised value over 100 years	**473,831**	**3,156,197**	**4,678,998**
Flood control	169,426	785,157	1,163,979
Surface and ground water supply	2,273	10,534	15,617
Water quality improvement	149,834	694,366	1,029,384
Non-consumptive recreation	-	338,885	502,390
Amenity and aesthetic services	-	621,473	921,321
Biodiversity	152,298	705,782	1,046,307
Capitalised Net benefits	**-294,259**	**2,398,587**	**3,931,867**
Capitalised Net benefits per ha	-14,574	2,815	194,743

Source:
http://www.worcswildlifetrust.co.uk/sites/worcestershire.live.wt.precedenthost.co.uk/files/files/valuation%20case%20study%20-%20gwen%20finch.pdf

10.2 Wicken Fen[17]

10.2.1 Introduction

Wicken Fen is a wetland nature reserve located in south east Cambridgeshire near the village of Wicken. It is one of Britain's oldest nature reserve and is maintained by the National Trust. This long-term initiative which looks to convert drained, intensively farmed arable land to a wetland habitat mosaic is driven by a desire to prevent biodiversity loss from the nationally important Wicken Fen National Nature Reserve (NNR) and to increase the provision of ecosystem services.

Source: Carole Laidlaw, National Trust

10.2.2 Method

The changes in ecosystem service delivery as a result of the land use change relied on the use of TESSA - Toolkit for Ecosystem Service Site-based Assessment to estimate biophysical and monetary values of ecosystem services provided by the restored wetland mosaic compared with the former arable land. In total, 470 hectares of arable land was converted.

10.2.3 Results

The overall results from these restoration activities has resulted in an estimated:

- Net gain to society of £124/ha/yr from one off investment of £1,451/ha/yr.
- Loss of arable production (opportunity cost) of £1,276/ha/yr ;
- Recreation gains of £420/ha/yr,
- Grazing gains of £75/ha/yr;
- Flood protection benefites of £30/ha/yr ; and
- £45/ha/yr gains in GHG emissions.

Table 10.5 shows the net value of all services resulting from the restoration of arable land to wetlands. It also provides the estimated value (costs and benefits) associated with the restored land (i.e. wetlands) and the values if the land had remained in arable production. For example, whilst under arable production, the 479ha provided no flood protection, but as a restored wetland,

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[17] Source: Peh, KSH et al., (2014)

it is estimated to provide £14,433/yr in benefits. Nature-based recreation gives a total value of £242,636 per year for the restored wetland compared with £41,506 per year for the arable land.

Table 10.5: Net value of all services resulting from the restoration of wetland from arable farmland.

	Restored wetland (£) (479ha)	Arable land (£) (479ha)	Difference (£) (479ha)	Difference (£/ha/yr)
Service flow (£/yr)				
Flood protection	14,433	-	14,433	30
Grazing	35,850	-	35,850	75
Arable production	-	610,244	610,244	1,274
Nature-based recreation	242,636	41,506	201,130	420
Disservice flow (£/yr)				
GHG emissions*	11,527	33,138	21,612	45
Management cost (£/yr)	55,695	452,678	396,984	829
Net annual benefit (£/yr)	225,697	165,972	59,725	124
Net annual benefit (£/yr/ha)	471	347	124	-
Initial restoration cost (£)	694,849	-	694,849	1,450

Note:

1. *The cost of greenhouse gas emission was based on the US Government CO_2 value of $22.78/t CO_2, adjusted to 2011.
2. Values were provided in USD in 2011 in the original study. These have been converted to GBP (2011) based on UDS to GBP monthly exchange rates from 2011. These can be found: http://customs.hmrc.gov.uk/channelsPortalWebApp/channelsPortalWebApp.portal?_nfpb=true&_pageLabel=pageImport_RatesCodesTools&columns=1&id=EXRATES_2011

For the five ecosystem services assessed, this study calculated a net monetary benefit of around £59,700 or £124 per hectare per year from the conversion of arable to land to wetland across 479 hectares. As can be seen from

Table 10.5, nature-based recreation, reduced GHG emissions, increased flood protection, and increased grazing by domestic stock are the main ecosystem services that have benefitted as a result of restoration. On the other hand, the main service lost as a result of restoration is arable production. It is important to note that these results have varying levels of confidence related to the accuracy and precision of the data.

Some ecosystem services that are likely to be provided through restoration could not be included in this assessment as they could not be measured. An example of this is the enhancement of the wildlife value of the restored land and its potential to buffer and make more viable the populations of rare species that occupy Wicken Fen NNR.

10.2.4 Conclusions

In addition to altering the type and value of ecosystem services generated in an areas, a change in land use from arable to a restored wetland will also alter the distribution of benefits. Under arable production, a small number of landowners and their employees gain the majority of the ecosystem service benefits provided by the site. However, under restoration there is greater societal benefit to a much broader range of stakeholders, including many more local (and some long-distance) visitors, as well as the global community (through reduced greenhouse gas emissions). Yet most of these benefits do not accrue to the landowner, who (in the absence of related incentives such as carbon payments) is therefore encouraged to continue arable production rather than undertake restoration.

10.3 Insh Marshes, Spey Valley, Scotland

The Insh Marshes, an internationally important Wetland in the Spey Valley, provides flood defence benefits to Aviemore and other downstream settlements (Alveres et al. 2007).

The marshes cover some 1,100 ha of Floodplain and their water storage role has been valued at > £83,000/annum, were it to be replaced by 7 km of flood defence banks around Aviemore. Alongside their flood defence services, the marshes provide many other functions that add economic, recreational and cultural value to the local community and visitors. Tourists contribute around £132,000 to the local economy each year, while fishing revenue provides a further £35,000. Additional ecosystem services, such as farming, water quality, education, training and conservation management, are also provided by the marshes; their total value, along with that of biodiversity, has not yet been quantified (Maltby and Ormerod 2011).

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INVESTMENT CASE: SALT MARSHES

SUMMARY

- *Managed realignment is now an established and trusted flood protection technique.*
- *Five-fold increase in managed realignment will help adaptation to climate change, realigning low-lying agricultural land and improving flood protection to coastal communities.*
- *High 1-off costs (approx. £50k/ha) are offset by saved flood spending, reduced flood damage risks, and ecosystem services values (carbon, amenity, fish nursery habitat, etc).*

<table>
<tr><td colspan="2">**Investment:**
To create new saltmarsh or enhance existing salt marshes, five times more managed realignment activity is needed per year to 2030.</td></tr>
<tr><td colspan="2">**Baseline:**
Managed realignment is established technique for more sustainable management of flood defences. Saltmarsh recharge less widely used and understood.</td></tr>
<tr><td>**PV of costs:**
£1.7bn</td><td>**PV of benefits:**
£2.4bn (50 years): Avoided flood defence costs of £285m; value of created habitat approx. £1,104m; carbon sequestration value of approx. £1,039m</td></tr>
<tr><td>**Monetised costs**: re-engineering of flood embankments.</td><td>**Monetised benefits**:
Flood control; Non-consumptive recreation; amenity and aesthetic services; biodiversity. Carbon storage. Avoided flood defence costs.</td></tr>
<tr><td colspan="2">**Non-monetised impacts**:
Opportunity costs of land, but given vulnerability to flooding, this is arguably low. Flood defence benefits are assessed generically, which likely underestimates their value.</td></tr>
<tr><td>**NPV**:
approx. £0.73bn. BCR = 1.4</td><td>**Time period**:
50 yrs</td></tr>
<tr><td colspan="2">**Key assumptions**:
Managed realignment can be targeted at defences backed by low-lying agricultural land, in a manner that reduces flood risk to developed land.</td></tr>
<tr><td colspan="2">**Additionality**:
Climate-Adaptation sub-Committee suggests five-fold increase needed in current realignment activity to meet shoreline management goals. So 4/5ths of investments additional to current level of activity.</td></tr>
<tr><td colspan="2">**Synergies/conflicts**:
Flood risk management (for managed realignment) and climate change adaptation for both types of investment.</td></tr>
<tr><td colspan="2">**Impact on natural capital assets**:
Ecological communities in intertidal zone.</td></tr>
<tr><td colspan="2">**Scale of impacts**:
A five-fold increase in current realignment activity would mean realigning 30km of coast per year to 2030 (i.e. approx. 450km), creating 42,750 ha of saltmarsh.</td></tr>
<tr><td colspan="2">**Distribution**:
Impacts on owners/managers of coastal agricultural land vulnerable to flooding. Improved flood protection of coastal communities (towns and infrastructure).</td></tr>
<tr><td colspan="2">**Uncertainties**:
Cost per ha reflects compensation requirements, without which unit costs could be lower. Acceptance of realignment by local communities and associated consultation costs.</td></tr>
</table>

Case Study: Medmerry

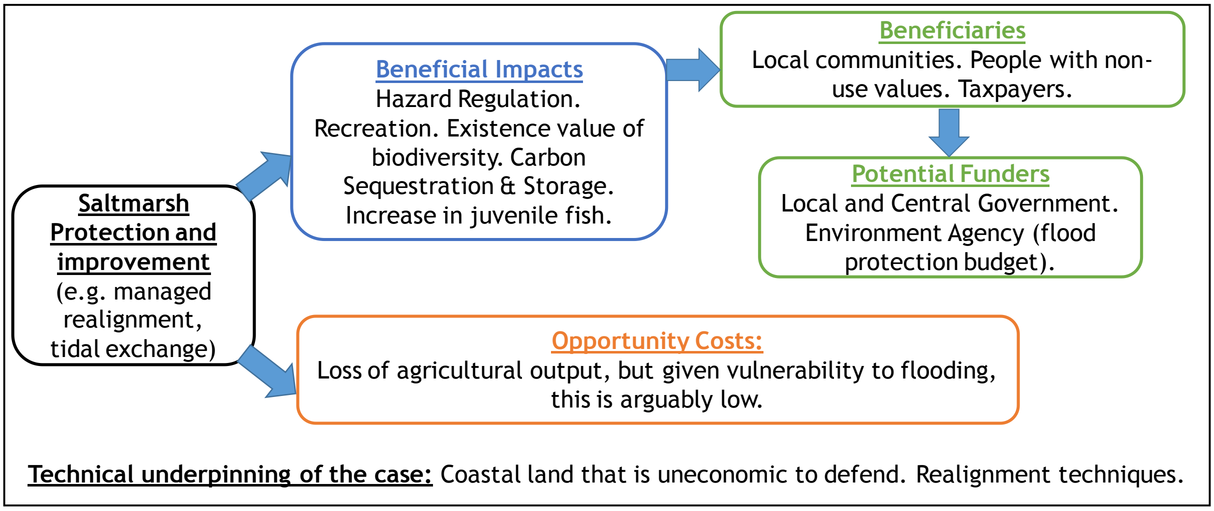
This is highlighted by the Environment Agency’s recent 450ha Medmerry managed realignment. This scheme was undertaken for flood protection reasons and also to provide compensatory habitats for losses of marshes elsewhere in the Solent. That project delivered 183ha of marsh up to HAT but it also created large areas of extra transitional habitat above HAT that can be treated as newly created habitat and not compensation for losses elsewhere. The project saves on recurring coastal protection expenditure (which averaged £300k per year along the formerly intact 2km shingle beach), and is likely to have helped avoid very large damages during the 2013/4 winter storms. Assessed benefits of over £90m, against actual project costs of £28m.

1. INTRODUCTION

This investment case focuses on the benefits that can be gained from increasing the area of saltmarsh in England. The investment case estimates an area of saltmarsh that would be created under suggested uses of managed realignment to adapt coastal flood protection approaches to climate change.

The main impacts of this investment are shown in Figure 1.1.

Figure 1.1: Salt marsh value chain



The following Sections of this paper outline known scientific evidence about saltmarsh, its current status in the UK and the impacts of actions to restore it. The costs and benefits of a programme of saltmarsh creation are analysed based on observed outcomes from recent activity in the UK. This includes benefits information associated with saltmarsh creation for a range of ecosystem services. The Brander et al meta-analysis function is used, which provides a bundled value estimation (i.e. all relevant services valued simultaneously), to estimate the benefits of saltmarsh creation.

2. ASSET DESCRIPTION

Saltmarshes are generally considered to be one of the most productive ecosystems in the world. They are well known for providing resources to support secondary production (i.e. the biomass of feeding species such as fish and invertebrates) in coastal and near-shore waters (Niering and Warren 1980; McKinney et al. 2009; Fletcher et al. 2011). Under stable conditions they also trap sediments, sequester carbon and absorb a large amount of wave energy at the coast to provide a key coastal protection function.

Saltmarsh is also a valuable roosting resource for waterbirds as they act as high tide refuges for birds feeding on adjacent mudflats. They also provide breeding sites for waders, gulls and terns, and are a source of food for passerine birds particularly in autumn and winter (Maddock, 2008). Coastal saltmarsh also provides an important nursery area for the juvenile stages of many fish species (including several commercial species) with vegetation and shallow creeks providing small fish with a refuge from predation by larger fish and birds (Dickie *et al*. 2014).

For the purposes of this study, the BAP definition of saltmarsh is used and includes both saltmarshes that are frequently inundated as well as transitional areas that are very rarely, if ever, covered by the tide. This is because of the collective importance of all these habitats in biodiversity terms and because transitional habitats will offer many, if not more, of the Ecosystem Services that are provided by saltmarsh habitats at lower tidal elevations.

The BAP definition encompasses transitional marshes between mean high water springs (MHWS) and the highest astronomical tide (HAT) as well as other higher-level coastal grazing marsh and terrestrial grassland. These transitional habitats between fresh and saline waters have a very high biodiversity value for invertebrates and birds and they are nationally protected (e.g. as BAP priority habitats such as Coastal and Floodplain Grazing Marsh). They are also very scarce nationally because there are comparatively few areas of the coast which have sufficiently broad transitional zones (due to the presence of coastal infrastructure, sea walls and the effects of historical land claim).

This broader BAP-based definition is also in keeping with taking long-term investment decisions because the higher terrestrial plant communities will increasingly become subject to tidal inundation as sea levels rise. Therefore taking the full breadth of successional plant communities between the sea and the land represents the best approach and the one that is most in-keeping with long-term sustainable planning.

Saltmarsh habitat is subject to national and international protection and is a key habitat feature within coastal and estuarine designated sites (including Sites of Special Scientific Interest (SSSIs), Special Areas of Conservation (SAC) and Special Protection areas (SPAs) and Ramsar Sites). The key protected habitats types that are listed Annex 1 of the Habitats Directive and form the basis for SAC designation in many coastal and estuaries of UK and Europe are as follows:

- Glasswort and other annuals colonising mud and sand (Ref:1310) Low Marsh;
- Cord-grass swards (Ref:1320) Low shore and channel fringes;
- Atlantic salt meadows (Ref:1330) Lower to Upper Marsh; and
- Mediterranean saltmarsh scrub (Ref:1420) Upper Marsh (upper limit of inundation).

Also, as noted above, at higher elevation saltmarsh grade into and Coastal and Floodplain Grazing Marsh which is protected nationally as a priority habitat.

3. BASELINE

3.1 Extent and condition of salt marshes

In total the extent of saltmarsh habitat in England and Wales[18] is around 40,500ha and although it is under pressure in many areas (as described further below) much of it is currently deemed to be in favourable condition. Of the marsh habitat which is located either within Sites of Special Scientific Interest (SSSI) or Special Areas of Conservation (SACs), around 58% is considered to be in a 'favourable condition' (Williams, 2006) with the remainder being 'unfavourable' or 'unfavourable recovering'. In general, lower shore *Salicornia* habitat is generally in a poorer condition than Atlantic salt meadow (Williams, 2006).

When viewed at a national scale then the majority (80-100%) of the SAC-designated marshes in the south west, the Wash and the Solway are in a favourable condition. By contrast the SAC-designated marshes in areas such as the Solent, Morecambe Bay and in the estuaries of Suffolk and Essex are in a poorer condition typically only 0-20% favourable. For the SSSI-designated marshes there is no distinct spatial pattern at a national scale.

3.2 Pressure/driver impacting asset

There are a range of pressures being faced by saltmarshes which drive their unfavourable condition in many locations. The most significant pressure is from coastal squeeze where the seaward faces of the marshes are eroding and/or are being lost through sea level rise while the presence of sea walls is blocking their landward migration. Other pressures include: grazing/agriculture, coastal management measures, pollution/water quality and recreational activities (Williams, 2006).

In many areas the decline in saltmarsh occurs as a physical reduction in their spatial extent as their exposed seaward faces are being eroded. In other areas there can also be a general qualitative deterioration of the habitat internally that is less easy to identify and quantify. This has been referred to as 'pan die back' and, while the causes of this are not fully understood, it appears to be prevalent in locations that have a poor sediment supply which constrains the ability of the marshes to elevate over time and thus to cope with sea level rise. Therefore marshes are subject to both lateral loss through erosion as well as processes of internal qualitative decay through die back.

The process of die back is difficult to identify and very complex to measure effectively. The lateral loss however can be easily quantified especially at a local scale. However making such measurements can be challenging at national scale where different data sources are available with differing levels of accuracy.

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[18] Based on the Environment Agency Saltmarsh Extents Data Layer (http://data.gov.uk/dataset/saltmarsh-extents) which is a Polygon data layer (40,521ha) showing the extent of Saltmarsh in Coastal and Transitional waters for use by both Flood and Coastal Risk Management and the implementation of Water Framework Directive.

Targets exists to offset ongoing losses through Shoreline Management Plans (SMP), Coastal Habitat Management plans (which including locations for compensation) as well as estuary strategies and Environment Agency biodiversity targets. The restoration measures are that can be undertaken to deliver these targets and restore coastal marshes are described in the following section.

4. INVESTING IN SALTMARSH: RESTORATION ACTIONS

A wide range of different measures exist for the protection and improvement of saltmarshes. These measures can divided into two broad types:

- those that involve creating new marshland through **managed realignment**; and
- those that encompass measures to protect and enhance existing marshes including through **sediment recharge, fencing and planting**.

Further details about the techniques, characteristics, costs and values of measures that have been and can be pursued under these two categories are summarised below.

4.1 Creating new marshes (managed realignment)

New saltmarsh habitats can be created by realigning the position of existing sea walls and allowing tidal water to inundate the hinterland terrestrial habitats. This process of introducing tidal waters to currently enwalled land is referred to as 'managed realignment'.

In many instances, the locations that are suitable for managed realignment were historically saltmarshes but have been claimed from the sea over the last few centuries and today are vulnerable to flooding (not least because claimed land tends to then compact down and reduce in elevation over time making it more vulnerable). Therefore, managed realignment is important both as flood protection and habitat enhancement measure to restore the marshes back to the historical condition.

Managed realignment schemes can be used to create a range of saltmarsh, mudflat and saline lagoon habitats and provide a distinct range of ecosystems services of direct benefit to people and wider society. These services are mainly related to clearly definable benefits such as amenity and recreation, fisheries and carbon sequestration as well as to a range of non-use values that people assign to goods even if they never have and never will use it (see Section 1.4).

Most managed realignment schemes also typically replace agricultural land that is of varying quality depending upon the location. The appropriateness of this change of land use is frequently contested by local landowners and farmers in particular. However, as it is often land likely to be at risk of coastal flooding the alternative would be to involve extra financial commitments to improve the existing sea walls. This means that the viability of continuing to farm on these sites will involve escalating costs and may be time limited.

There are many different types of managed realignment with the size and design of schemes being dependent upon their location, the landform, the surrounding environment and the primary motives for the work. However, this process can be sub-divided into two main sub-categories:

- Removing a section of the existing sea wall or creating an open breach through it so that the tide is allowed to flood and ebb to freely over the land in an unconstrained way; or

- Installing a ‘regulated tidal exchange’ (RTE) structure within the existing sea wall (e.g. a culvert) to control the volume of tidal water that is exchanged so that there is finite limit to the volumes of tidal water exchanged.

The number of projects that have been undertaken and the extent of habitats that they have created, through these two techniques are audited on an ongoing basis within the ABPmer online database (www.omreg.net). In total 63 managed realignment projects have been completed in the UK alone and a further 54 at least have been carried out across the rest of Europe (Figure 4.1). This work has been done using a wide variety of different techniques in a wide range of coastal and estuarine environments (Figure 4.2)

Figure 4.1: Distribution of managed realignment projects in Northern Europe

(source www.omreg.net)

Figure 4.2: Examples of the many techniques used for managed realignment over the last 20 years

The UK projects have resulted in the creation of around 2,300ha of mainly intertidal habitat and transitional grassland. The majority of this area (2,106ha or 92%) was created through 40 open breach realignments while the remainder (191ha or 8%) was created through 22 generally smaller regulated tidal exchange projects.

From all of these projects around 930ha (40%) of saltmarsh habitat and 291ha (13%) of transitional grassland has been created so far. However, most of the schemes are naturally accreting with sediment and this means that their lower mudflat areas are being gradually increasing in elevation and hence the proportion of marshes will also naturally increase over time.

Of the 63 projects undertaken in the UK, 18 have been carried out to provide compensation for losses of intertidal habitats from developments or from coastal squeeze effects[19]. These 18 projects are often relatively large and they have collectively created 1,728ha (75%) of the 2,300ha of the overall habitat. As the habitats created for these compensatory schemes are offsetting other losses, they do not necessarily represent a net habitat gain.

Distinguishing the amount of habitat that is compensatory from that which can be considered to be a biodiversity gain is, however, not very clear at present. This is because, as described in Annex2 for the Medmerry project, not all of the habitats with compensatory sites have been allocated for compensation. There will also be larger areas of higher level transitional marshes and coastal grazing habitat above HAT that can be viewed as new habitats providing new value.

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[19] In total 14 of these compensatory projects were sea wall breach realignments while four were RTEs.

In each of the projects, the shape of the landform behind the existing sea wall will dictate the extent and the type of new habitat that is created. Specific habitat targets can be achieved by adjusting this landform as part of the design and this re-shaping can be done by either just moving soils within the site or importing sediments (such as dredge materials) to raise the landscape. This has been done at Allfleet's Marsh on Wallasea Island, Essex where dredge sediments were used to create saltmarsh (see Image 5).

The shape of the hinterland will also determine the length of new protective sea wall that will be required to the rear of the site to protect the landside features and properties. The sea wall construction is often the most costly component of a project and therefore the length of the sea wall will make a major contribution to the overall cost. Some projects, such as that at Abbotts Hall, Essex, (see image 5) require only small sections of new sea wall because the natural topography of the land is sufficiently high to ensure that there is no further hinterland flooding.

The costs incurred for undertaking managed realignment projects has been analysed by Rowlands (2011), as shown in Table 4.1. For that study a cost analysis was carried out on 42 UK realignment and RTE schemes (that were both existing and undergoing implementation at the time), and the conclusion was that overall average unit cost (i.e. costs per hectare) was £34,000 over the last 20 years. However these costs had also increased over time as land prices have increased and as the projects themselves have become larger and more ambitious. **As a result, the average costs for implementing UK realignment and RTE schemes, before long term maintenance is accounted for, is now typically around £50,000/ha on average.**

In general, compensatory schemes are often the most expensive and this is especially true for projects that are designed to offset project development impacts as these have the most detailed objectives. These compensatory schemes cost on average £74,725/ha (Rowlands 2011).

Table 4. 1: Variation in average scheme area (ha) and unit total cost (£/ha) by time period

Period	Number of Schemes	Average Scheme Size	Average Unit Total Cost (2011 prices)
1995 - 1999	8	13 hectares	£7,393 per hectare
2000 - 2004	20	20 hectares	£32,638 per hectare
2005 - 2009	72	72 hectares	£43,643 per hectare
2010 - 2014	110	110 hectares	£47,090 per hectare

Source Rowlands (2011) using OMReg database.

There is no evidence of economies of scale on these projects because larger schemes incur higher relative costs due to the greater technical challenges that need to be overcome. These challenges include: longer sea walls, larger land-forming work and engineering requirements; more consents and permissions, greater mitigation and monitoring commitments and, importantly, the need for more detailed stakeholder engagement processes.

As one example of the costs being incurred for large scale projects, the recent Environment Agency Steart scheme which was breached in 2014 cost around £21 million. This resulted in the creation of 475ha of habitats which 300ha was saltmarsh and a further 118ha was transitional grassland habitat. That equates to around £44,000/ha for all habitats created.

Another Environment Agency project at Medmerry, which was breached in September 2013, was 450ha in size of which 130ha was saltmarsh and a further 41ha was transitional grassland. This cost £28 million which equates to around £62,000/ha with these higher costs being incurred because of certain technical challenges including the need to mitigate for high level of protected species and a higher than expected value of the site in archaeological terms.

Managed realignment and RTE projects are typically the most costly type of habitat restoration especially where they are undertaken for compensation reasons. However, it must be emphasised that the primary benefit/motive for such schemes should be to improve flood protection to coastal areas. This flood protection benefit clearly brings with it large costs, to which the habitat gains can be seen as additional. Overall the key characteristics of managed realignment can be summarised as follows:

- There is a **lot of past project experience** not least because there have been clear strategic and legal drivers for undertaking this work (especially flood protection and habitat creation);
- This experience has led to a **high confidence in the process** and to projects being undertaken at increasingly large scales over time;
- There is a general **perception of lower environmental risk** among coastal mangers and regulators due to past experience and good evidence/science;
- As the work is undertaken over a discrete area, the benefits and **the extent of habitat delivery is relatively easy to quantify**;
- The **total cost for projects can be high** (depending on project's scale, location and drivers);
- As the amount of habitat that is created is well defined it is **possible to create clear measures of the habitat area benefited and clear cost/hectare values for this work**;
- The **key benefits are well defined** and reasonably well understood; and
- There has been a **relatively large amount of ecosystem services review work carried out on past project** (see Section 1.5) even though many uncertainties remain when seeking to make accurate cost quantifications.

Finally, it is also worth noting that at a strategic level there is more that needs to be done to achieve targets for managed realignment as a coastal management measure in the future. This was indicated by the UK Climate Change Adaptation Sub-Committee (2013) who reviewed shoreline management plan (SMP) objectives for coastal managed realignment over the coming epochs and compared the amount delivered so far against objectives for the next 40 years (Adaptation Sub-Committee 2013). It was found that overall progress has been slow and that there "would have to be a five-fold increase from the current levels of around 6km of coastline realigned every year to around 30km, in order to meet the 2030 goal stated in the SMPs".

4.2 Opportunities for protecting and enhancing existing marshes

There are many different techniques for protecting or enhancing existing marshes including:

- **Undertaking sediment recharge**: Adding sediments, often using dredge silt, to 'recharge' deteriorating marshes and counteract the loss of sediment occurring through erosion or the effects of sea levels rise;
- **Constructing protective fences:** Installing fences or other protective structures to slow the rate of marsh erosion and, ideally also and help to trap sediments and promote accretion; and

- **Planting**: Either deliberately planting seeds or growing saltmarsh plants separately under greenhouse conditions and planting them in deteriorating habitats or areas where there is a desire to prompt marsh formation.

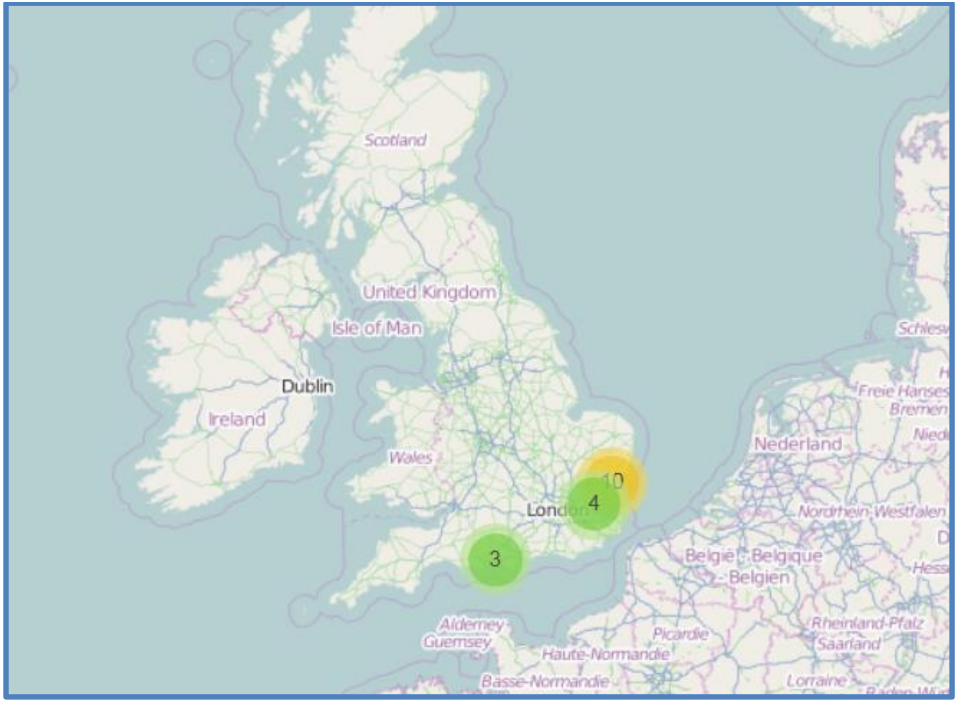
Often a saltmarsh protection initiative might involve these techniques being applied in combination. In particular fences are often placed within marshes in advance of sediment recharge to help retain the imported sediment.

Of these techniques, planting is probably the least effective and though used historically, is now less common. One key reason for the limited use of planting today is likely to be because plant species have been shown to quickly colonise sediments naturally as long as suitable physical conditions are provided (see Image 2). The use of sediment recharge and or fencing is important for trying to create such suitable conditions. However, recent studies have indicated that not all plant species colonise quickly and that some can take decades to occur (Mossman et al). Therefore, there may well be extra value in including the planting of certain key species in restoration projects to enhance biodiversity.

To date, sediment recharge and fencing projects have mainly been undertaken at a small-scale and on an ad hoc basis when needs, funding and stakeholder/community support allow. There are also only relatively few such projects when compared to managed realignments. For example there are less than 20 sediment recharge projects that have been undertaken with the aim of directly enhancing or protecting saltmarshes (Figure 4.3).

It has long been argued that the use of sediment recharge as a habitat management measure should be more common than it is. There is a requirement to identify beneficial use options for sediment as part of dredging operations, however, in reality much of the sediment excavated from ports, harbours and marinas is instead deposited at offshore disposal sites. A recent forecast for the south marine plan area (MMO, 2014) found that from ports and harbours on the south coast, there will be 50 million tonnes of dredged materials that could be available over the next 10 years, and yet only around 5 million tonnes of this is currently envisaged to be beneficially re-used in planned projects

Figure 4.3: Distribution of Saltmarsh Sediment Recharge projects in the UK



(source www.omreg.net)

The current situation is that any beneficial use often involves mainly depositing materials subtidally within an estuarine system. These provide intrinsic benefit of retaining sediment within an estuarine system but no determinable or detectable values in terms of intertidal marsh of mudflat restoration. There are some examples (as noted above and shown in Figure 4.3) of sediments being placed at or near intertidal areas to achieve a more direct benefit to deteriorating saltmarshes. Two recent examples from Lymington estuary (in the west Solent), which were undertaken as mitigation for separate developments in the channel, provide insights into the costs and value of such work.

These two projects were undertaken by the Lymington Harbour Commission and Wightlink Ltd and both projects involved two recharges on spate areas of the adjacent marshes in 2102 and 2013. They cost £120,000 and £550,000 respectively over the two years with the Wightlink Ltd project being more expensive because it was more logistically complex and was subject to greater monitoring commitments. These were comparatively small-projects involving the use of only around 2,000 m^3 of sediment placed on area of around 0.5ha (for the Lymington Harbour Commission scheme) and 4,000m^3 placed over 1ha (for the Wightlink Ltd work).

If the costs were compared only against the area of the work, then the fees per hectare would be much more costly than for managed realignment projects. However, the areas in which the sediment was placed have larger benefits in terms of delaying losses to the surrounding marshes from loss and extending the lifespan of these wider marshes. To try and describe this effect, the benefits of these projects were estimated in ‘hectare-years’ which is the amount of hectares delayed from loss over a period of time. This unit is complex to define or measure and it has not been applied elsewhere in the country. However when used here it gave an indicative values such as 29 hectare-year gain as a result of the Wightlink work. Against that number, the relatively expensive Wightlink project had undiscounted costs of £19,000/ha-year over 30 years[20].

In each case these projects also included the installation of fences to retain the recharge sediment and these are like to have ongoing benefits for protecting the marshes by helping them to trap (accrete) suspended sediments. Another example of the combined use of recharge and fences is at Sutton Hoo on the Deben Estuary. At this site, the existing breached sea wall had been historically damaged when a returning payload was dropped on it during WWII. In its deteriorating condition it was beginning to cause problems for estuary navigation as sediment fanned out through the downstream breach. The breaches in the wall were therefore blocked with a combination of geotextiles and there has been a sediment recharge at the back of the site. This project cost around £70,000.

There are other projects that do not include recharge but just involve fences to act as erosion protection and or to become silt traps that help marshes to accrete over time. These represent some of the cheapest alternatives and one such example is at King's Fleet Marshes near Falkenham also on the Deben Estuary. This marsh lies in front of a large expanse of low lying reclaimed agricultural land with the King's Fleet pumping station drains this land and causing local erosion at its discharge point.

Here the restoration work is, like the recharges at Lymington, designed to reverse the localised erosion and the wider fragmentation of the marsh. A main fence alignment (of polders and bales) has been placed in a curved manner to deflect erosive flows caused by the Fleet drain (see Image 8). Other smaller structures (made with bales, polders and geotextile) have been placed in marsh creek to reduce the flow speeds and promote accretion. This work costs in the region of £20,000. While relatively cheap, the benefits of this type of projects will be difficult to quantify unless there is a substantial and progressive increase in marsh siltation levels as a result.

One of the key costs considerations with respect to recharge work however is that it can save money that might otherwise be spent delivering dredge sediment to offshore disposal grounds. As another example, the Lymington Harbour Commission has recently received permissions to deposit dredge sediment subtidally near to the eroding marshes. The costs of this work are projected to be much lower (£88,000 over three years) than the saltmarsh recharge.

This value is also equivalent to the fees that would have been incurred for offshore disposal so represents close to no additional cost at all. However, it is also likely to be very difficult to measure or quantify the benefits from such work in terms of saltmarsh condition given that the materials are placed subtidally and there is no clear defined area of habitat benefit (its simply makes more sense and entails no extra cost to place material here where it can feed into the local environment than offshore where it is lost).

Most of the projects that have been undertaken are of a relatively low cost (especially when compared to managed realignment) and small scale. However, one notable exception is the work undertaken at Horsey Island in Hamford water. For this project a degraded marsh was supplied with approximately 200,000m^3 material from Harwich Haven ports (more than 50 times as much as

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[20] A similar hectare-year approach if used for managed realignment would clearly greatly reduce the perceived long-term net costs of those schemes also given the relative permanency of the habitats created using that approach

that used or the Lymington projects). The existing saltmarsh was raised through the recharge process to help it cope with increasing sea level rise. This resulted in a large gain of marsh habitat and a substantial through unquantified delay to the loss of this habitat.

For these different intervention measures there is a high level of variation in terms of the number of projects undertaken, the costs incurred, the practical experience and the degree to which they can deliver quantifiable benefits. Compared against managed realignment and RTE, these measures generally have the following characteristics:

- There is **low to moderate amount of project experience** but a wide variety of techniques have been applied over the last 20 years so many lessons have been learned, however the strategic and legal drivers for this work are not as clear as for managed realignment and such projects have mainly been ad hoc and undertaken at a small-scale;
- This limited (albeit highly varied) experience can result in **low to moderate certainty of outcome** depending upon approach;
- While initiatives such as fencing and planting are undertaken as modest simple initiatives with little perceived impact there remains a **perception that higher environmental risks exist** with respect to sediment recharge projects (this concern is probably linked to limited amount of experience and monitoring);
- As the work is undertaken at a small-scale within existing habitats and involve modest changes to existing processes, the benefits and **the extent of habitat delivery is often difficult to quantify**;
- The **total costs for projects are often comparatively low** and certainly these schemes are do not incur the fees associated with managed realignment and RTE;
- As these projects do not create discrete areas of new habitats it is often **not possible to create a clear measures of habitat benefited and clear cost/hectare values for this work** as these value will depend not just on the size of the project areas but the extent of the surrounding habitats areas that are protected by such work and, also, the duration of the delay to habitat loss that is achieved; and
- While there are there clear generic benefits from protecting saltmarshes (as evidenced by ecosystem services work done for managed realignments) there has been **a low amount of ES review work specifically undertaken on such projects.**

These projects therefore highlight how small-scale and relatively cheap initiatives can be undertaken to restore and protect saltmarshes. However it is notable that while the costs are lower the benefits can be less easy to define. What is absent from current UK saltmarsh protection work is large-scale projects using these methods. It is very likely that, sediment recharge projects in particular could have clear economies of scale and could lead to large areas of marsh being protected and/or enhanced at a comparatively low costs.

5. RESTORATION OUTCOME

Saltmarshes (and also the connected intertidal mudflats which lie in front of them) provide a wide range processes which underpin ecosystem services (ES). Applying the TEEB (The Economics of Ecosystems and Biodiversity) framework Fletcher *et al.* (2011) listed the primary ecosystem services by coastal saltmarsh and saline reedbeds as follows:

- fisheries;
- fertiliser/feed;
- natural hazard protection;
- environmental resilience;
- regulation of pollution;
- tourism and nature watching; and possibly
- wild harvesting.

As summarised in the preceding sections, several studies have been undertaken to understand and quantify the extent to which these benefits are realised for individual managed realignment projects. However, the ecosystem service value of smaller-scale habitat protection and recharge initiatives (Section 1.3.2) has been subject to less scrutiny presumably because of the infrequency of such work and the challenges associated with quantifying habitat gains in their own right.

The key managed realignment ecosystem services project reviews are summarised in Annex 1) together with four other relevant studies (based on analysis within ABPmer/ARUP 2012). Most of the recent studies broadly use the Millennium Ecosystem Assessment (MEA) classification of ES, and have proceeded to an economic valuation (with the exception of Welwick study (IECS, 2011)). However, they differ in their approach to valuing schemes or services and in the extent to which they focus on final services. They also vary in terms of the services which are included. Most studies valued a mix of aggregated/bundled ES and individual ES. This applies to all the quoted eftec and University of East Anglia (UEA) studies.

Habitat gains and losses were generally valued in an aggregated form; the given values are understood to include the following services: water quality, recreation, biodiversity and aesthetic amenity. These aggregate values were derived from the Brander et al. (2008; 2011) analysis of ES associated with European wetlands. The 2008 function is applied, which was also used to derive the aggregate/'default' values shown in the eftec (2010) and EEA (2010). For saltmarsh habitat the indicative 'first cut' value was approximately £1,300/ha/yr; range £200-£4,500/ha/yr [21]. The present value (PV) of £1,300/ha/yr discounted at HMT recommended rates over 50yrs is £32,000.

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[21] These are indicative first cut values and for a detailed valuation, eftec (2010a) recommend using values which take account of the non-linearity of habitat values (i.e. the authors argue that these vary depending on size of habitat created and proximity to other 'substitute' wetlands).

The studies which used bundled habitat values (mostly eftec and UEA), would then also value at least one further individual final ES which is deemed to not be captured by the default aggregate habitat value, these were most notably carbon sequestration and flood risk management. Further details about some of the valuations for individual services and overall findings from these studies are presented below.

With respect to flood risk management it is possible to readily calculate the saving that can be made from managed realignment due to reduced maintenance of the sea wall (e.g. £300,000/year from the Medmerry projects). Also, saltmarsh themselves provide a substantial wave energy absorption effect. The consequence of this is that they can be seen as a coastal defence in their own right, and where they front sea walls they are features which can reduce the costs of construction and maintenance of those sea walls.

Studies by the Cambridge Coastal Research Unit (CCRU) have shown for instance that saltmarshes can attenuate more than 80% of the wave energy over 160m of marsh under low energy conditions. Also, following a recent study within a 300m flume it was found that that there was 20% wave dissipation over the marsh under storm-type surge conditions (when the marshes may have around 1-2m of water overlying them). This attenuation is caused by the physical presence of the marsh platform. By comparing vegetated and mowed surfaces they showed that a substantial proportion of the observed wave height reduction (60%) was due to the vegetation alone (Moller et al 2014).

To examine the long term costs and benefits of managed realignment, Luisetti et al (2011) reviewed and valued realignments along the Blackwater and Humber estuaries. Four different policy options were assessed for these estuaries and for both of the estuaries studies analysed, the benefits of managed realignment were found to outweigh the costs in the long-term. The Humber Estuary's Net Present Value (NPV) was found positive for timescales longer than 25 years, suggesting that managed realignment in the Humber Estuary would be of benefit, but only in the long-term.

The Blackwater Estuary case study showed a much stronger net benefit from managed realignment over all of the timescales tested. For example, the 50-year NPV for the Blackwater was £156 million, compared to the Humber's £4million. The marked difference between the NPV values quoted is largely due to the different values used for the 'amenity and recreation' ES, although slightly higher values were also applied for 'carbon sequestration' on the Blackwater, and also 'fish nursery benefits' were valued here, but not for the Humber.

With regards to the 'amenity and recreation' ES, for the Humber, a proxy value of £621/ha/yr was employed, whereas for the Blackwater, a dedicated 'willingness to pay' WTP (choice experiment) study involving over 500 individual interviews was undertaken. Results produced by the WTP study suggest amenity and recreation benefits for use and non-use values between £3,472/ha/yr and £77,784/ha/yr and for use values only between 2,674/ha/yr and £54,000/ha/yr depending on the policy option.

With respect to carbon sequestration, all the studies reviewed here appear to have used sequestration values derived from Sheperd et al. (2007) and/or Andrews et al. (2006) (UEA) studies. These studies estimated the carbon storage values of intertidal habitats using relatively low accretion rates of 1 to 6mm per annum. However the rate of accretion is often much greater than this in many realignment sites, particularly during the initial years following realignment (until the habitats match the elevation of external mature marshes at which time accretion rates might be closer to the range applied by Andrews and Shepherd). Accretion is particularly high in sediment-rich estuaries like those in the Humber.

In relation to carbon valuation, the studies differ with respect to the carbon values applied. eftec applied non-traded values ranging between £25 and £75/t CO_2 equivalent (CO2e), following Defra and DECC guidance applicable at the time of the study, whereas UEA tends to apply significantly lower traded (social) values (e.g. Turner et al. (2006) used a value of £7.7/t CO_2e). The time horizons used for ES analysis also varied and ranged from 25 to 100 years.

Many services have not been valued, partly due to research gaps, and partly due to many being assumed to be included in other services or aggregated values. Therefore, while the 'in principle' benefits of managed realignment are well understood there are notable gaps in knowledge regarding some of the more obvious benefits and their values that these schemes confer.

To take forward some of this thinking and describe the details of analysis at a project level, the following managed realignment cases examples are discussed in the Annex to this investment case:

- The Environment Agency's Medmerry Project (Selsey Peninsula);
- The Environment Agency's Alkborough project Humber Estuary; and
- The Defra/RSPB projects at Wallasea Island

These managed realignment projects create clearly defined areas of new coastal marsh and fringing terrestrial grassland that provide services that can be relatively easily defined. Although several gaps in understanding still exist about the value of the services provided, the studies that have been undertaken consistently show that managed realignment is valuable especially when viewed in the long term. Indeed, managed realignment should always be viewed with a long-term perspective because they are undertaken in response to coastal strategies which identify as relevant measures from the long-term management of the coast.

The investment case for managed realignment is therefore relative clear and the evidence for it relatively consistent. Over time as gaps in understanding about ES values are filled it is expected that this case will become even stronger over time.

As noted previously there will also continue to be a strategic imperative for managed realignment and the UK Climate Change Adaptation Sub-Committee (2013) found that managed realignment would have to increase five-fold from the current levels of around 6km of coastline realigned every year to around 30km, in order to meet the 2030 goal stated in the SMPs. The extent to which this can, and will be, achieved is based on funding, perceived urgency and policy drivers. Currently much of the funding is driven by the need to create compensatory habitats (hence the large proportion (75%) of habitat created that is compensatory rather than new as described above) and the implementation of future sites may need to have other drivers and greater clarity in terms of the range of benefits provided.

In many instances managed realignment projects can meet with local community opposition (although it should be noted that there are also now many good examples of communities supporting schemes on their doorstep following successful consultations). However, such opposition may become more significant in the future because the next generations of realignment will probably need to be undertaken in locations that are more sensitive than the somewhat 'easier' projects that have been completed to date. It may well be that there are only a few projects in the short-term and that longer timeframes for implementation of many other sites will be needed to allow landowners, businesses and society to prepare and adapt.

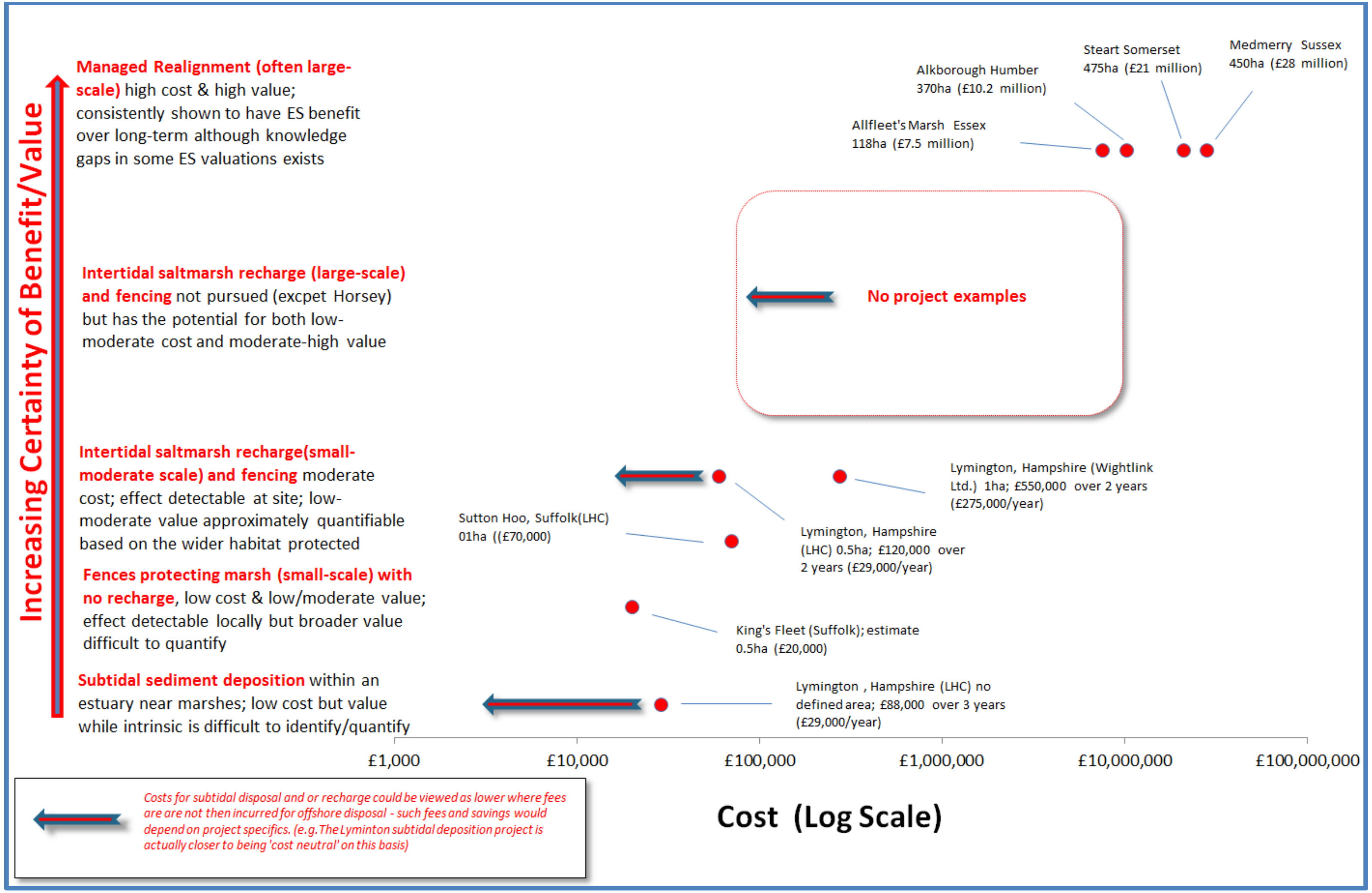
While the strategic coastal adaptation imperative will always exist and will form the foundation for future implementation, demonstrating the ES case based on past projects will become increasingly important in the implementation process given the likely sensitivities of communities. The evidence from the Medmerry project is one of the best examples of this. Had it not been completed (as directed by the coastal strategy) in September 2103, the hinterland properties and business would have suffered substantial damage and loss during the 2013/14 winter storms. Also the Environment Agency would have incurred further costs (in addition to those required elsewhere on the coast). This illustrates that failure to adapt, especially in the context of sea level rise, brings a real increase in risk.

The investments in enhancing saltmarsh have been small in scale and relatively ad hoc. These measures inherently have value and can maintain or even enhance the services provided by existing habitats but this case has not been well made in the past. There is a need for the ES case to be made in greater detail (building on ES work undertaken for managed realignments) in order to secure buy-in and funding from the multiple stakeholders who can benefit.

There is a need for larger-scale recharge projects to be increasingly considered. The possibility exists that such larger-scale projects could begin to expand rather than just maintain existing marshes and thus bring in extra ES values for a comparatively low cost when compared to managed realignment. In other words the benefit-cost ratio (BCR) could be greater for larger projects and they may well also have economies of scale that are not being realised for large-scale managed realignments. The case for these larger projects needs to be considered further.

To summarise this position, a qualitative cost-benefit relationship plot for range of the saltmarsh creation and management measures cited in this document is shown in Figure 5.1. This compares projects costs against the degree of evidence and certainty that exists as the values provided.

Figure 5.1: Estimated Cost: Benefit relationship for range of saltmarsh creation and management measures



6. COSTS

This section sets out the costs of managed realignment in England. Managed realignment leads to the creation of intertidal habitat, which includes both saltmarsh and mudflats.

6.1 Capital costs of intertidal habitat creation

In order to assess the costs associated with the creation of intertidal habitat, it is assumed that for every 1km of managed realignment that takes place a total of 95ha of intertidal habitat is created. This is made up of 35ha of saltmarsh and 60ha of mudflat. These figures are based on average outcomes/predictions for recent UK managed realignment projects. These and other assumptions are shown in Table 6.1.

The current extent of managed realignment in England is 6km/year meaning that 570ha/yr of intertidal habitat is created. The Climate Change Committee (CCC) Adaptation Sub-Committee (ASC) suggests that a fivefold increase in managed realignment is needed in Shoreline Management Plans (SMP) to 30km/year. This would mean that 2,850ha/yr of intertidal habitat is created. The one-off capital cost (CAPEX) of intertidal habitat creation is estimated to be £50,000/ha, based on the average costs from recent UK projects. It is assumed that annual maintenance costs are incorporated into the cost of intertidal habitat creation.

Over 15 years the amount of managed realignment is estimated to be 450km (8% of the English coastline of 5,496 km) with 42,750ha of intertidal habitat created (2,850ha each year). **Total cost (PV, over 50years) is £1,62m.**

Table 6.1: Cost of intertidal habitat (saltmarsh and mudflat) creation

	Value	Assumptions/Notes
Amount of managed realignment per year	30km	-
Amount of intertidal habitat created per year	2,850ha	95ha of intertidal habitat is created for every km realigned.
Cost of intertidal habitat creation	£50,000/ha	Average costs from recent UK experience.
Cost of intertidal habitat created over 15 years (PV terms)	£1,698m	The amount of saltmarsh/mudflat created each year increases by 2,850ha until year 15, where it remains at 42,750ha.

7. BENEFITS

This section sets out the benefits of managed realignment in England and centres on the avoided flood defence costs associated with the creation of intertidal habitats and the improved ecosystem service provision using Brander et al (2008) meta-analysis function.

7.1 Avoided flood defence costs

Managed realignment involves the full or partial breaching of an existing sea wall in order to foster intertidal habitat creation. Realignment avoids, or significantly reduces, the need to maintain the existing sea wall. It may involve the creation of a new sea wall (or may not if the tidal extent reaches natural contours in the land). Where a new sea wall is required its maintenance costs are usually significantly lower than the existing sea wall. This is due to the existing wall being much more exposed to erosion (and hence being in a location suitable for realignment), whereas the new sea wall is typically protected by a new extent of intertidal area.

Costs of sea wall maintenance are therefore avoided or reduced once managed realignment takes place. These avoided operational OPEX costs are ongoing (i.e. they are avoided every year). Based on recent projects in the UK, they are estimated to be £33k/yr for every km of coast where managed realignment takes place.

This means that the benefits of avoiding maintenance costs increase every year for the first 15years as an additional 30km is realigned. These benefits are then assumed to continue over the 50year period appraised. Discounted over 50 years, the present value of avoided flood defence costs is **£285m**.

As managed realignment is another form of flood defence, it is assumed that there is no difference in the level of flood defence compared to that of a traditional sea wall. However, managed realignment is often undertaken in locations where existing lines of flood defence are vulnerable, meaning that realignment creates a benefit. This is either of avoiding the costs of engineering higher standards of flood defence, or of avoiding flood damages as a result of providing higher standards of flood protection that would otherwise be possible. This flood risk management value is reflected generically in the Brander valuation function (see below). However, this likely underestimates its value, which is context-specific, depending on local flood risk management strategies and assets at risk.

Total benefit (PV, 50 years) of avoided flood defence costs is £285m.

7.2 Ecosystem service provision

The valuation of intertidal habitat creation in terms of improved ecosystem service provision has been estimated using the Brander et al. (2008; EEA 2010) meta-analysis function[22]. Using this function provides a bundled value estimation of wetland creation, which controls for wetland characteristics (e.g. the type of wetland being valued); context characteristics (e.g. GDP per capita, population density, and wetland size); and the characteristics of the meta-analysis source studies (e.g. the study method, such as contingent valuation or travel cost). The Brander et al. function examines how observed wetlands values vary with these characteristics.

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[22] The function specification and parameters applied are as reported in Brander et al. (2008; EEA 2010).

Table 7.1: Value function for wetland[23]

Variable	Coefficient value	Value of explanatory variable used for this valuation	
Constant	-3.078	1	-
Wetland Type: Saltmarsh	0.143	0.37	Based on the outlined assumptions of saltmarsh creation, 37% of intertidal habitat created is assumed to be saltmarsh.
Wetland Type: Intertidal mudflat	0.11	0.63	Based on the outlined assumptions of mudflat creation, 63% of intertidal habitat created is assumed to be mudflat.
Wetland Size	-0.294	*In^{a} 50, 100, and 200 ha*	Three scenarios of original intertidal habitat sizes are tested: 50ha, 100ha, and 200ha.
Flood control	1.102	1	Assumed ecosystem service provision: flood control; surface and groundwater supply; water quality improvement; non-consumptive recreation; amenity and aesthetic services; and biodiversity.
Surface and groundwater supply	0.009	1	
Water quality improvement	0.893	1	
Non-consumptive recreation	0.34	1	
Amenity and aesthetic services	0.452	1	
Biodiversity	0.917	1	
GDP per capita (2003US$)	0.468	*In* 31,981	UK GDP per capita is taken from Eurostat (in euros) in 2003, converted into US dollars ($) using PPP in 2003 as $31,981 (Eurostat, 2014; OECD 2014) and uprated for inflation to 2013 prices (ONS, 2013).
Population density per km^2 within 50km	0.579	*In* 353	The population density within 50 km has been approximated from the average population density England (excluding London) of 353 people per km^2 (ONS, 2013)
Wetland area within 50km	-0.023	*In* 1,500 (5,000)	The population density within 50km has been approximated by halving the average population density in England (excluding London), which results in a population density of approximately 177 people per km^2. Half of the full figure is used due to the fact that managed realignment would take place on the coast, with 50% of the total area within a 50km radius being in the sea.

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[23] This is a truncated version of the full Brander et al. (2008) function, only including variables that were used in estimation of wetland values in this report. Parameters that were set to zero (e.g. peat bog, inland marsh) are not reported.

Variable	Coefficient value	Value of explanatory variable used for this valuation
Source: Brander et al. (2008; 2011)		

[a] ln represents the natural logarithm of a number

Factors controlled for in the meta-analysis function include::

- **Wetland size (in hectares):** (size of wetland created in terms of this case study). The coefficient estimate is negative (and statistically significant), implying the unit value for wetland (£/ha) decreases as the size of the wetland increases (all else equal); i.e. indicating decreasing returns to scale.
- **Flood control service:** The coefficient estimate is positive (and statistically significant), indicating that wetlands that provide flood control and/or storm buffering are associated with higher values than those that do not. Note that in this case study flood control benefits of intertidal habitat creation are valued only through application of the Brander et al. function. Other appraisal guidance (e.g. the Environment Agency FCERM guidance) has not been applied.
- **Water quality improvement:** The coefficient estimate is positive (and statistically significant), indicating that wetlands that contribute to water quality improvements are associated with higher values than those that do not.
- **Biodiversity:** The coefficient estimate is positive (and statistically significant), indicating that wetlands associated with enhanced biodiversity outcomes are associated with higher values than those that do not.
- **Income of the population in the vicinity (or users) of the wetland.** The coefficient estimate is positive (and statistically significant), indicating that higher wetland values are observed in regions with higher levels of GDP per capita.
- **The population within 50 km of the intertidal habitat.** The coefficient estimate is positive (and statistically significant) indicating that the unit value for wetland increases with the size of the population within 50km.

Table 7.2 reports the estimated value per hectare for intertidal habitat based on the application of the Brander et al. function as described in Table 7.1, along with the corresponding PV over 50 years. The present value estimates are based on 2,850ha of intertidal habitat being created each year for 15 years. Estimates are reported for alternative initial habitat sizes for sites being 50ha, 100ha, or 200ha.

Table 7.2: Value of intertidal habitat creation

Initial wetland size (ha)	Wetland within 50km (ha) (Substitute)	Value (2012)	
		per ha/yr	Total (PV over 50yrs)
50	1,500	£1,650	£1,356m
100		£1,343	£1,104m
200		£1,093	£898m

The decreasing value per hectare is attributed to the diminishing returns to scale illustrated in the Brander et al. function.

The total benefit (PV, 50 years) of the central case (i.e. with sites of 100ha being created) of intertidal habitat creation is £1,104m.

7.3 Carbon sequestration

The creation of intertidal habitat is expected to result in carbon sequestration benefits. Rates of around 2-4 tonnes of carbon sequestered per hectare per year are observed for recent UK managed realignment schemes[24]. Estimates of carbon sequestration assume that for 2,850 ha/yr of intertidal habitat created per year, approximately 1,050 ha behaves like established saltmarsh from the outset storing 2tC/ha/yr over 50 years, whilst approximately 1,800 ha accretes more rapidly for the first 15 years, storing 4tC/ha/yr before storing at a lower rate consistent with established saltmarsh (2tC/ha/yr).

DECC carbon valuation guidance is applied to value sequestered carbon, using the non-traded price of carbon schedule (DECC, 2014a). Estimates of carbon sequestration are converted to tCO2e (DECC, 2014b). Application of the DECC values give a PV benefit of approximately £1.0 billion over 50 years.

The total benefit (PV, 50 years, 2014 GBP) of carbon sequestration of the intertidal habitat created is £1,039m.

7.4 Net present value

The central estimate of total costs and benefits, as well as the net present value (NPV) and benefit-cost ratio (BCR), over 50 years in present value terms, is outlined in Error! Reference source not found.. This shows that there is potential for a net present value of approximately £1.2 billion associated with managed realignment. It should be noted that the benefits of flood protection are not is excluded from these calculations, which would result in additional costs. Adjusting the wetland within 50km figure by a factor of ten for sensitivity analysis results in an increase in BCR values of about 5%. Therefore, this sensitivity analysis is not included in Error! Reference source not found..

Table 7.3: Costs, benefits, NPV and BCR of intertidal habitat creation over 50 years (£2014)

Economic metric		Estimate
Total costs (PV over 50yrs)		**£1,698m**
Benefits	Avoided costs	£285m
	Ecosystem service benefits - central case (100ha sites of intertidal habitat created)	£1,104m
	Carbon sequestration	£1,501m
	Total benefits (PV over 50yrs)	**£2,890m**
NPV (over 50yrs)		**£1,192m**
BCR		**1.70**

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[24] http://www.abpmer.co.uk/About_Us/Publications/Buzz/ABPmers_Blue_Carbon_Calculator/

7.5 Feasibility/Uncertainty

Results from application of the Brander et al. function are relatively sensitive to the assumptions that are applied as has been shown above. The meta-analysis approach provides a transparent account of how values estimated for a specific site can be scaled to the aggregate national level. Factors to take into consideration are the following:

- The average size of sites is highly significant as smaller areas provide proportionately greater benefits, due to diminishing returns to scale. The central case assumes that sites of 100ha will be created to meet the annual addition of 2,850ha of intertidal habitat, but smaller sites making up the 2,850ha a year would increase benefits as shown in Table 7.2
- Recent UK findings show that on average 25ha of saltmarshes are created per 1km of sea defence realigned, while almost 100ha of combined mud, marsh, and transitional grassland are created. It must be noted, though, that typically, managed realignments accrete with sediment after they are breached and therefore their habitats will evolve over time with mudflat typically changing to marshes. Given that, the recommended averages are 33ha of saltmarsh per km of managed realignment, recognising that this value can range from a half to double this level, and can reach levels of over 100ha to nearly 300ha for individual projects. Therefore, the assumption of 95ha of both saltmarsh and mudflat creation is an appropriate mid-level estimate.

The size of individual habitat sites is a key determinant of the scale of benefits obtained from investing in intertidal habitats. In reality, intertidal habitat creation would happen across a variety of sites with a range of different sizes. The range of 50ha to 200ha is thought to encompass the size of the majority of sites where saltmarsh/mudflat creation is likely.

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ANNEX 1: Managed Realignment Valuation Studies

Table 1.1: Table of managed realignment valuation studies (ranging from national scale to project-level)

Study	Location, statistics	Framework / method applied	Valuation undertaken	Applicability to Humber / potential limitations
NEA, 2011	UK	MEA. Valuation of aggregate & individual values.	Quantitative values for total ES provided by UK coastal margins (incl. saltmarsh). Total value of £48billion provided.	Low applicability as valuations done at UK or national level.
Fletcher et al. 2011	UK wide	TEEB. No valuation.	Qualitative assessment (review of evidence base) of beneficial ecosystem processes and services provided by broadscale habitats, and habitats and species of conservation interest likely to be protected by MPAs in the UK.	No quantitative information; however beneficial ecosystem processes and services identified will be directly applicable to Humber habitats.
Luisetti *et al.* 2011 (UEA)*	Humber estuary and Blackwater Estuary	Humber: MEA; Blackwater: Fisher & Turner, 2008. Valuation of aggregate & individual values.	Environmental Statement quantified: flood protection, amenity and recreation (aggregated proxy values for Humber; dedicated WTP study for Blackwater), carbon sequestration and fish nursery benefits (latter Blackwater only). Overall net present values (NPVs) calculated for 3 scenarios. Various sensitivity tests. Humber Estuary's NPV was positive for timescales > 25 years, so MR would be of benefit in the long-term. NPV for Blackwater positive over majority of timescales - mainly due to use of site-specific data to assess amenity and recreation benefit (with per-hectare values ranging from £2.4k/ha/yr to £77.8k/ha/yr).	Geographically applicable. Blackwater highly applicable (estuaries have similar physical similarities and risk profiles; also same legislative regime). Benefits transfer should be feasible (provided adjustments made for population and methodology). Potentially very high values could result from WTP studies (though very size dependant). Aggregation risks missing services.
Eftec, 2010b	Severn Estuary	MEA. Valuation of aggregate & individual values.	Quantitative value of environmental impacts of Severn Tidal Power schemes. ES quantified: Loss/gain of habitat (aggregated proxy values), carbon sequestration. Over 120yrs, PV of costs ranged £5.9million to £218.6million.	Low applicability. Aggregation risks missing services. Underestimates of impacts; magnitude of underestimates unknown.
Everard, 2009	Alkborough Flats MR (370ha, 2006), Humber	Classification of ES based on MEA. Valuation of final services and supporting services.	Many ES quantified: food, fibre, genetic resources (provisioning services); climate regulation, natural hazard regulation (regulatory services); recreation and tourism (cultural services); primary production; provision of habitat (supporting services). Overall gross benefit value: ~ £28 million over 25yrs (no sensitivity analysis/ranges). Benefit cost ratio of 3.22 (compared to 2.72 in Agency's PAR).	Geographically applicable, though several services site specific. Some assumptions / valuations unclear, and some risk of double counting supporting services. No sensitivity analysis.
GHK and Eftec, 2008	Alkborough Flats MR (370ha, 2006), Humber	Not specified (MEA?). Valuation of aggregate &	ES quantified: carbon storage, habitat creation (aggregated proxy values, incl. nutrient cycling), recreation. Annual benefit value of c. £200,000, (over 25a); ~£3.65million in PV terms over 25yrs	Geographically applicable, but scheme only. Aggregation of benefits risks missing some services values. Note: superseded by eftec 2010a

Study	Location, statistics	Framework / method applied	Valuation undertaken	Applicability to Humber / potential limitations
		individual values.	(discounted at 3.5%).	case study.
Eftec, 2010a	Alkborough Flats MR (370ha, 2006), Humber	Classification of ES based on MEA. Valuation of aggregate & individual values.	Qualitative assessment of potential services. ES quantified: Habitat gains and losses (aggregated values as proxy for following ES: water quality, recreation, biodiversity and aesthetic amenity). Carbon storage. Flood storage. Found substantial benefits – 100yr midpoint estimate £18million; range £12-25million (close to PAR).	Geographically applicable, but scheme only. Possibly overly conservative / aggregation risks missing services. Assumptions re. accretion rates unclear. Annex 1 Habitat lookup table very useful for studies using aggregate values.
	Paull Holme Strays MR (80ha, 2003), Humber	Classification of ES based on MEA. Valuation of aggregate & individual values.	Qualitative assessment of potential services. Quantitative valuation of range of scenarios. ES quantified: Habitat gains and losses (aggregated proxy value (see row above)). Carbon storage. Implemented MR option: substantial benefits – 100yr mid point estimate £4.5million; range £3-6million. Highlighted the benefit of ES valuation, as this led to positive cost benefit ratio being achieved (not achieved without ES).	As row above; also lagoon value assumed same as saltmarsh. FRM benefit assessment unclear.
	Wareham - potential MR (approx.. 400ha), Poole Harbour, Dorset	Classification of ES based on MEA. Valuation of aggregate & individual values. Qualitative assessment incorporated.	Qualitative assessment of potential services. Quantitative valuation of range of scenarios. Habitat gains and losses valued as a proxy for the assumed ES provided (see row above). Carbon storage. Nutrient storage. Overall impacts presented as a combination of monetarised and qualitative values (e.g. MR vision: £21.39million ++, MR Unconstrained: £21.89million ++- - (negative values refer to significant risk of large scale adverse impacts on navigation).	Low direct applicability. Regional spatial scale. Possibly overly conservative / aggregation risks missing services. Nutrient cycling possibly double counted. Habitat values based on different study than other eftec 2010 case studies. Accretion assumptions unclear.
IECS, 2011	Welwick MR (54ha, 2006), Humber	ES and Societal Benefits. No valuation.	Qualitative summary of the ES provided. Proposed valuation to assess economic valuation of fish ES, but insufficient data for quantitative valuation.	Geographically applicable. No valuation, but suggestions for fish valuation.
Kremezi, 2007	Paull Holme Strays MR (80ha, 2003), Humber	MEA Valuation of aggregate & individual values.	ES quantified: Habitat loss/creation (aggregated proxy values), carbon storage. Full retreat habitat creation total value £1.3million (saltmarsh £415,000, mudflat £664,000; saline lagoons £249,000); carbon storage full retreat £146,000.	Geographically directly applicable, but scheme only. Aggregation risks. Unit values used were 'average values from range of estimates. Note: superseded by eftec 2010a case study.
Mangi *et al.,* 2011	Tetney Marshes, Humber Estuary (extant marshes)	No framework per se. WTP and preventative costs method	Valued sea defence value of saltmarshes. Coastal residents in Humber (small sample of 10) were willing to pay £231 per year to prevent a reduction in the present coverage of wetlands. The preventative cost method concluded that potential mean saving on seawall construction cost ranged from £12,237–30,057 per m^2.	Only one ES valued, though interesting insights into confidence in the ability of wetlands to protect settlements by local residents.

Study	Location, statistics	Framework / method applied	Valuation undertaken	Applicability to Humber / potential limitations
Eftec, 2008	Wallasea – future MR (approx. 585ha), Essex	Not specified. Valuation of aggregate & individual values.	ES quantified: flood risk management cost savings, habitat creation (aggregated proxy values), carbon storage, tourism. Present value (discounted over 50yrs) for the ES could exceed £14million.	Low direct applicability. Regional spatial scale. Aggregation risks and missing services.
*note: there are various earlier papers on these two case studies, including: Luisetti et al., 2008 and Turner et al., 2006.				

(Source: ABPmer/Arup, 2012).

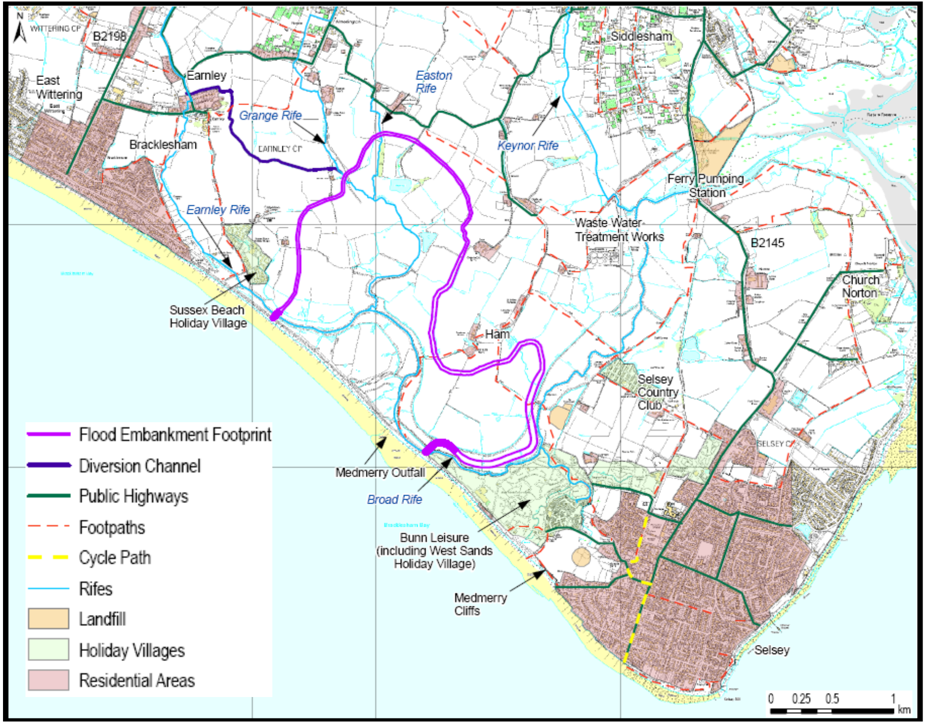
ANNEX 2: CASE STUDIES

Case Example - Medmerry Managed Realignment

Medmerry is located on the south coast of England between East Head and Selsey Bill, on the Selsey Peninsula, in West Sussex (see Location Plan below). This location was fronted by a mobile shingle bank which required regular maintenance on an annual basis.

This area was previously subject to occasional, but significant, coastal flood events and, without intervention the hinterland would have continued to be at risk into the future. As the land behind the wall is low-lying an inevitable unmanaged breach of the shingle defences would have occurred and caused large areas of land to flood on each tide and resulted in damage to Selsey and the peninsula's villages and holiday parks. Given the baseline landform, such events would also have caused Selsey's only road link would be severed and the waste water treatment works situated in the Medmerry floodplain to be flooded.

Figure 2.1: Location of the Medmerry Managed Realignment



Following a detailed series of design iterations, in consultation with the local community, a proposal was developed which involved the creation of a new 7km long new sea wall set up to 2km back from the existing sea defences. Then in September 2013, a 100m wide breach was placed in the sea defences at the most appropriate location and regular tidal flooding was introduced to an area of 183ha. There is a further 114ha inside the sea walls that is transitional grassland with some arable and grazing livestock.

Figure 2.2: Medmerry Realignment shortly after breaching (September 2013) also showing Bunn Leisure island breakwaters near to the breach

(Source J Akerman for the Environment Agency)

Prior to the work being undertaken an economic assessment of the potential benefits of this project was undertaken (Environment Agency 2010). This was done for the Pagham to East Head Coastal Defence Strategy and based on the Defra's Flood and Coastal Defence Project Appraisal Guidance to Economic and Social Appraisals (Defra, 2006; 2008). It was also based on the use of the Economic Valuation of Environmental Effects (EVEE) Handbook published by eftec (2007) for the Environment Agency – using an ecosystem services approach for environmental benefits.

The potential benefits for implementing managed realignment were valued at £91.7m (including £13.5m of benefits derived using the EVEE guidance). These increased to £97.7m (including £12.1m of benefits derived using the EVEE guidance) if the works were combined with a separate proposed coastal defence measure at the Bunn Leisure scheme, as all the assets of the Bunn Leisure site would be protected rather than just a proportion. That separate proposal was undertaken by Bunn Leisure and involved the creation of two rock armour breakwater and a shingle recharge exercises in an areas just to the east of the Medmerry site. These features are visible in Image 10.

This pre-construction appraisal was based on projected typical prices (in £ per hectare) for arable land in the South East region ranging from £12,356 in the first half of 2009 to £13,591 in the second half of the year (RICS, 2009). The total estimated value of the 250ha of agricultural land (the remaining 50ha within the 300ha site was an RSPB reserve and SSSI) was estimated to be £3m. The actual cost of the land purchased by the Environment Agency at Medmerry was around £2,600 per hectare, which includes a compensation of around £300 per hectare for disturbance caused.

Through the construction work a range of technical challenges were encountered which incurred an extra cost. These included dealing with important archaeological finds and mitigating for populations of protected water vole species. On completion of the construction phase, the project has been quoted as costing £28 million to create and will continue to incur small costs for monitoring (which will be led by the Environment Agency) and site management (which will be led by the RSPB).

The site now helps protect 348 homes as well as important infrastructure that serves over 5,000 households. It has also created an intertidal habitat that is expected to boost tourism in the area[25]. The shingle bank fronting the site now no longer needs ongoing management to retain its form. This, on its own, saves around £300,000 annually (which is the typical fee incurred by the Environment Agency in previous years). However, these defence maintenance costs would have been much higher in the first winter following the completion of the work: a series of severe storm-surges hit this coastline during the 2013/14 winter and caused a major readjustment of the shingle defences. Instead of requiring restoration measures, the shingle has been allowed to naturally roll-back in a sustainable manner and the breach has evolved and remained open and is functioning as designed.

Also, since it was breached, the site has proven to be highly valuable for wading birds species and in the Summer of 2014, the freshwater flood storage areas supported nesting Black-winged Stilts for the first time in the UK for 27 years. It is expected to sequester carbon at a typical rate for saltmarshes and to have a high value for fish populations.

Overall the potential benefits of managed realignment are valued to be at least £91.7m and these outweigh the value of the original arable land at Medmerry.

Table 2.1: Medmerry Summary Case Example

Author	Environment Agency 2010
Type of Ecosystem Service	Flood protection- although the scheme has some additional biodiversity, recreation and fisheries benefits
Type of intervention	This is the largest UK realignment in a coastal (rather than estuarine) location. It involved construction of a new 7km-long sea defence with a 100m wide breach then being cut into the existing coastal shingle defences. Tidal waters now flood 186ha of the hinterland and this area of new intertidal habitat compensates for losses (from coastal squeeze) of mudflat and marshes in the Solent. The remaining 114ha of the site includes large expanses of transitional grassland part which contribute to national biodiversity targets. The project has a number of additional biodiversity benefits. A large part of the area remains available for arable farming and there is additional income from grazing livestock. The area has become a haven for wildlife and a recreational area.
Value for money metric	The project cost an estimated £28 million to create and will continue to incur costs for management which will be led by the RSPB. As the shingle bank no longer needs ongoing management to retain its form this saves £300,000 annually. The restored intertidal area will also play a role in: climate regulation through air nutrient and pollutant sequestration and recreation and tourism. Benefits appraised ex-ante at approx £82m of infrastructure protection and £13m of environmental benefits. Assessed benefits outweigh actual costs by over 3:1.

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[25] Dr Paul Leinster, Chief Executive of the Environment Agency quoted in the British Construction Industry (BCI) awards for where the project received the Civil Engineering Project of the Year (£10m - £50m) and the Prime Minister's Better Public Building Award 2014 https://www.gov.uk/government/news/prime-ministers-better-public-building-award-2014

Case Example - Alkborough

The Alkborough project was a large-scale (370ha) project undertaken by the Environment Agency in the upper Humber Estuary. It is a site that was designed to provide habitat in compensation for coastal squeeze losses elsewhere in the estuary, but also to act as a flood storage area during storm surge events. There were a number of technical challenges with this project (stakeholder engagement, need for details assessment and the presence of unexploded ordnance on site) and its overall cost was around £10.2 million m^3.

The Ecosystem Services provided by the Alkborough Managed Realignment site was reviewed by quantified Everard (2009). This study was comprehensive in terms of the number of individual ES valued, although quantitative valuations were also made of several supporting services (which may lead double counting). The values derived for several of the ES have not been reported elsewhere in the managed realignment valuation literature, and many of these would be helpful to organisations undertaking future ES valuation studies, be it in the Humber region or elsewhere (i.e. useful for benefit transfer).

The main services that were quantified in this study were: food, fibre, genetic resources (provisioning services); climate regulation, natural hazard regulation (regulatory services); recreation and tourism (cultural services); primary production; provision of habitat (supporting services). The overall gross benefit value was calculated as being £28 million over 25yrs (no sensitivity analysis/ranges) and the benefit cost ratio was quoted as 3.22.

A review by eftec (2010a) involved a qualitative assessment of potential services from this site (see Table 5). The services quantified included habitat gains and losses (aggregated values as proxy for following ES: water quality, recreation, biodiversity and aesthetic amenity); carbon storage; Flood storage. Eftec (2010a) concluded that there were substantial benefits from the scheme with a 100yr midpoint estimate of £18million; range £12-25million.

Table 2.2. Alkborough Summary Case Example

Author	Natural England: "No Charge?" Citing paper by Everard (Environment Agency)[26]
Type of Ecosystem Service	Flood protection- although the scheme has some additional biodiversity benefits and carbon sequestration benefits.
Type of intervention	In 2006 a 20m wide breach was cut into the flood defence bank and 170 ha of land was converted to inter-tidal mudflat, saltmarsh and reedbed. The Alkborough Flats project has a number of additional biodiversity benefits. The area is no longer available for arable farming, but there is additional income from grazing livestock. The area has become a haven for wildlife with 150 bird species recorded, including thousands of migratory birds such as lapwing and golden plover in winter.
Value for money metric	The remaining land serves as storage capacity during extreme storm surges. It is calculated that there is an annual flood protection benefit of £400,667. The restored intertidal area also plays a role in climate regulation (approximately 539 tonnes per year of carbon are trapped in sediments worth an estimated £14,553 per year), air quality improvement, nutrient and pollutant sequestration and recreation and tourism. Using economic valuation techniques, wildlife and wildlife habitat on the site has been valued at £535,000 a year. Assessed benefits of £18m - £28m outweigh costs of £10m by between 2:1 or 3:1.

Case Example - Wallasea Island

At Wallasea Island in Essex a series of managed realignment schemes have been and are being undertaken. This island lends itself to (and indeed strategically requires) managed realignment because it is low lying and this allows for the creation of mudflat habitat but this also means that in order to create saltmarsh habitat there is a need to raise the landform to the correct tidal elevation using imported sediments and dredge arisings.

This low lying nature of the land also presents a significant flood risk because it means that an unmanaged flood event will happen in the future which will not only cause damage to the land and surrounding properties but will then cause more wider and more substantial damage to the adjacent Crouch and Roach Estuaries.

The first realignment was undertaken in 2006. This was 115ha in size and carried out by Defra as compensation for losses of mudflat and saltmarsh habitats following port developments in the Thames area. The saltmarsh here was created through the importation of 550,000m^3 of dredge sediments from channel maintenance dredge work at Harwich. This project cost around £7 million to create 118ha.

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[26] http://www.naturalengland.org.uk/ourwork/securefuture/default.aspx

Figure 2.3. Wallasea Island Wild Coast schematic design showing 5 discrete cells

Over more recent years the RSPB has been undertaking a larger-scale project on the island. This involves raising and reshaping the land-form across an area of 677ha to create a mix of saltmarsh and mudflat habitats. When all phases of work are complete, the restored wetland will extend over nearly 800ha, equivalent to around 1300 football pitches.

The work is being undertaken in phases or ‘cells’ as shown in Image 11. Cells 1, 2 and 4 will be managed realignments with full breaching of the existing sea walls. Cell 3 will be a regulated tidal exchange area with tidal connection to Cells 1 and 2 being controlled by a sluice structure. Cell 5 lies on the landside of the final new sea wall and will included mitigation habitats for protected species, freshwater storage area and visitor access facilities.

This is an innovative coastal wetland creation project of a scale that has not been seen before in Europe. This work is being undertaken in partnership with national infrastructure projects that will be providing landscaping sediments. These sediments are transported by sea to Wallasea to raise the island back up to its historical elevations. Thus excavated material that would otherwise be considered as landfill waste would be beneficially used to sensitively restore and reshape the island (see Image 12). This will allow it to function as intertidal habitat, and thus to sequester sediment and integrate over time with the adjacent estuaries while also avoiding the adverse effects that would come from an unmanaged flood of the island.

Figure 2.4: Wallasea Island Wild Coast Cell 1 under construction as viewed from south east (August 2014)

The first phase of the work is being done with London Crossrail who are providing nearly 17 million m^3 of sediment excavated from this new underground rail project. Given the scale and ambition of the Wallasea Island Wild Coast Project there are costs incurred for its creation will be higher than average for a realignment. However, the project also crucially provides a location for the beneficial use of excavated 'wastes' that would otherwise go to landfill with associated implications and costs associated. There are also a wide range of benefits and Ecosystem Service benefits that will accrue. These are summarised in Image 13.

This site will provide significant biodiversity and flood protection gains, but there are many other long-term benefits to society that will arise from the creation of a quality wetland environment. These include: creating full time jobs; providing contracts to local companies; increasing public access to the coast, helping to boost the local economy and promoting sequestration of carbon and contaminants. In addition this project will help to improve public understanding about the coastal management and provide a location for research into a range of social, economic and environmental issues (e.g. into the value of the new wetland for the local oyster fishery).

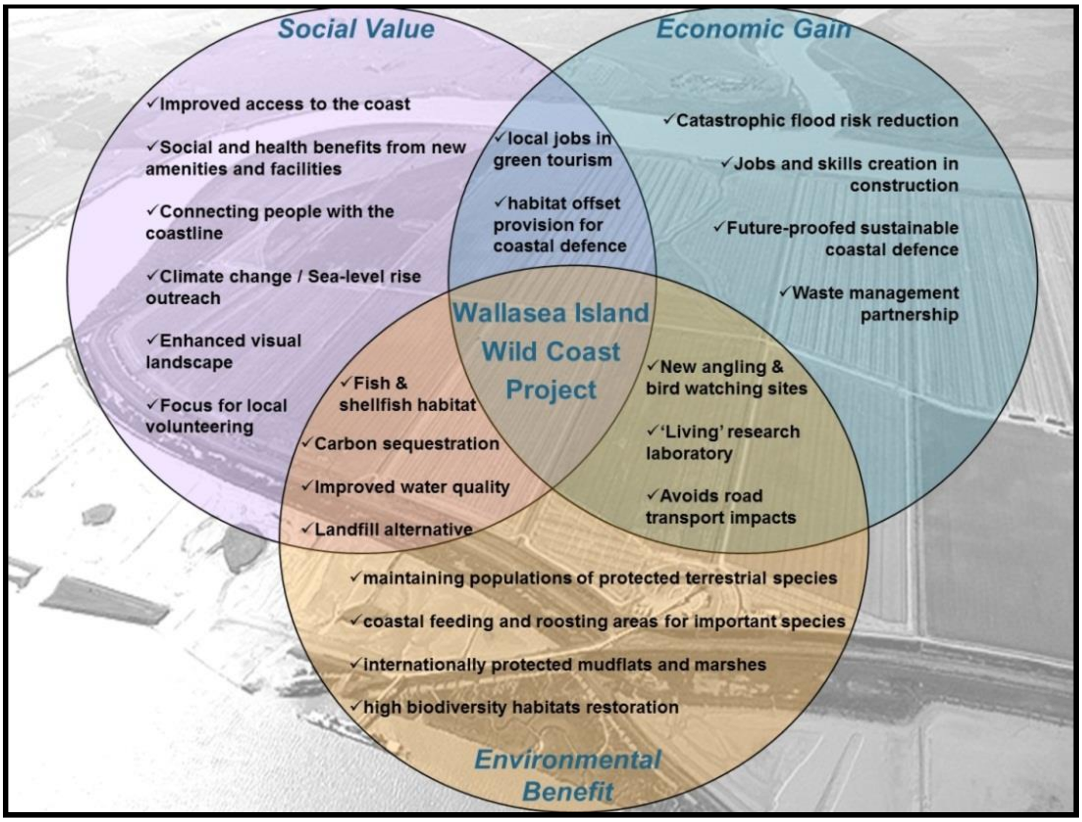
To better understand the economic implications of the proposed Wallasea Island Wild Coast scheme an 'Economic Benefits Study' was carried out by eftec (2008) on behalf of East of England Development (EEDA). In summary, this study concluded that the project will bring about costs savings as well as safeguarding jobs. Recognising that the impacts of unmanaged flooding are necessarily unpredictable the study concluded that the flood risk management role of the projects was estimated to save the following costs over the next 10 years:

- Expenditure for the maintenance of coastal defence infrastructure on the Island of £650,000 or expenditure for adverse impacts to coastal defence infrastructure from an unmanaged breach on the Island of £5–10million.

- Costs for the loss of built assets on Wallasea worth £3.1 m (under moderate flood event scenarios).

The study also concluded, with respect to jobs, that it would create a net estimated 16 to 21 Full-Time Equivalent (FTE) jobs. In addition, around 110 jobs would be safeguarded in areas such as the oyster fishery on the estuary and the transport and marina businesses that use the dock facilities in the north-west corner of Wallasea. The longer term potential of the Wallasea project to create jobs was estimated at between 10 and 20 FTE jobs over years 10 to 20 of the project with the 110 FTE jobs safeguarded being continually protected. In addition to these jobs, beyond the 10 year timescale the project could also be expected to support jobs through the development of visitor facilities.

Figure 2.5: Multiple benefits of the Wallasea Island Project expressed a Sustainable Development Venn diagram



The eftec study notes that, in addition to these employment impacts, the project will have other less-tangible, but nevertheless important benefits. It would be an innovative and a unique example of sustainable coastal adaptation to climate change on the soft low-lying coastlines of East Anglia and the rest of the southern North Sea basin. In maintaining and managing natural coastal processes it will produce benefits from ecosystem services, in particular in fisheries productivity (partly reflected in the shellfisheries benefits above) and carbon sequestration (valued at £1.7m over the next 50 years).

Based on experience through the first few years of the project's implementation, around 50 people are employed in a full time role on this project for the duration of the construction work. This is to undertake the main material handling and landscaping work as well as the associated requirements for maintenance and technical support. In addition, there have been, and will be, many temporary/part time posts during the works where it is necessary to undertake discrete components of the project such as piling or culvert installation.

In addition to the employment on site, many off-site but often local firms and organisations have been employed, especially during the work required to install, refurbish and maintain the unloading facility and conveyor as well as to provide ongoing support. There are six main companies and a further 19 other companies from Essex alone providing support, products or goods and around 19 of the posts (whether full or part time) are filled by people who live locally. There is also volunteer involvement at events and as part of initiatives such as island litter collections and visitor guidance.

Table 2.3: Wallasea Summary Case Example

Author	eftec 2008 for the East of England Development (EEDA).
Type of Ecosystem Service	Flood protection, Habitat Creation and Carbon sequestration benefits.
Type of intervention	A series of managed realignments occurring over the whole 800ha island in a phased manner. Allfleet's Marsh undertaken in 2006 by Defra (118ha) and now the wider Wallasea island Wild Coast project being pursued by RSPB and Crossrail (677ha).
Value for money metric	Conclusion that project has high and undefined costs, but substantial gains

INVESTMENT CASE - WOODLAND

SUMMARY

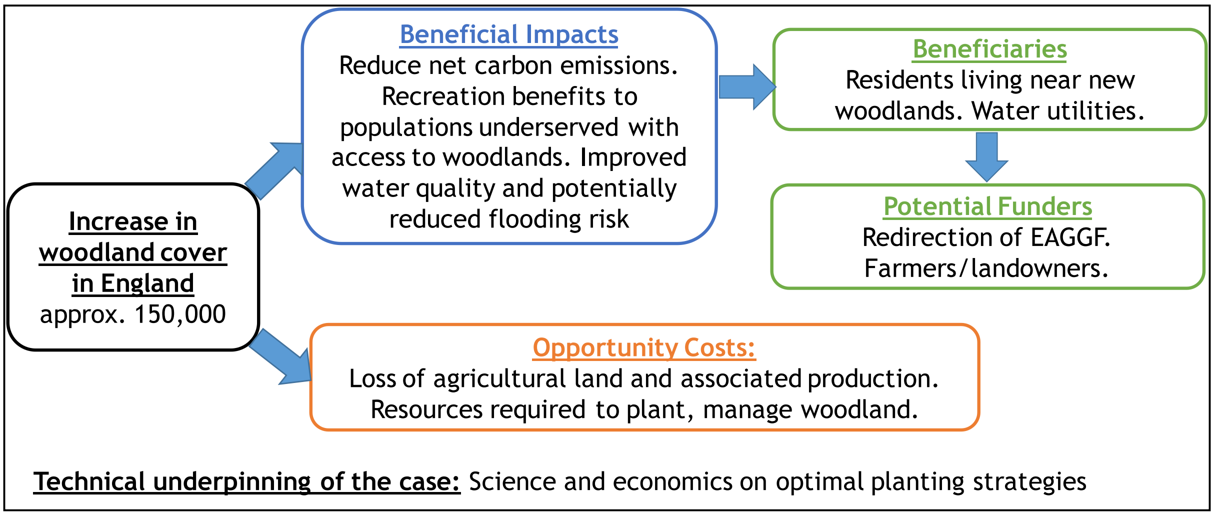
- *Well-managed and diverse forestry produces a wide range of ecosystem services: including provisioning, regulating (especially carbon sequestration), cultural (especially recreation) and supporting services.*
- *The evidence is that a large scale planting programme of 250,000 hectares of diverse woodlands in England could produce a social benefit cost return of at least 5 to 6:1.*
- *This return would be higher if the benefits of water quality and water catchment management were fully quantified and monetised.*
- *Based on the ecosystem services analysed, the appropriate amount of woodland creation may be lower than 250,000 ha. However, taking into account water regulating services, investment in more than 250,000 ha may be justified. Overall the economic evidence suggests a target for investment in woodland creation of between 100,000 and 300,000 ha. Further modelling could help to refine this target, and identification of the most suitable locations for woodland creation. Both of which could also learn from further experience of woodland creation. For comparison to other investments, a conservative target area of an estimated 150,000 ha of woodland creation is suggested.*

Investment: Creation of approximately 150,000 ha of woodland may be an appropriate target. Costs and benefits below relate to an area of 250,000 ha.	
Baseline: The woodland area is currently expanding in the UK by less than 3,000 ha per year. The Government has a shared objective with the sector for an average planting rate of 5,000 ha per year, to achieve 12% woodland cover by 2060.	
These costs and benefits relate to an investment in 250,000 ha of woodland:	
PV of costs: £108m	**PV of benefits:** £461m
Monetised costs: Opportunity costs of agricultural and timber profits	**Monetised benefits:** Recreation, carbon emissions, water quality, biodiversity.
Non-monetised impacts: Costs of maintaining recreational facilities. Landscape benefits.	
NPV: £354m. Benefit-Cost ratio: 5+	**Time period:** 50 years.
Key assumptions: Forests are owned and managed so that they operate as effective recreational locations. Figures are representative of actual costs and benefits, which are location dependent.	
Additionality: Creating 150,000 ha over 25 years requires 6,000 ha per yr, which is a significant increase over the current rate of woodland planting, and a change in emphasis to lowlands.	
Synergies/conflicts: Complement to investments in hedgerows, and synergy with other potential catchment actions.	
Impact on natural capital assets: Improve ecological communities and protect soil asset.	
Scale of impacts: This analysis models an England-wide programme, and uses a spatially explicit result for 250,000 ha of new woodland. The appropriate area of woodland creation is conservatively judged to be less than this, at 150,000 ha. New planting is mainly in lowland areas where recreational values highest.	

1. INTRODUCTION

This evidence base looks at the case for investing in woodland creation in England. It reviews scientific evidence on the impacts of woodland creation. An economic analysis of the costs and benefits of woodland creation is then presented, based on recent analysis of a hypothetical case of creating 250,000 ha of woodland in England. The key impacts identified in this analysis are summarised in the following value chain.

Figure 1: Woodlands Investment Case - value chain



2. SCIENCE EVIDENCE

This section reviews scientific evidence on woodlands, particularly in the context of understanding the impacts of increasing the area of woodland in England. It draws on the UK National Ecosystems Assessment (UKNEA, 2011) and UKNEA Follow On (UKNEAFO, 2014), various scientific papers and Defra reports on woodland management.

2.1. Ecosystem Services

The ecosystem services provided by woodland include the following, which are summarised in Table 2.1:

- Woodlands provide timber for construction materials and fuel, even though currently 80% of the UK's wood and wood product needs are met by imports (Quine at al. 2011). According to the UKNEA (2011) approx. 60% of the annual increment of coniferous forests is harvested for timber, and only 20% of Broadleaved woodlands. However, this is due in part to broadleaves tending to be in smaller more fragmented woodlands set within the landscape, where smaller scale harvesting would incur greater costs.
- Woodlands are a source of non-timber products including meat from culled deer and wild game.
- Woodlands have the capacity to sequester carbon to play a role in climate regulation. The average carbon content across non-organic forest soils in Great Britain is 288t CO_2 equivalent/ha, while on peaty soils and deep peats, carbon stocks of 160-700t CO_2 equivalent/ha are found depending on peat-layer depth (Quine et al, 2011). Coniferous forests can remove around 24 t CO_2/ha/yr from the atmosphere at peak growth, with a net long-term average for productive coniferous crops of around 14t CO_2/ha/yr (Jarvis *et al*. 2009). Rates of

around 15t CO_2/ha/yr have been measured in oak forests at peak growth, with a net long-term average likely to be around 7t CO_2/ha/yr.

- Trees can protect soil from erosion.
- Woodland and trees have an important role in water regulation, mitigating the impacts of extreme weather effects, and moderating the rate and quantity of through-flow.
- Woodlands are also important for regulating water quality through purification and detoxification, they can capture pollutants in the air (e.g. ammonia emissions in rural areas) and in soil and water.
- Cultural services provided by woodlands include recreation, and associated health benefits, aesthetic appeal and landscape value. Woodlands are one of the most valued components of the landscape (Norton et al, 2012).
- Woodlands are important for biodiversity. Long timescales are required to create ancient woodlands and they are associated with endemic and specialist plants and invertebrates. Even more recent woodlands provide habitats for woodland specialists. The heterogeneity of habitat structure within a woodland i.e. multi-layered canopy, woodland rides and glades is beneficial to birds, butterflies and many other species.
- The UKNEAFO work (2014) uses Simpsons bird diversity index as the only measure of biodiversity. This is a very useful measure when trading off different habitats as it can use specialist bird species for farmland and woodland as well as rarer species to estimate value changes. However, as other species such as plants and invertebrates are more localised and affected by small scale changes in habitat extent and quality, they are likely to produce different value patterns.

Table 2.1: Ecosystem services provided by woodlands

Provisioning services	Non-timber products such as meat (from culled deer), berries, honey, fungi, wild game
	Trees for timber and trees for bio/wood fuel
Regulating services	Local climate regulation- protection from extremes of temperature and strong winds
	Carbon sequestration
	Protection from soil erosion
	Protection from flooding
	Detoxification and purification of water
	Improvements to air quality, capture of atmospheric pollutants
Cultural services	Wild species diversity
	Recreation includes game shooting
	Landscape value
Supporting services	Soil formation, nutrient cycling, water cycling, oxygen production
	Biodiversity- many habitat specialists

2.2. Baseline (Current) Conditions of Woodland in England

The area of woodland in England was estimated to be 1,294,000ha in 2010[27] (Table 2.2). This is very similar to the Countryside Survey figure of 1,238,000 ha in 2007 where 981 000ha were broadleaved

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[27] Source: Forestry Commission's National Forest Inventory (NFI).

and mixed yew woodland and 257 000ha were coniferous woodland. Woodland is 9% of the land area of England, which is much lower than the EU average of 37% (FAO, 2005).

The extent of ancient and semi-natural woods in England is shown in Table 2.2 (Quine et al, 2011): ASNW (Ancient semi-natural woodland) includes both ancient and semi-natural, PAWS (Plantation on an Ancient woodland site is ancient but not semi-natural); OSNW (Other Semi-Natural Woodland) is semi-natural but not ancient. The ASNW is the most valuable woodland for biodiversity, but other woodland types can provide a range of ecosystem services.

Table 2.2: Extent of woodland in England ('000s ha)

	Area (100's ha) by Data Source*		
Woodland category	**NFI**	**CS**	**FC**
Broadleaved woodland	886	981	
Coniferous woodland		257	
ASNW (Ancient semi-natural woodland)			206
PAWS (plantation on Ancient woodland site)			135
OSNW (Other semi-natural woodland)			210
Total woodland	1,294	1,234	

*Sources: NFI = National Forest Inventory, CS = Countryside Survey, FC = Forestry Commission.

Woodlands are an important part of the network of areas protected for nature conservation. One quarter of SSSIs in England include broadleaved woodland (Quine et al, 2011). More than 90% of these SSSIs are in favourable or recovering condition. However this is less likely for non-SSSI woodland.

The most common tree species are Sitka spruce and Scots pine and for broadleaved trees; oak, ash and birch (FC and CS). There is some evidence that coniferous plantations are improving for biodiversity with distinctive assemblages (Quine and Humphrey 2010). New woodland planting totals given in Quine et al. in the three year period to 2009 are: 5,700ha coniferous trees and 11,600 ha broadleaved. Since 1991 broadleaved planting has been greater than coniferous. There is a 'generation gap' in English woodlands with no replacements for veteran trees at a less mature level. This will be exacerbated by current tree disease threats. There are also new types of woodland emerging, including agro-forestry, short rotation coppice and energy crops (Quine et al, 2011).

Defra recently commissioned a survey to fill knowledge gaps on private woodland owners; who they are and what motivates them (Quick et al., 2014). Woodlands are considered to be very important as a 'home for wildlife' (76%) and 'important for carbon storage' (39%) by a large proportion of owners/ managers. It was found that those who were not under FC grants and regulations and were not members of the National Farmers' Union (NFU) still carried out some management. Farm woodland is not actively managed for diverse benefits e.g. recreation. The survey results[28] indicate that farms over 250ha are more likely to plant woodland, whilst those who own a smaller area of land were more often 'very unlikely' to create woodland. There is lesser difference when

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[28] The comparison of one variable against another is unweighted, i.e. the comparison is only for the sample not for the national picture.

comparing farms in the 20-49ha range with those in the 100-249ha range. The survey found that farmers with woodland on their land are more than twice as likely to plant woodland. Targeting farms with existing woodland therefore seems logical.

Since 2000, populations of woodland birds have been fairly stable in the UK (JNCC, 2013) with increases in birds, such as goshawk (*Accipiter gentilis*) and crossbill (*Loxia curvirostra*), which are associated with large conifer forests. Within broadleaved woodland, various studies indicate reductions in vascular plant species richness and shifts towards more competitive species at different scales (Kirby *et al*. 2005; Keith *et al*. 2009; Carey *et al*. 2008). There have been some changes in the distribution of butterflies associated with changing management (decline of glade species e.g. high brown fritillary), climate change (northward range expansion by the speckled wood butterfly) and there are likely to be more localised changes in distribution in future associated with both changes in management and climate.

All of the woodland in the UK has been influenced by anthropogenic activity to some extent: for example, there is no primary woodland (NEA 2011). Pressures affecting the asset include:

- Pollution and atmospheric deposition, in the past couple of decades sulphur deposition had a significant effect through acidification. Currently eutrophication is a more significant driver of changes in British Woodlands (Corney et al 2004, 2006);
- Climate change has had some effect with faster tree growth and altered phenology (Quine et al) and will have greater impacts in the future (e.g. changes in water availability through drought/flooding, increased frequency of severe storms). It is likely that there will be considerable changes in woodland composition with expansion of species currently in England and introduction/dispersal of species better adapted to changing climatic conditions;
- Increases in wild herbivores have also had a significant effect on forest structure and composition. Overgrazing by wild or domestic animals leads to a reduced understory (Fuller and Gill 2001) and limited recruitment of canopy trees or alternatively a dense understory of unpalatable vegetation;
- Habitat fragmentation and isolation has increased, and
- A lack of appropriate management, invasive species, drainage or water quality issues.

2.3. Actions: create or improve woodlands

Management actions taken to improve the condition of existing woodland include to:

- Exclude livestock;
- Remove inappropriate species;
- Undertake planting;
- Protect trees from grazing damage; and
- Re-introduce a selective felling or coppicing cycle to restructure the habitat including replacement of coniferous trees by broadleaved.

Other management measures, such as maintaining rides and glades within the woodland by grazing or cutting, and rotational coppicing, can also be required for some woodland types.

Woodlands can also be created through planting, resulting in a change of land use type.

Both woodland improvement and creation of new woodland may be funded through Government schemes: Agri-environment schemes (e.g. Higher-level stewardship) focus on small woodlands as part of the farmed landscape. The Forestry Commission English woodland grant scheme funds management of larger woodlands, although currently the woodland management and creation grants are closed and other funding is focused on tree health issues.

Management of woodlands contributes to a range of policy objectives, including:

- International targets under the convention on biological diversity (CBD), to which the UK is a signatory, such as Aichi targets, Strategic Goal B. Target 7: By 2020, areas under agriculture, aquaculture and forestry are managed sustainably, ensuring conservation of biodiversity, and
- The UK's Forestry and Woodland policy statement (Defra 2013), which aims for two thirds of woodland to be in active management over the next five years rising to 80% if markets expand, and to achieve 12% woodland cover by 2060.
- The woodland area is currently expanding in the UK by less than 3,000 ha per year. The Government has a shared objective with the sector for an average planting rate of 5,000 ha per year, to achieve 12% woodland cover by 2060 (Defra, 2013).

2.4. Improvement Outcome

It is difficult to obtain data on the requisite timescales of recovery for woodlands. However, Broadbalk and Geescroft woods at (Rothamsted) were created on arable land and have been monitored for over 100 years (Harmer et al., 2001). They are currently mature mixed deciduous woodland (dominated by ash and sycamore). Their monitoring showed the following developments over time since their creation:

- Woody species colonised after 10 years (also found by Rebel and Franz in Germany);
- 20-30 years to complete canopy cover (Harmer et al., 2001);
- 20-40 years change in flora from light demanding to shade tolerant;
- pH Broadbalk changed from pH8 to pH 7, Geescroft pH 7 to pH 4.2 over 100 years, and
- Ground flora: many characteristic woodland plants still hadn't established after 100 years.

Other studies looking at the recovery of woodlands after logging found that:

- Even 50-80 years after the disturbance, tree species richness, diversity and abundance had still not recovered although many were on a recovery trajectory (Moola and Vasseur 2004, Duffy and Meier 1992);
- The same was true for ground beetle species composition and abundance after 27 years (Niemela et al. 1993) and ant species composition after 100 years (Palladini et al 2007);
- Nitrogen cycling had only just returned to pre-disturbance levels after 75 years (McLauchlan 2007);
- A number of soil parameters (Soil c, N, P, nitrification, infiltration) had not recovered 50 years (Harden and Matthews 2000) and 120 years (Compton and Boone 2000) after cultivation and abandonment;
- Flinn and Marks (2005) found that the pH and nutrients were slightly higher on woodland on restored agricultural sites than nearby uncleared sites after 80-100 years, but that the variation was not as high as with other uncleared woodland sites in alternate locations, and
- Soil compaction from machine logging at a forest in Belgium had not recovered after seven years (Rohand et al 2003).

However, it should be noted that in England, the long history of woodland management means the context of recovery from logging is to a woodland's previously managed state.

Evidence on the changes in goods and services provided, and/or resilience, as a result of creating woodlands, includes:

- New forests increase carbon storage, with faster growing species and better quality sites allowing trees to grow faster and fix more carbon more quickly;
- Afforestation of upland peat that is in good condition can result in loss of carbon stores. However, if afforestation occurs on peatlands that are degraded by grazing at high stocking densities, this may reduce the rate of carbon loss (Bateman et al. 2014);
- Restoration of woodland as part of a catchment/floodplain would help regulate water quantity and provide biodiversity habitat. There is some evidence that trees improve water infiltration. In a research project in the Pontbren catchment (Bird et al 2003, Marshall et al. 2009, 2013) it was found that mean water infiltration rates were much higher in areas planted with trees compared to the open grazed pastures. After five years, soil infiltration rates were 6-7 times greater in plots planted with trees. Comparing plantations 2, 5 and 7 years after planting found that older ones had higher infiltration than younger ones (2, 5, 7 years compared). Soil compaction followed a similar pattern with lower soil compaction in wooded areas. This study demonstrates the potential role of rural land use management in flood risk mitigation;
- Increases in extent and change in condition of woodlands should be beneficial for biodiversity of woodland specialists. The UKNEAFO (2014) work demonstrates that there may be some tradeoffs between farmland and woodland birds if woodland planting is on agricultural land, this may be reflected in increased reductions in red data book species if more of these are farmland birds. The timescale of recovery of woodlands (see below) can be decades and may not result in restoration to species and communities equivalent to undisturbed ancient woodland. Restoration can be speeded up or the chances of success can be increased if it takes place on habitats where ancient woodland indicators are still present (e.g. PAWS scheme) or if connectivity is high and there is potential for dispersal of woodland species;
- Currently the UKNEAFO work does not explicitly consider the formation of ecological networks and connectivity (Lawton et al, 2014). These should be incorporated into new planting which should not just consist of areas of woodland, but linear networks (hedgerows, lines of trees) and individual tree planting (for further discussion see ‘Hedgerows’ and ‘Integrated Catchment Management’ Sections of this document;
- The UKNEAFO identifies woodlands as a major source of recreational services, but their value is maximised if they are accessible and near areas with high population densities. However, the enhancement of access facilities in more remote woodlands (such as the creation of forest parks with facilities for specialist activities, e.g. Grizedale in Cumbria, Coed y brenin in Wales) can provide a tourist facility attracting people from quite large distances; and
- Woodland thinning improves forest condition for aesthetics and biodiversity. Introduction of a coppice regime can bring other cultural benefits associated with this traditional practice, as well as generate wood for future or as fibre.

Re-creation of woodland ecosystems depends upon dispersal of relevant species, including from available parent trees. For example, creation of woodland on arable fields, if not adjacent or connected somehow to existing woodland, will be difficult for dispersal of shade tolerant species. It is likely to be more successful on lower fertility soils. Rebel and Franz (REF) found that there were twice as many woodland species on low or medium fertility sites than on high fertility ones, and woody colonisation was also much slower on the resource rich sites probably because the fertility favoured perennial colonisation which inhibited colonisation by woody species.

Finally it should be noted that there can be conflicts between provision of different ecosystem services from woodland. Improving woodland for biodiversity/recreation/cultural aesthetic may conflict with timber production. Large scale timber production with clear felling has clear conflicts with recreation and diversity, and possibly water regulating services. Within larger sites, these activities can co-exist without conflicts, but possibilities for conflict are greater in smaller sites. Increasing broadleaved woodland planting can enable the use of traditional methods (e.g. coppicing) that support a range of ecosystem services, although timber harvests will be reduced.

3. ECONOMIC EVIDENCE

3.1. Approach Taken

The approach taken in this investment case was to draw on the existing extensive work recently carried out as part of the UK National Ecosystems Assessment Follow On (UKNEAFO), work package Report 3: Economic Value of Ecosystem Services[29]. This study has been selected as it is recent, England-scale and reasonably comprehensive in terms of the key ecosystem services and analyses a relevant investment scenario. It is therefore preferred over aggregating results from several smaller studies.

This work, led by Professor Ian Bateman, developed a tool called The Integrated model (TIM) to combine natural science and economic evidence to create a decision-making tool for assessing investment in additional areas of woodlands in England, Scotland and Wales. Bateman et al assess the impact of different planting strategies upon:

- Market values
  - Agricultural profits
  - Timber profits
- Non-market values
  - Agricultural land use change impacts on a range of greenhouse gases (CO_2, N_20, CH_4)
  - Forest impact on the same greenhouse gases
  - Recreation value
  - Biodiversity (proxied by bird species)
  - Water quality (concentrations of N and P)

The analysis also provides monetary estimates of all the above impacts with the exception of water quality and biodiversity. These were not monetised due to a lack of available robust economic value estimate for the kind of change analysed. The authors speculate that, while this deficiency might reasonably be addressed in the case of water quality, they were not as certain about the likelihood of robustly estimating the non-use value of biodiversity. Given this, both are assessed by placing constraints on the analysis which reject any scenario leading to a decline in water quality or biodiversity in any given area (thereby allowing the costs of such constraints to be estimated).

Other factors which might enter an ecosystem services assessment approach such as landscape change or flooding are not assessed in the analysis.

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[29] Bateman, I., Day, B., Agarwala, M., Bacon, P., Bad'ura, T., Binner, A., De-Gol, A., Ditchburn, B., Dugdale, S., Emmett, B., Ferrini,S., Carlo Fezzi, C., Harwood, A., Hillier, J., Hiscock, K., Hulme, M., Jackson, B., Lovett, A., Mackie, E., Matthews, R., Sen, A., Siriwardena, G., Smith, P., Snowdon, P., Sünnenberg, G., Vetter, S., & Vinjili, S. (2014) UK National Ecosystem Assessment Follow-on. Work Package Report 3: Economic value of ecosystem services. UNEP-WCMC, LWEC, UK [*Bateman et al, 2014*]

Discounted values are estimated for the policy objective of planting 250,000 ha of new woodland separately in England, Scotland and Wales over a 50 year time horizon (or an assumed 5,000 hectares of new woodland per annum for in each country each year between 2014 and 2063). The TIM model considers all feasible permutations regarding the location of this planting. For each permutation, an assessment is made of the market, non-market and cumulative social values generated. By considering all permutations, the optimal planting strategy is identified.

3.2. The main results from the work

Key results that inform a strategy for tree planting based on social welfare considerations, as defined in Bateman et al (2014) (planting based on maximising overall market and non-market benefits subject to the constraints set out above) are:

- There is a very major difference between market value and overall social value (typically market values were negatively correlated with non-market values);
- The market (opportunity) cost of planting per hectare on average varies relatively modestly between the three countries - reflecting the different use of agricultural land taken by forestry. However, within country variations in opportunity costs were very high, showing the key importance of selecting the optimal locations of new woodlands;
- If non-market values are ignored in the planting decision, then woodlands are located to areas of very low agricultural value. However, these locations are typically remote from populations and yield negligible recreation values. Furthermore, these locations include ecologically fragile peat moorlands where planting emits more carbon than is stored;
- Including non-market values moves the optimal locations off peatlands, resulting in net reductions in greenhouse gas emissions from land-use. This approach also locates some woodlands near to high population areas generating very significant gains in recreation values;
- Excluding non-market values, the economic case for increasing woodlands in England is weak. However, inclusion of non-market values strongly supports proposals to extend British woodlands;
- The ratio of the non-market benefits to the market (negative) value is another way of expressing the benefit cost ratio[30]. **For this level of planting (and even using the lowest carbon price) the overall BCR comes out at around 3. However it varies widely from just 1.2 in Wales to over 5 in England**;
- Controversy regarding the value of abating greenhouse gas emissions is captured through sensitivity analysis. Not surprisingly, these show that changing the value of a tonne of CO_2 emissions substantially varies analysis results. Similarly the BCRs are sensitive to the assumed price of carbon and improve at a higher carbon price (the greatest proportional improvement in Wales and then Scotland as the social benefits are more reliant on carbon savings here). With the higher carbon price the **BCR for planting in England rises to 5.8**.

These results are reflected in Table 3.1 below.

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[30] The cost to society is the opportunity cost of the land used (its agricultural value) plus the costs of planting and managing less the timber profits. These values are negative and could alternatively be thought of as the potential costs to the public purse of pursuing a woodland planting strategy. This is only a proxy for the BCR, but a reasonable approximation

Table 3.1: Annuity values - difference between the business as usual baseline (2013 values) and a scenario that maximises social values (planting Pedunculate Oak and lowest carbon price - max SV POK C1)

Market values £ms	GB £ms	England £ms	Scotland £ms	Wales £ms
Agricultural profits	-£226.3	-£87.1	-£62.7	-£76.5
Timber profits	-£61.0	-£20.5	-£20.3	-£20.3
Total Market Value	**-£287.4**	**-£107.6**	**-£83.0**	**-£96.8**
Agricultural carbon reduction savings	£12.0	£3.1	£3.5	£5.4
Forest carbon sequestration benefits	£8.8	£3.1	£2.7	£3.0
Recreation benefits	£755.8	£543.4	£121.4	£91.0
Single Payment Scheme (transfer to farmers)	**£56.9**	**£19.3**	**£18.9**	**£18.7**
Total Non-Market Value	£833.4	£568.9	£146.5	£118.0
Total Social Value	**£546.0**	**£461.2**	**£63.5**	**£21.3**
Total average value per hectare planted £s	£s/hectare	£s/hectare	£s/hectare	£s/hectare
All market value £/hectare	**-£383**	**-£430**	**-£332**	**-£387**
All non-market value £/hectare	**£1,111**	**£2,275**	**£586**	**£472**
Total social value £/hectare	**£728**	**£1,845**	**£254**	**£85**
Ratio non-market to social value	153%	123%	231%	555%
Ratio non-market to market value	290%	529%	177%	122%
Implied benefit cost ratio	**2.9**	**5.3**	**1.8**	**1.2**
*Benefit cost ratio at higher price of carbon**	*3.3*	*5.8*	*2.3*	*2.2*

Source: Table 3.37 in NEAFO Work Package 3

Notes: no (monetary) valuation of impacts on biodiversity or landscape or water; based on lowest carbon price modelled. * drawn from Table 3.38 in NAEFO Work Package 3. Agricultural profits reflect the land value in its current use (which could range of arable, to pastoral to upland peatlands with very low value)

3.3. The issues raised by the work

The best social return comes from planting on locations that are:

- Accessible to large urban populations, in order to maximise recreational benefits (given that woodlands are assumed to be accessible);
- On soil types that would otherwise tend to be used for relatively high carbon producing agriculture, and
- For the scale of planting envisioned in this analysis, an examination of the data suggests that the GHG emissions savings are not in themselves sufficient to offset the costs of the intervention (at the carbon price used in the analysis). So whilst the GHG savings are a benefit, the recreation benefits are needed in order to justify the investment. However, at lower levels of afforestation, appropriately targeted to high value locations, either GHG of recreation values are sufficient to justify planting.

The work assumes that forests are owned and managed so that they operate as effective recreational locations. It therefore also assumes that there is public access to the new woodlands planted. Therefore there might be some additional minor ongoing management costs on maintaining facilities required to ensure visitor benefits[31]. These costs could impact on the overall BCRs although this change would be minor.

The work does not consider the **biodiversity impact on species other than birds and on vegetation**. This would tend to impact on the detailed site level planting strategies, for instance in: (1) the consideration of the creation of corridors for ecological connectivity; (2) resilience to climate change[32]; and (3) ensuring that protected species on the land to be planted were not adversely affected. Resilience in terms of plant species diversity (canopy and ground flora) in relation to tree disease and the loss of key canopy species should also be considered.

There is no valuation of **landscape impacts**: these could potentially go in different directions and depend on the location of woodlands and species planted. Other work has in some cases placed these at around 1/3rd of total recreation value[33].

As noted, there is no economic valuation of impacts on water quality. However the quantification suggests this impact is always positive compared to the BAU scenario and the benefits are greater with strategies aimed to maximise social (essentially recreational) value.

There is potentially a further interaction (and overlap) between strategies for planting woodlands and the impact on catchment/flood management and associated ecosystem services. This will be considered in the catchment investment case. This could provide a significant synergy between investments in catchments and woodland planting and, potentially, further improve the BCRs. However, including this impact in decision-making might lead to a different optimal planting location strategy and might conflict with maximising the recreation benefits of forestry.

3.4. Conclusions

The key points are:

- There is clearly a strong overall social cost-beneficial case for substantial woodland planting, especially in England. The Benefit Cost Ratios (BCRs) for the level of planting modelled in the UKNEAFO, of 250,000 hectares in England are strongly positive, based on the recreation benefits and the carbon saving benefits. It is unlikely that taking other factors into account would substantially reduce these BCRs. Indeed they might be increased once ecosystem services such as the value of improvements in water quality and flood management are added.
- The appropriate amount of woodland creation may be lower than 250,000 ha. However, taking into account water regulating services, investment in more than 250,000 ha may be justified. Overall the economic evidence suggests a target for investment in woodland creation of

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[31] The costs of further facilities to enhance visitor benefits could of course increase recreation benefits

[32] 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.J., Tew, T.E., Varley, J., & Wynne, G.R. (2010) Making Space for Nature: a Review of England's Wildlife Sites and Ecological Network. London: Department for Environment, Food and Rural Affairs. http://archive.defra.gov.uk/environment/biodiversity/documents/201009space-for-nature.pdf

[33] eftec (2010), Initial Assessment of the Costs and Benefits of the National Forest, for Defra and The National Forest Company, final report, July 2010

between 100,000 and 300,000 ha. Further modelling could help to refine this target, and identification of the most suitable locations for woodland creation. Both of which could also learn from further experience of woodland creation. For comparison to other investments, a conservative target area of an estimated 150,000 ha of woodland creation is used.

- The work shows the results for a variety of planting strategies, all with the same overall level of planting and similar opportunity cost. The work is therefore not clear whether the average return is higher or lower than the marginal return for planting at these levels. However, marginal values can be expected to be higher for lower levels of planting (as woodland is planted in locations that add most value to recreation benefits and have the lowest opportunity cost in agricultural terms).
- Clearly the whole idea of an average return from planting is challenging as it is so location specific, so deciding on the optimal scaling up level/strategy is problematic. The TIM model solves this problem by allowing the analyst to identify those areas with the highest values. A useful extension of this work would be to undertake the analysis and, potentially, explore the relationship between average and marginal social returns from planting strategies as they scale up.

An important issue is the practicality of the potential scale of woodland planting modelled in the UKNEAFO work. It would require a suitable funding regime to compensate/encourage landowners and a willingness to invest in and then manage new woodland, for which an important role would be public benefit and so associated public access. Recent research for Defra by Quick et al (2014)[34] on woodland management indicates that there would be a willingness to plant new or extra woodland by a sizeable minority of existing woodland owners (40%) and land owners with no woodland (18%)[35].

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[34] Quick, T., Smith, S., Johnson, M., Eves, C., Langley, E., Jenner, M., Richardson, W., Glynn, M., Anable, J., Crabtree, B., White, C., Black, J., MacDonald, C., and Slee, B. (2014). Analysis of the potential effects of various influences and interventions on woodland management and creation decisions, using a segmentation model to categorise sub-groups - Volume 1: Summary for Policy-Makers. Defra [draft report]

[35] See Figure 12 in Quick et al 2014, op cit

4. CASE STUDIES

4.1. The National Forest

In 2010 eftec[36] completed a study of the actual and forecast costs and benefit of creation of The National Forest in central England. This forecast that:

- The total costs of all investment associated with bringing land into forest management would be around £190m in 2010 present value terms over the period 1991 to 2011;
- Total social benefits were estimated at around £900m or a BCR of 4.8 to 1 (this is in the same order of magnitude as the BCR from the NEAFO work for forestry planting in England), and
- As with the NEAFO work the main benefits are recreation and carbon savings which between them account for over 80% of all benefits. The economic value of timber production is relatively small in the case of the National Forest (in part because the main purpose of the creation of the National Forest.

These findings are summarised in the results in Table 4.1, below.

Table 4.1: Estimated monetised benefits from creation of The National Forest

	Time period			
	1991 to 2010	2011 to 2100	1991 to 2100	
Element of benefit	**£ms PV**	**£ms PV**	**£ms PV**	**Share of total**
Timber	1	9	10	1.1%
Recreation	186	375	561	62.5%
Carbon	9	177	187	20.8%
Landscape	4	47	51	5.7%
Biodiversity	4	47	50	5.6%
Regeneration	24	16	39	4.3%
Total	228	671	898	100.0%
Total costs	80	99	188	
BCR	2.9	6.8	4.8	

4.2. The Mersey Forest

In 2009 Regeneris Consulting carried out an assessment for the Mersey Forest of the societal value of the past investment in the creation of new community woodland in the Merseyside area[37]. The research looked at the impacts of past investment in new woodland creation and in improved woodland management to increase recreational access. The investment had supported the creation of 264 hectares of new woodland and the management of 357 hectares of woodland. The sites were all located by or very close to urban areas, often including particularly deprived communities.

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[36] eftec (2010) op cit

[37] Regeneris Consulting, 2009, The Economic Contribution of The Mersey Forest's Objective One-Funded Investments, for the Mersey Forest

The assessment, based on a benefits transfer approach and after taking account of displacement[38] effects, concluded that the BCR for the investment was positive. Every £1 invested in the Programme was estimated to generate over the lifetime of the investment:

- £2.3 in increased GVA;
- £3.0 in increased GVA and social cost savings, and
- £10.2 in increased GVA, social cost savings and other non-market well-being benefits.

The majority of benefits were impacts on quality of life from improve landscape and form recreation and tourism benefits, as shown in Table 4.2.

Table 4.2: Estimated net monetised benefits from extra woodland planting by the Mersey Forest funded by ERDF, 2009

Source of Benefit	£ms PV	%
Carbon Sequestration	£1.4	2.0%
Biodiversity	£1.4	1.9%
Products from the land	£6.0	8.4%
Quality of Place - landscape (from home)	£15.0	21.2%
Quality of Place - landscape (while travelling)	£19.2	27.1%
Recreation	£14.8	20.8%
Tourism	£9.2	13.0%
Health benefits	£3.9	5.5%
Total Monetised Benefit	£70.8	100.0%

Source: Table 5.1, Regeneris (2009)

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[38] At the level of Merseyside not the UK

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LOWLAND FARMLAND EVIDENCE BASE

SUMMARY

This evidence base examines measures that could be taken to enhance natural capital within the lowland farmed environment in England. Given the extent of lowland farming (approximately two thirds of England), better management of natural capital in these areas can have significant impacts on the delivery of ecosystem services nationally.

A large number of different measures to protect and improve natural capital can be identified across farmland areas with different characteristics. There is also a range of economic information on the costs and benefits of such measures. However, this information is varied typically relating to different types and/or scales of measures in different circumstances. Thus generalizable information on the costs and benefits of a specific set of actions, that can be used to analyse a scalable investment case is not available.

This evidence base looks in detail at three specific examples of natural capital management: pollinator strips on field margins, re-establishment and maintenance of hedgerows, and improvement in the condition of low-input improved grassland. These measures are described further below. They are examples of measures that can potentially be taken on a widespread basis, across the arable and livestock systems than cover the majority of lowland England.

This evidence base describes some of the site-level evidence on the ecosystem services these measures can enhance, but their cumulative effects on farmland natural capital are poorly understood, for both:

- The amount and value of ecosystem service enhancement across the landscape. Impacts and values are context and location specific. For example, biodiversity benefits rely on habitat provision, but also habitat connectivity. Water regulating services are dependent on the habitat context within a farm, and also the location of a farm in a catchment.
- The potential costs of actions can be identified from current agri-environment payment rates. However, these rates do not vary to take account of local opportunity costs. Demonstration farms have shown that measures that enhance natural capital can be incorporated into commercial farming systems without compromising profitability. Therefore, current agri-environment rates are only a guide to the future costs of these measures.

The key impacts and assumptions in the three measures to enhance natural capital that are examined in detail in this evidence base are as follows. Evidence is described in more detail, including references to sources, in the evidence base chapters:

Grassland

- Approximately 1/3rd of England is covered by Improved (22%) and Neutral (11%) grasslands. Reduced stock density and fertiliser input, and use of more diverse seed mix, can change improved low-input grassland to legume and herb rich swards (neutral grassland), resulting in benefits to biodiversity including pollinators.
- This intervention has been formulated to be appropriate to existing grassland, assuming that current levels of soil compaction are reversible. In this case, this results in improvements to water regulation services, and improved quality of forage.

- Costs to the farm business are estimated at £120-460 per ha, but do not allow for benefits of improved forage.

Hedgerows

- There are an estimated 402,000km of hedgerows and 154,000km of tree/hedge lines not managed as hedgerows in England. For a substantial proportion of these latter features, gapping-up and rejuvenation to bring trees back into a hedge management cycle alongside maintenance of adjacent grass margins allows improvement of hedgerow condition and associated ecosystem services
- Benefits to biodiversity including pollinators, better regulation of water runoff and soil erosion, pest control in arable crops, and improved landscape.
- Improving up to 154,000 km of former hedge lines into hedgerows costs approx. £7,000 per km.
- A further threat to English hedgerows is that 20% of trees within them are estimated to be Ash, and so vulnerable to current Ash die-back disease. For hedges losing ash trees, rejuvenation and gapping up with appropriate hedgerow species will help to address losses in hedgerow extent and condition.

Pollinator Strips

- Populations of many wild pollinators are declining. Approximately 30% of England is covered by Arable and Horticultural land, and so creating pollinator strips on field margins can significantly increase biodiversity, including of vulnerable wild pollinator populations, retaining their option value for future crop production changes.
- Further benefits include pest control in crops, and possible water and carbon regulation services. These benefits depend on the location of pollinator strips in relation to topography and surrounding habitats.
- Agri-environment payments for field margins are £485 per ha, such measures have been used in some commercial demonstration farms without compromising profitability.
- There is some uncertainty over the longevity of the beneficial impacts of pollinator strips based on; the species sown, seed provenance and whether strips have a permanent location within fields

Economic impacts of farmland natural capital measures

There is some economic evidence related to the costs and benefits of the three measures above. Both are substantial, with estimated present value (PV) costs over 50 years of £5.6bn for grasslands, up to £1bn for hedgerows, and £2.4bn for pollinator strips. The benefits from these measures would be a substantial part of the overall benefits expected from agri-environment measures, of which they are a part, which have an estimated PV of £12bn. These costs and benefits are not for the same sets of actions so cannot be directly compared, but appear to be of a similar order of magnitude.

In addition to this evidence relating to the three specific measures examined, there is also economic evidence available from the recent appraisal of Common Agricultural Policy (CAP) spending options. The Rural Development Programme for England (RDPE) is the mechanism through which the CAP's Pillar 2 funds are distributed. Evidence on outcomes associated with RDPE has been used to estimate the benefits associated with transferring funds from support for agricultural production (known as Pillar 1) into measures that target environment outcomes (known as Pillar 2). Defra (2013a) looked at increasing spending to Pillar 2 from Pillar 1 by £670m during the 2014 – 2019 budget period (2011 prices). The present value (PV) of the benefits, net of the cost of delivering and administering the RDPE programmes, were £1,410m – £1,510m. The costs of this transfer are a small reduction in agricultural production, which has an estimated PV of approximately £100m. This analysis suggests that transfer of spending to Pillar 2 has a benefit:cost ratio of over 10.

Scale of benefits

The three management measures can be undertaken on a widespread basis across lowland farmland in England. The majority of the benefits from them arise at a local level (e.g. pollination, landscape, water regulation), and therefore are not expected to diminish with scale. Benefits to biodiversity would be expected to have some diminishing returns, for example as scare species become more widespread, the marginal non-use value of further improving their populations would be expected to fall. The Defra (2013a) analysis does not take these issues into account, but implicitly assumes that Pillar 2 spending offers constant returns to scale.

Additionality

It is recognised that the three management measures proposed are already undertaken on many farms. However, the extent proposed here goes beyond what is currently undertaken, or what could be undertaken with existing policies and funding. For example, the New Environmental Stewardship scheme includes proposed grass, legume and forb seed mixtures, and agri-environment schemes already fund field-margin measures. However, it is highly likely that funds will be insufficient to support more widespread adoption of these measures.

Agri-environment schemes are estimated to have funded protection and/or improvement of 40,000 km of hedges in the last two decades. Even allowing for voluntary good management of hedgerows by farmers, there is likely to be scope for widespread and additional investment in significant further lengths of hedgerows. Therefore, for all three management measures, significant additional actions and benefits are possible.

Synergies

There are significant potential synergies between the three management measures discussed, and between them and other investment cases. For example, all three measures can make a significant contribution to catchment management (see 'Integrated Catchment Management: Evidence Base' Section of this document for further analysis). Hedgerow and other habitat (e.g. wetland) investments have a synergy with pollination, in the provision of both nesting and feeding sites for pollinating insects and the wider food chain. They can also increase connectivity of bio-diverse habitats, for example hedgerow improvements can contribute to the connectivity, and therefore the biodiversity benefits, of woodland investment.

1. INTRODUCTION

Lowland farming occupies a substantial area of England, with Arable and Horticultural land occupying 30%, Improved Grassland 22% and Neutral Grassland 11% (the larger proportion of which will be farmland) (Countryside Survey (CS), 2007). Thus management of natural capital on lowland farms can have significant national impacts on the delivery of ecosystem services (ES).

Farms are small business management units that are dominated by one ES: food production. However, as described in the UKNEA (2011), lowland farmland provides a wide range of ES, and these often feature in farm business decisions, alongside food production. Provision of ES other than food can be motivated by a range of factors. Within a farm business, effective management of ES can help ensure long-term sustainability and productivity of farmland. Incentives are provided by agri-environment scheme payments, or other payments (e.g. payment for ecosystem services (PES) arrangements from private water companies). Individual farmers can also have other motivations, such as stewardship of the environment and/or a desire to maintain traditional activities. Managing ecosystem services from lowland farmland remains an ongoing subject of research. For example, Firbank et al. (2013) review the delivery of ecosystem services from enclosed farmland in the UK, and explore how the expected demands for ecosystem services might be met in the future.

A large number of different activities to protect and improve natural capital can be identified across a farm and across farmland areas with different characteristics. However, they will do so in a variety of ways and over different time and spatial scales. Given the typical duration of many agri-environment options of 5 – 10 years, they may only prevent short-term declines in, or achieve temporary improvement of, natural capital.

Natural capital protection and improvement on farms may cover a wide range of activities, including:

- Hedge rejuvenation and restoration;
- Reintroducing legume and herb-rich swards (either for grazing or as an arable ley);
- Establishment of nectar and pollen strips;
- Set-aside land;
- Sediment ponds/ditch/drainage management, and
- A wide range of options incentivised by agri-environment schemes, including measures for birds, insects and other species, hedgerow and field margin management, soil and water management and other measures[39].

These activities may have important synergies, working together to provide greater value than the sum of their parts (this is discussed further in Section 6.3 and in the catchment management

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[39] Measures include: **birds**: skylark plots, over-wintered stubble, uncropped cultivated areas for ground-nesting bird, wild birds seed mixture; **foraging habitats for insects and other species**: nectar flower mixtures, cereal headlands, uncropped cultivated margins for rare plants, undersown cereals; **for water voles, dragonflies, newts and toads**: ditch management, buffers for in-field ponds, 2m, 4m, 6m and 12m buffer strips on cultivated land; **hedgerow and field margins**: hedgerow tree establishment, buffer strips for hedgerow trees, supplement to add wildflowers to buffer strips and field corners, management of field corners, nectar flower mixture, beetle banks; **other**: winter cover crops, earth bank restoration, woodland livestock exclusion. All of these options have an income foregone costs associated with them under agri-environment prescriptions.

evidence base). They also often work in combination with built capital (fences, buildings and walls) to maximise ES delivery.

Within the scope of this analysis, it is only possible to focus on a small subset of the many possible investments in natural capital management activities within lowland farmland.

1.1. Selection of Lowland Farmland Natural Capital Investments for Analysis

The condition of farmland habitats relates to their long term productive capacity for food, and their impacts on the delivery of other ES. Some of these impacts are reflected in the NCC's risk register in SoNC II (NCC, 2014), which was a high-level assessment of risks across broad habitats and therefore cannot reflect all the trends in ES for specific farmland habitat types. The provision of biodiversity from enclosed farmland and grassland was identified in the NCC's risk register in SoNC II as a service at very high risk, clean water from enclosed farmland was also identified as at high risk. Both of these assessments had high confidence.

More specifically for lowland farmland, measures of potential biodiversity service delivery (numbers of bird and butterfly food plants) across farmed habitats showed significant declines across the period 1978 to 2007, although for Arable and Horticultural land there were increases between 1998 and 2007 (CS, 2007). Farmland biodiversity declines have been driven by intensification of food production, supported by supplies of agro-chemical inputs (fertilisers and nutrients) and changes in agricultural technologies. Decreases in the lengths of hedges and increases in the lengths of lines of trees and shrubs between 1984 and 2007 indicate declines in hedge management (CS, 2007).

The impacts of farm practices on water quality are covered in the 'catchment' evidence case, key issues resulting in water pollution are: soil compaction, field applications (fertiliser, pesticides, slurry and manure), boundary management and stock management adjacent to water bodies. Significant declines in soil carbon concentration in Arable and Horticultural habitats and non-significant declines across all habitats between 1998 and 2007 indicate a negative impact of farm practices on soil quality. Soil carbon is an important indicator of soil quality because of its role in nutrient and water retention as well as improving soil physical properties.

The following analysis focuses on lowland farmland natural capital assets which have declined over recent decades, in particular biodiversity. However, in assessing the impacts of potential protection and improvement actions, a wide range of ES are considered.

Even looking with this narrower scope of protecting and improving biodiversity ES from lowland farmland there are a wide range of potential actions to be considered. The review by Dicks et al. (2013) provides a summary of evidence for a whole range of restoration actions which can be taken specifically to enhance wildlife conservation on farms. Table 1.1 summarises this evidence further, listing the beneficial effects of interventions on biodiversity and the ES which they are likely to impact on. For many options, evidence of success is mixed, and this variability is understood to be related, in part, to previous land management, spatial context, climatic and soil differences as well as local species pools and management of adjacent land. Where evidence is too complex to summarise the reader is referred to the source document.

In Table 1.1, interventions that are more promising from the perspective of this study are shaded grey. These interventions are scalable and deliver benefits across a range of ES. Interventions may not be scalable for different reasons, including; unwillingness of farmers to take up the measure (e.g. skylark plots), too great a conflict with food production (e.g. set-aside) or the extent of the habitat (e.g. species rich grassland).

Table 1.1: Potential Interventions to Restore Lowland Farmland Biodiversity

Intervention	Evidence	Ecosystem services	Representative of large scale actions?
Set-aside on arable land	20 of 37 studies showed benefits for all wildlife groups considered, 13 showed mixed effects of set-aside over cropped land, 4 showed no effects and 1 showed negative impacts.	Biodiversity, may also provide food for pollinators, and predators of crop pests; lack of applications may lead to positive impacts on water quality over productive land	Yes. Set-aside was compulsory for large arable farmers between 1992 and 2008.
Connecting patches of semi-natural habitats	Townsend & Levey (2005) showed that connecting habitat patches enhanced pollen transfer.	Pollination services	Yes.
Hedge management – including laying/coppicing and gapping-up	Mixed, but 10 of 15 studies showed beneficial effects of managing hedgerows for wildlife. 5 studies showed management did not affect plant species richness, numbers of bumblebee queens or farmland birds	Biodiversity, plus a wide range of other ES offered by hedgerows (see Evidence case)	Yes
Hedge planting	4 studies only, but all positive		
Ditch management	5 of 8 studies found positive effects. 3 studies showed that ditch management had negative or no clear effects on farmland bird species or plants.	Biodiversity – dredging actions may also help flood mitigation and clean water provision.	Yes, in areas with extensive ditch network
Wild bird seed cover	21 of 30 studies showed positive effects, 9 studies showed mixed or no effects of wild bird food cover compared to other farmland habitats	Biodiversity May also provide food for pollinators, and predators of crop pests, protect boundary features from spray and field applications. May also enhance water ES dependent on location through providing a buffer strip function (absorbing water and nutrients)	Yes.
Plant nectar flower mixture/wildflower strips	64 of 80 studies show benefits for one or more species group (for full details see Table Source).		
Create uncultivated margins	24 of 39 studies showed benefits		
Plant grass buffer	34 studies showed		

Intervention	Evidence	Ecosystem services	Representative of large scale actions?
strips/margins around arable/ pasture fields Buffer strips along water courses	positive effects of grass buffer strips on biodiversity, 6 studies showed no positive effects. 6 of 6 studies showed positive effects of buffer strips on biodiversity		
Undersow crops with clover	11 of 16 studies showed beneficial effects of undersowing on biodiversity (for full details see Table Source).	Biodiversity. Undersowing may also benefit pollinators and will enhance soil N and soil carbon/structure if incorporated	Yes.
Create beetle banks	14 reports from 8 studies found that beetle banks provide benefits to farmland biodiversity. 5 studies found lower or no difference in invertebrate densities or numbers on beetle banks relative to other habitats.	Biodiversity, may also provide food for pollinators, and predators of crop pests. May also enhance water ES dependent on location through providing a buffer strip function (absorbing water and nutrients)	Yes.
Reduced tillage	32 of 41 studies showed that reduced tillage had positive impacts on some measures of biodiversity, 26 (including some of those above) showed negative or no consistent effects on measures of biodiversity.	Biodiversity, may also impact on soil nutrients and water quality.	Yes.
Skylark plots	All 8 studies showed that undrilled in-field plots were beneficial for biodiversity	Biodiversity, pollinators, crop pest predators	Possibly, but faces cultural barrier - has not proved popular with farmers
Intercropping	3 of 3 studies and a review on effects on ground beetles showed beneficial effects for biodiversity	May also benefit soil nutrients	Yes, though may result in complex harvesting
Maintaining species rich grassland	14 of 22 studies identified management regimes that maintained species rich grassland (for full details see Table Source).	May also benefit soil carbon, pollinators and water quality and quantity (where grazing and inputs are reduced)	No. Species rich grassland is uncommon.
Creating species rich grassland	20 of 28 studies showed positive	Biodiversity, may also soil Carbon, pollinators	No. Low productivity of such grassland and

	effects on biodiversity. 7 studies showed no clear effects of restoration on biodiversity. Restoration techniques included grazing, introducing plant species and mowing. Time taken <5- 60 years.	and water quality and quantity (where grazing and inputs are reduced)	high initial costs for creation make this unattractive to food producers, except potentially on marginal land and where it can attract significant support.
Management changes on permanent grassland	The majority of studies showed positive effects of reducing pesticide and fertilizer use and delaying mowing dates, (for full details see Table Source).	Biodiversity, may also impact on pollinators and water quality.	Yes, but problem due to negative impacts on production of animals
Delaying first grazing/mowing date	8 of 14 studies showed beneficial effects on biodiversity. Six studies found no clear effects.	Biodiversity, may also impact on pollinators.	
Reduce grazing intensity on permanent grassland	15 of 27 studies had only positive impacts on biodiversity, a further 9 had mixed impacts and 3 showed no benefits.	Biodiversity, may also impact on pollinators water quality and water quantity.	
Raising water levels in ditches or grassland	Varied results dependent on management	Biodiversity - Positive for species favouring wet conditions.	No. Only appropriate on flood plains.

Source: Data summarised from Dicks et al. (2013) ‘

The more promising interventions shaded in Table 1.1 are:

- Hedgerow management and planting measures;
- Establishing diverse vegetation in field margins, such as wild bird seed cover, nectar flower mixture/wildflower strips, and grass buffer strips around fields margins;
- Beetle banks;
- Reduced tillage approaches, and
- Changes to permanent grassland.

Within the range of actions on grassland, management changes on high-input permanent grassland are judged to have too great a conflict with food production. For similar reasons low/reduced tillage practices are not covered in detail here. Such approaches require significant changes to agricultural practices at field scales, which could substantially impact production (although more evidence is needed into both the short- and long-term impacts).

Therefore, from these measures three interventions are examined in more detail in the remainder of this analysis: 1) Hedgerows are chosen as potentially the most widespread of the measures, being relevant to both grassland and arable systems, 2) Field margins are confined to arable habitats, these are covered by the evidence case for pollen and nectar mixes which incorporates some information on the ES benefits of tussocky grass strips (as used for beetle banks). Beetle banks are a specific version of field margin vegetation cover, although they need not be implemented along field margins, and 3) Changes to grassland management are chosen due to the extent of Improved Grassland across England and the dominance of Lolium perenne swards. Lolium perenne has been the most common species recorded in Countryside Survey in Great Britain since 1990.

It is noted that assessing these interventions in isolation potentially overlooks synergies at a farm scale. Combinations of options may be more beneficial than individual options in terms of impacts on ES. For example, enhancing pollinator populations across a farm may benefit production and may itself be enhanced by improving both availability of nectar across a farm and availability of pollinators' nesting habitat (e.g. hedges and wildflower strips). Another important synergy is improving habitat connectivity for biodiversity, making it easier for species to move across and use landscapes. These synergies are assessed for water regulating services in the catchment management evidence base (see 'Integrated Catchment Management: Evidence Base' Section of this document). Each of the shortlisted interventions above can play a role in minimising nutrient loss (by water or wind) from farms. This is especially the case when the features involved follow slope contours. All of the interventions are also beneficial for enhancing soil carbon.

2. SEMI-NATURAL GRASSLAND

2.1. Introduction

Descriptions of grassland types discussed here are shown in Table 2.1. The investment examined is to reduce the area of grassland in the row in blue, and by restoring it to the row in green, which thus increases in area.

Table 2.1: Grassland Types

Grassland type	Description
Improved Grassland – high input	Often grown as a silage crop, or for intensive grazing (e.g. dairy), primarily comprised of Lolium perenne sward
Improved Grassland – low input (covers a spectrum from semi-improved Neutral Grassland (relatively species rich) to Improved Grassland with very few species.	Grazing grass, primarily comprised of Lolium perenne and Trifolium repens but may include a wider range of species due to lower nutrient concentrations
Legume and herb rich swards (semi-improved Neutral grassland)	Sown multi-species mix to enhance the quality of low input grasslands (grazed)
Species rich grassland	Uncommon: grasslands managed for biodiversity rather than production (including grazing management, but little or no inputs)

The habitat under consideration here is low input Improved Grassland for grazing, specifically the restoration of legume and herb rich swards from Improved Grassland (*Lolium perenne/trifolium repens*). This ecosystem is the focus as it is the most widespread type of lowland grassland in England, but has the potential for ecosystem services restoration. The analysis does not cover the most intensively managed grasslands, or species rich grasslands (e.g. those found on chalk or as upland/ lowland hay meadows with highest potential biodiversity), because:

- Species rich grasslands are understood to be valuable for a range of ecosystem services (UKNEA, 2011), but they are a relatively restricted habitat, and so are not considered to offer potential for a large-scale investment in natural capital. The UK has lost over 90% of its lowland semi-natural grassland (SNG) to intensification or conversion to arable farming (UKNEA, 2011). The area of 'SNG' in England is 109,576ha. SNG now occupies only 1% of England, and a large proportion is protected to some degree (68% of SNG is within SSSI, other designations also protect e.g. SAC, AONB). The % favourable status is 36%, or 39,487ha, across SSSI and non-SSSI. These figures allow us to estimate that around 64%, or 70,090ha, of SNG is either recovering or in unfavourable condition (or not assessed).
- The nutrient content of intensively managed improved grasslands means that restoration to more semi-natural grasslands takes significant periods of time (several years, over which nutrient levels decline). The actions required are often costly (including nutrient stripping and planting of desirable species) before levels of biodiversity (and associated ES) may increase. In contrast to the type of grassland covered in this evidence case, species rich grasslands rely on a low level of grazing to retain their condition as opposed to grasslands for which the primary purpose is to produce forage for livestock.

It is recognised that as well as being dependent on management, the time taken to restore grassland biodiversity will be dependent on a number of factors including spatial context and local species pools.

2.2. Current Management

Improved grasslands cover a large area of England, on a range of different soil types. Optimal agricultural management for Improved Grassland constitutes of periodic re-sowing (every 3-5 years or more) to maintain grazing quality for livestock production. Improved Grasslands (across the spectrum from high input Improved to low input semi-improved Neutral grassland) including clover, are broadly comparable to arable leys which are deliberately introduced into arable cropping to provide a break from the crop and to restore soil nutrient levels. They may be grazed if livestock are present on the farm or cut if not, and are usually short-term (1-3 years). The LegLiNK project showed that combinations of legumes and grasses as a ley in an arable system enhanced soil nitrogen content and crop yield (Döring et al. 2013). The comparability of these 'ley' approaches with grassland management approaches described below indicates potential for even broader restoration of Ecosystem Services across lowland farming systems (i.e. restoration that incorporates arable habitats well as Improved Grassland).

Grasslands provide some significant ecosystem services, alongside biodiversity and food production including:

2.2.1 Climate regulation

The Countryside Survey (2007) estimates that Improved and Neutral Grasslands in England contain 65 t/ha and 66 t/ha, respectively, of carbon in the top 15 cm soil layer (Chamberlain et al. 2010). Due to their extent these two habitats therefore constitute the most important habitats for carbon storage in England. Poor management of the habitats could lead to a release of this stored carbon e.g. due to soil erosion. However, it is unclear how quickly carbon would be released.

2.2.2 Water quantity and quality regulation

Grasslands can regulate water flows and prevent soil erosion, but on more intensively managed grasslands these services are at risk due to soil compaction by animals and loss of applied nutrients (slurry/fertilisers) through leaching into waterbodies during periods of rainfall.

2.2.3 Cultural services

Grasslands cover a large extent of England and together with associated field boundary structures and grazing animals provide an important component of the English landscape.

IEEP (2013) identify key pressures affecting the condition of grassland ecosystems across Europe. These include the key pressures in the UK of over-grazing, management intensification (fertilisation and herbicide treatments), hydrological modification and drainage and eutrophication from air pollution. The main pressures affecting low input Improved Grassland (semi-improved neutral grassland) is the addition of fertiliser and cultivation of species poor seed mixes (typically ryegrass and *trifolium repens/ pratensis*). This species poor mix results in minimal benefits for biodiversity and potentially impacts the resilience of grazing systems, for example, too great a reliance on one or two species may be dangerous in cases of plant disease or pest impacts, or when conditions change.

2.3. Examples of Grassland Actions

This case focuses on experimental work carried out by CEH (Carvell et al. 2007, Defra (2013b, BD5208). Evidence is available from two sites (in Devon and Berkshire), which monitored experimental plots of where actions were taken to restore semi-improved Neutral Grassland within fields at sub-field scale (minimum treatment size 0.06ha). Prior to taking these actions, the fields were low input improved grassland swards (*Lolium perenne/trifolium repens*), of more than 5 years old. Before the intervention the levels of ecosystem services they were providing were stable or deteriorating. Reasons for deterioration included soil compaction, which can increase runoff and thus reduce levels of water quality and quantity regulating services and decreasing levels of nutrients provided by the grassland.

The actions taken at the two case study sites included the following experimental actions:

1) Seed mixtures; 'grass only' (G), 'grass & legume' (GL), and 'grass, legume & forb' (GLF) seed mixtures,
2) Seed bed preparation; 'minimal tillage cultivation' or 'conventional deep ploughing';
3) Sward management; cut or grazed; and
4) Management intensity; typical continuous management or a summer rested period.

The two case studies were monitored for four years. Seed bed preparation had a significant impact on grass establishment, but its affects varied between sites. Shallow cultivation at North Wyke, Devon, which created only 40-50% bare ground, was less successful than ploughing and conventional seed bed preparation in allowing the sown species to establish. At Jealott's Hill, Berks where the shallow cultivation created more than 80% bare ground the benefits of ploughing over shallow cultivation for establishing the sown species were equivocal (Defra, 2013c (BD1466)). These treatments were experimental, but representative of potential large scale actions to improve the condition of SNG. The costs of these seed mixtures ranged from £100 ha/yr for the grass-only prescription to £140-230 ha/yr for the legume/forb/grass mixture. They do not include ongoing management costs, which are reflected in the agri-environment payment levels discussed below.

The success of these actions in restoring neutral grassland depended on persistence of legume cultivars in the mix, with cheap cultivars tending to be shorter lived. Compared to grazing, management of the grassland by cutting promoted the persistence of legumes and forbs. Rested management practices supported higher invertebrate abundance and seed resource availability.

There were differences in the local characteristics of the two sites (in Devon and Berkshire) which affected the establishment of the grassland and its delivery of ecosystem services. This reflects that there will be large variation across sites in England in terms of service delivery. However, in all cases forage quality and ecosystem service delivery from 'grass & legume' (GL), and 'grass, legume & forb' (GLF) seed mixtures are higher than for a grass only mixes. More specifically, key impacts included:

- Increased herbage biomass, nutrient quality and livestock production: Swards sown with both legumes and non-legume forbs have increased dry matter yield, forage quality and animal performance compared to non-fertilized grass-only swards. This means the benefits of fertilising the sward are lower for a diverse sward compared to a grass-only sward. However, the degree of benefit varied in size and persistence between the options.
- More diverse seed mixtures may reduce some aspects of soil compaction: Sowing both legumes and forbs was shown to reduce the force needed to penetrate soils, although this effect may be more pronounced on highly compacted soils., i.e. as legumes and forbs are deeper rooted

than grass species, they reduce soil compaction preventing runoff and associated nutrient loss to water bodies.

- Modest but wide scale enhancement of floristic diversity using simple seed mixtures was shown to dramatically increase the resource base of flowering plants as well as their utilisation by insect pollinators. This would be likely to lead to positive population growth for a suite of insect pollinators in agricultural land, although other caveats like the availability of nesting sites for bees would be an issue. Particularly in the context of mixed agricultural systems this may benefit the delivery of pollination services that contribute to increased yields of mass flowering crops, soft and top fruit.
- Including both legumes and non-legume forbs within seed mixtures increases the persistence of flowering resources for insect pollinators. The rapid loss of agricultural cultivars of legumes from the sward can be compensated by a modest increase in forb flower density over the typical five year agreements associated with ELS.

The measures trialled in the example above (grass, legume and forb seed mixtures) have now been included as an option in Environmental Stewardship (EK21) which was made available in 2013 (and monitored in 2014). It is proposed to offer the option in the New Environmental Stewardship Scheme starting in 2015. It is now referred to as ‘EE12 (wildflower supplement to buffer strips)’, and attracts a payment of 400+63 = 463 points or £463 per ha.

Further research at field scales would help to refine management options for optimal management to balance – losses and gains to the farm business from lower stocking densities and higher quality forage, respectively, and gains in other ecosystem services (e.g. climate and water regulation services, and biodiversity). At landscape scales an understanding of how implementation of these approaches will best deliver biodiversity and ecosystem service goals in a cost effective manner is required.

3. HEDGEROWS

3.1. Introduction

Hedgerows are linear features within farmed landscapes that incorporate a shrub component, hedgerow trees (where present) and associated ground flora. They are a feature of both arable and grassland systems and are very widespread across England. There are an estimated 402,000 km of managed hedgerows in England and a further estimated 154,000 km of lines of trees/shrubs/relict hedge (of which a substantial proportion will have formerly been hedges) (results from CS, 2007). Hedges provide structural habitat diversity in homogeneous agricultural landscapes and produce wide-ranging ecosystem services (Wolton, et al.; 2014 and 2013); see also Hedgelink website[40]). Ash trees are estimated to constitute around 20% of tree species in English hedges or lines of trees/shrubs/relict hedge with individual ash also being the most common species of individual hedgerow tree.

A lot of data around hedges is at a large scale (temporal and spatial). This is primarily because hedges are long-lived features which do not lend themselves to short-term studies (which form the basis of most research projects). Shorter term studies tend to be focused on short-term management impacts on berry or wood production or on hedgerow ground flora. The case focuses on evidence around; 1) the known benefits of hedges from a large variety of Defra reports, conference proceedings, papers and Countryside Survey; 2) the spatial extent of hedgerows and their importance for provision of biodiversity and ecosystem services in the wider countryside and; 3) the loss of hedges due to poor management and neglect and (as seems likely in the near future given its rate of spread in Suffolk) ash dieback.

A range of sources provide information on the extent, condition and ecosystem services from hedgerows (numbers relate to studies in the project data base): Boatman et al. (2008), (Wolton et al. (2014), Defra (2010), 2012 Hedgerow Futures Conference[40], European IALE (UK) conference, University of Birmingham (Hedgerows of the World, 2001), Staley et al. (2012 and 2013), Croxton et al. (2004), Defra Hedgerow research projects (BD2108, Defra, 2002 (BD2102), Defra, 2002 (BD2106), Defra, 2007a (BD2302). Data on the extent and condition of hedgerows has been gathered from the UK Countryside Survey which consists of a sample of 1km squares within UK countries including England. Other studies cover surveyed hedges, e.g. at county level and individual hedges, some in experimental set ups, others not.

3.2. Current Management

Research has provided evidence of the roles of hedgerows in the following ecosystem services provided by hedgerows:

1) Water quality regulation;
2) Flood mitigation;
3) Climate mitigation;
4) Agricultural production (through impacts on micro-climate, soil erosion, crop pollination, crop pest populations and livestock shelter), and
5) Biodiversity.

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[40] http://www.hedgelink.org.uk/Hedgerow-Futures-Conference-2012.htm

In addition, the importance of hedges for landscape cultural services is widely reflected in their inclusion as key landscape characteristics in many Landscape Character Area descriptions and regulations restricting the removal of hedgerows. The Natural England report 'Experiencing Nature' (NE, 2011) revealed that hedgerows were important components of cultural landscapes. Services are enhanced by a combination of good structural condition and associated basal condition, with both components offering a range of services both individually and in combination. For example, the hedge basal area may provide nesting locations and larval and adult food plants for plant pollinators, and the woody component provides important nectar sources for plant pollinators.

Spatial configuration is a very important aspect of the contribution of hedgerows to ES provision. Contoured hedgerows may be particularly important for water regulating ES (this is discussed further in the 'Integrated Catchment Management: Evidence Base' Section of this document). Hedgerows also provide ecological connectivity in landscapes, important for the maintenance of biodiversity (and its role in ES provision, e.g. pollinators, predators of crop pests)[41]. Hedge position may also affect wind borne soil erosion.

Historically the main pressure was hedgerow removal, but since the introduction of the Hedgerow Regulations[42] the most significant problems are neglect (i.e. a lack of adequate management), impacts of management in the adjacent crop and tree diseases. The length of managed hedgerows (excluding relict hedges and lines of trees) declined by 6% between 1998 and 2007. Only 50% of hedges were reported to be in good 'structural condition' (according to the Hedgerow Action Plan condition criteria) in 2007 and only 12% in overall 'good condition' (including margins and basal flora) on arable land. Structural condition criteria include: height, width (and resultant cross-sectional area), height of the hedge base (indicative of effective management). Extra condition criteria include the width of associated margins (width of perennial vegetation >1m and distance from the centre to the edge of the plough >2m), and presence of aggressive weed species such as *Urtica dioica* and *Galium aparine*.

Data on both the extent and condition of hedges point to significant deterioration in hedge length and condition (including the condition of vegetation associated with hedge bases) over the period 1978 - 2007 (CS, 2007). This is despite considerable funding for hedge maintenance (and a much lower amount for hedge recreation and rejuvenation) across this period through agri-environment schemes (Boatman et al. 2008). Over the 20 year period 1991 to 2012 Defra funded restoration works or new planting of hedgerow under the Countryside Stewardship scheme and the Environmentally Sensitive Areas (ESA) scheme (1998 to 2004 only). Between the two schemes, over 40,000 km of hedgerows have been protected and/or restored, but this is only approximately 10% of hedgerows. Approximately 50% of Environmental Stewardship money is paid for hedge management (Davey et al. 2010) with moneys being paid primarily for maintenance, with a presumption that farmers will gap up hedges. There is little evidence of hedges being 'improved' as a result of being in stewardship (NE, 2013a).

This information suggests there is considerable scope for additional actions to improve the extent of hedgerows (through gapping up) and their condition. Improvements in condition can potentially occur on the majority of hedgerows (as the majority are not in good overall condition – see above).

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[41] Refer to hedge ES review, Wolton et al. 2014

[42] http://www.legislation.gov.uk/uksi/1997/1160/contents/made

This includes further actions where there are existing agri-environment agreements. These actions are discussed in the following subsection.

3.3. Protection and Improvement Actions

Key actions to improve the condition of hedgerows include:

- ‘Gapping up’ (planting regionally relevant new hedgerow plants in gaps at an appropriate spacing and density);
- Rejuvenation of hedges through management which may include hedge laying or coppicing and other locally relevant (traditional) management practices and fencing on both sides to restrict livestock access during establishment and regeneration, and.
- Improvement of ground flora will at least require limiting stock access and stopping application of fertiliser, it may require more extreme measures such as turf stripping or adding seeds and propagules.

Once hedges are restored or rejuvenated they need to be kept in a management cycle to ensure that they continue to form effective hedges and produce associated ecosystem services. Potentially, management may incorporate harvesting of wood as fuel, either as part of the regular cutting cycle (2-3 yrs) or the longer term laying/coppicing cycle. Management of ground flora will require a fertiliser/pesticide free margin adjacent to the hedge (of at least 2m from hedge centre and 1m from the edge of the extent of canopy - in accordance with cross compliance requirements).

As well as improving the condition of individual hedgerows, their value for biodiversity (including by providing connectivity between different patches of habitats) and landscape services is maximised through presence of a continuous woody network of well managed hedges incorporating standard hedgerow trees and ground flora appropriate to the location and hedge type.

The timescale over which these improvements are expected to occur depends on location, the initial state of the hedge and what actions are taken. Actions to increase the woody element of a hedge by laying or replanting are likely to take between 5 and 10 years to produce a hedge in structurally ‘good’ condition. Recovery of associated ground flora may be rapid if interventionist action is taken (e.g. turf is stripped and flora sown into place), but will take considerably longer if reliant on natural recruitment from local species pools. Recovery of hedgerow trees depends on tree species and rate of growth, but will take decades.

There is a well established management cycle for optimising hedge condition[43]. Dependent on action, for woody element restoration of hedge and hedgerow trees, increases in associated ecosystem services may be linear as the woody component ages until it reaches a plateau after which regeneration through coppicing or laying may be required. There is no evidence available on the rate of recovery of hedgerow ground flora and associated ecosystem services.

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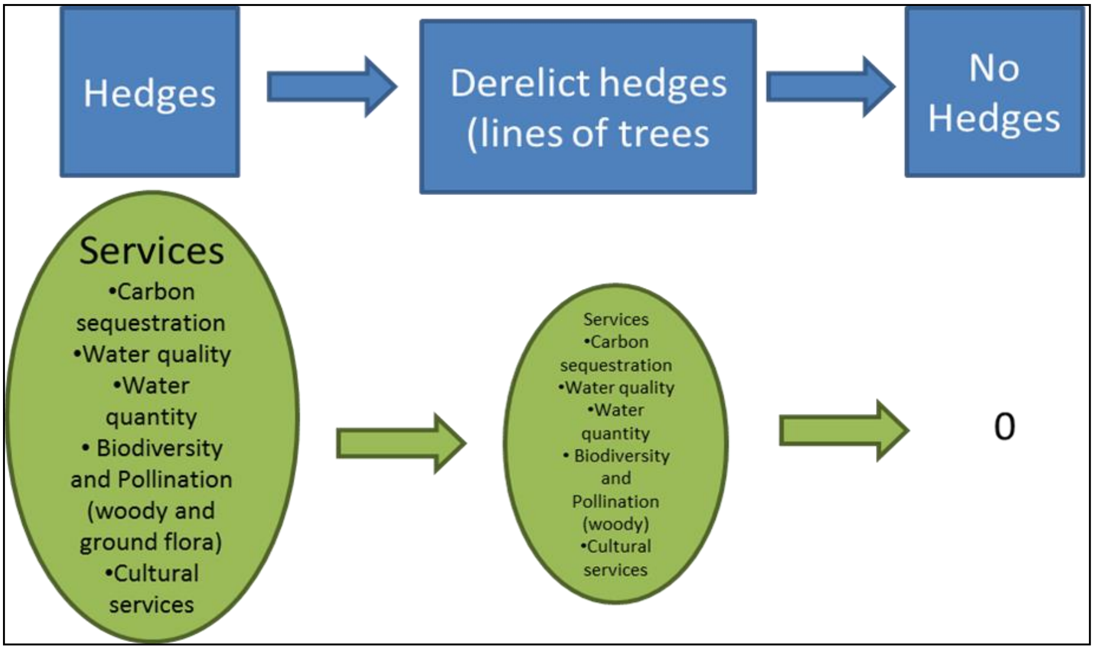
[43] http://www.hedgelink.org.uk/hedgerow-management.htm?searched=management+cycle&highlight=ajaxSearch_highlight+ajaxSearch_highlight1+ajaxSearch_highlight2

3.4. Costs and Benefits of Improvements

Evidence around the impacts of the recovery of the woody component of hedgerows, including trees, is limited. It is assumed, based on studies showing how hedges impact on ES provision, that hedges which do not form continuous woody structures across the landscape can only provide partial services. Whilst individual shrubs which are no longer managed may provide comparable or improved **wood, berry and pollen production** in the short term (through being allowed to grow to maximum size), contributions to **improving water quality** and **preventing erosion** will be less than they would as part of a continuous structure (forming a physical barrier of both ground based vegetation and woody stems often along a bank). Associations with a particular ground flora (and hence pollen production) are also likely to be lost due to decreased shade and increased incursion of grass species. In the longer term individual shrubs will age and die much faster than they would as part of a hedge in a hedge management cycle leading to loss of all hedgerow associated services. This relationship is illustrated in Figure 3.1.

Figure 3.1: Hedgerow Structure and Ecosystem Services.



The value of many of the ecosystem services identified in Figure 3.1 can be hard to establish. Carbon benefits can be calculated if the levels of storage of sequestered carbon are known. The value of water regulating benefits is very context specific, and the product of combined actions and circumstances in a catchment. However, as described further in the catchments evidence base, some initiatives have been evaluated and shown to have positive benefit:cost ratios. Biodiversity, pollination and cultural services are hardest to value, but the limited evidence available on these ES values is discussed in Section 6.

There is some evidence showing the costs of hedgerow management actions as reflected in the income foregone based payments made by agri-environment schemes for creation and /or restoration of new hedgerows. The costs of these actions are clearly linked to the extent to which the hedgerows are improved. They are a widespread offering under the relevant schemes, suggesting the actions involved are scalable to a very large area of England’s farmland. One potential constraint on scaling up these actions is the availability, amongst farmers or relevant contractors, of expertise in hedge rejuvenation. Furthermore there may be an unwillingness to re-instate hedges because of the subsequent long term time commitment to their management.

Better evidence of hedgerow's contribution to ecosystem service delivery at a landscape scale is clearly needed. This needs to take into account interactions between hedges and other landscape components within the agricultural environment, in particular measures under cross-compliance or greening requirements that are likely to involve similar actions.

4. POLLINATOR STRIPS

4.1. Introduction

Pollinator strips are arable field margins (adjacent to hedgerows) which are created to contain a variety of pollen and nectar rich plants. As approximately 30% of land in England is in the Arable and Horticultural Broad Habitat (Results from CS, 2007), this measure is potentially applicable on a widespread basis.

Arable field margins are the optimal place to sacrifice a proportion of crop land within the field from both a farm business and environmental perspective. They are less productive than field centres due to a range of factors including weed competition and soil compaction. Arable field margins help to protect hedgerows and associated basal flora and fauna from the effects of fertilisers and pesticides. Pollution and eutrophication associated with pesticides and fertilisers may result in the loss of species and habitats, and may also serve to perturb key ecosystem functions, including pollination, natural regulation of pest species, carbon sequestration and soil nutrient cycling. Arable field margins are important 'spaces' for arable weed species. However, field margins are readily invaded by weed species such as black grass particularly in conventional systems; this can result in crop damage.

In State of Natural Capital II, the risk assessment for enclosed farmland identified the ecosystem service 'wildlife' as at high risk (with high confidence) and the service 'food' also at risk, but with low confidence. The latter risk is influenced by pollinators as well as other factors such as soil degradation.

A case study to test the Natural Capital Asset Check approach in the UKNEAFO (Dickie et al. (2014))[44] examined the natural capital assets that provide wild pollination. It identified that:

- Farmers can use other commercialised pollinators alongside wild pollinators and different crops have different pollination requirements making some more or less vulnerable than others to changes in pollination services. It identified the importance of maintaining a diverse assemblage of pollinators for their option value: both to reduce the impact of fluctuations in populations, and to prevent over-reliance on one pollinator group which may not be appropriate for providing pollination to crops with diverse needs and may reduce the ability for services to be provided in the future.

  The decline of wild pollinators in the UK does not appear to have crossed a threshold in terms of its inputs to crop production. However, the case study illustrates the loss of option value when natural capital declines, bringing the risk that our requirements for wild pollinators may increase beyond the current capacity of this asset to provide the service. This risk could arise

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[44] See case study on pollination in Annex 1

should our crop production patterns change significantly. Such changes are entirely possible, as reflected by past changes in crop production (e.g. the massive increase in oil seed rape cultivation means we need 40% more pollinators), and further changes that are expected in the context of climate change.

Wild species pollinate do a large proportion of crops across the UK, but may not be sufficiently abundant to meet increased pollination needs, particularly across large fields associated with oil seed rape production. There is continued loss of wild flower diversity and pollinator diversity. While short-tongued bumblebees and generalist populations do not seem in peril, those with a narrower habitat niche are in decline.

4.2. Investment Evidence

Wider Farmland Conservation Evidence (Dicks et al. (2013), Evidence on Pollinator Strips and Operation Pollinator (Defra, 2007b)

There is a range of evidence on measures that can be characterised as 'pollinator strips': there are over sixty UK studies on sown flowering strips that show some benefits to one or more wildlife groups. In general, though there is variability between sites and studies, the studies show positive impacts on plants, invertebrates, birds and mammals.

The BUZZ (Defra, 2007b) study used trialled six different 6 metre field margin options on east and west facing margins on arable fields. The measures took the form of a range of different management treatments. **Those treatments in bold reflect the potential options for improving biodiversity and associated ecosystem services in arable field margins considered here,** and therefore costs were identified for these options:

1) a conservation headland – crop remained in place, no spraying or fertilising,
2) cutting and cultivating to 15cm to allow natural regeneration,
3) **Sowing a low cost mixture of six fine- and broad-leaved grass species at 20 kg ha-1 (£60 ha-1; €70 ha-1) to create tall, dense tussocky grass strip**,
4) **Sowing a pollen and nectar seed mixture comprised of four agricultural varieties of legumes with three fine-leaved grass species at 20 kg ha-1 (£90 ha-1; €111 ha-1) specifically designed to provide mid- to late-season foraging resources for pollinating insects, particularly bumblebees and butterflies** (Carvell et al. 2007; Defra, 2007b),
5) **Sowing a wildflower treatment incorporating 21 species of native forbs comprising a range of functional types with three fine-leaved grass species at 37.2 kg ha-1 (£891 ha-1; €1098 ha-1) to provide vegetation with both a diverse structure and composition for the widest range of invertebrate species**,
6) a control treatment consisting of a winter-sown cereal (wheat, barley or oats) grown with conventional inputs of fertiliser and pesticide.

In the establishment year the sown habitats were managed by cutting and removal of herbage in May and September to reduce competition from crop volunteers and other undesirable species. Management upon establishment and continued management (cutting etc.) and the quality of the seeds used affected the success of the measures. In subsequent years the pollen and nectar and wildflower treatments were always cut and removed in September with an occasional cut in April if required. Herbicides, molluscicides and insecticides were applied as required in year 1.

The enhancement of Ecosystem Services in the established field margins was measured over 5 years after establishment. Topsoil carbon was enhanced by the sown margins, species richness was higher in the sown treatments, but did decline in the pollen nectar mix over time. Numbers of flowers were highest in the pollen and nectar and wildflower mixes in the first 3 years and then declined in the pollen nectar mix (though it remained highest in the wildflower mix compared to all other treatments).

Numbers of pollinators mirrored changes in flower numbers with the pollen and nectar mix having highest numbers until year 3 and thereafter the wildflower mix having higher numbers. Species richness of bees and butterflies also followed similar patterns, although there were also within year effects dictated by the availability of key pollen sources throughout the spring/summer. Soil invertebrates and earthworms in particular were more abundant in the sown margins – indicative of improved soil condition (over the cropped land). Finally, there is evidence that the complexity and therefore the stability of invertebrate food webs are higher in the non-cropped margins, and particularly those sown with wildflowers. This will have important implications for the regulation of pest species and the strength of trophic cascades. Previous work on beetle banks has shown that they can support diverse invertebrate communities, including of cereal crop pests. The pest-control benefits they provided outweighed the labour and seed costs required to establish them[45].

The project has since been expanded through the Entry-Level Scheme agri-environment measures (to 670 farmers by 2009), and also through ‘operation pollinator’. Through Operation Pollinator’s habitat creation, bumblebee numbers have been seen to increase by up to 600%, butterfly numbers up 12 fold and other insects more than 10 fold within three years. Numbers of birds and small mammals have also increased. A major species conservation success of the project has been the return of the rare bumblebee species ‘Bombus ruderatus’, on a Worcestershire farm. This bumblebee has been classified on the verge of extinction, and a key target in the Government’s initiative to protect and resurrect UK farmland biodiversity.

Operation Pollinator has helped growers successfully establish and manage pollen and nectar-rich habitats on less productive areas around the farm. Crop yields are maintained and improved through adoption of these sustainable practices. Operation Pollinator clearly shows that biodiversity conservation and productive agriculture are not only compatible, but mutually beneficial.

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[45] e.g.: http://www.sare.org/Learning-Center/Books/Manage-Insects-on-Your-Farm/Text-Version/Principles-of-Ecologically-Based-Pest-Management/Beetle-Banks-Boost-Beneficials

5. ECONOMIC COSTS AND BENEFITS FOR LOWLAND FARMLAND INVESTMENTS

5.1. Introduction

Lowland farming results in a range of impacts on the economy and the environment. This section considers the main costs and benefits that are relevant to determining potential investments in natural capital on lowland farmland. While a variety of data is available, it does not provide cost and benefit evidence for specific actions that could form widespread investments in natural capital assets on lowland farmland. Therefore, an 'investment case' cannot be formulated.

The main costs considered are those within the farm business, as this is where the costs of actions to protect and improve natural capital are borne. Some of these costs may be compensated through agri-environment schemes, transferring the costs to taxpayers. Other costs from lowland farming include environmental externalities (e.g. pollution of water), which are discussed in other investment cases (e.g. see catchment management).

The main benefits considered are the values of ecosystem services that can the maintained and/or enhanced as a result of actions to protect and improve natural capital. Other socio-economic benefits from lowland farming include its contribution to GDP and providing rural employment. While impacts on productivity of farming systems is considered under costs, these socio-economic benefits are not considered in detail.

5.2. Farm Business Costs

Evidence on the costs of Natural Capital Restoration on farms is limited. The costs of some actions to protect and improve natural capital are as discussed in the preceding chapters The payments made for agri-environment measures give some indication of the costs of management measures, as they are generally set to reflect income forgone, potentially with some premium or incentive also added. These costs represent actual financial costs to government.

An alternative source of evidence on costs is provided by farms operated by organisations wishing to demonstrate the feasibility of different environmental practices within a commercial farming operation. Examples include: Loddington (Leics), Hope Farm (Cambridgeshire), Syngenta at Jealott's Hill (Berkshire), and Wakelyn's (Suffolk).

These farms contain a range of cropped and non-cropped habitats typical of lowland farmland in England. They have been used to illustrate a range of management measures and farm level combinations of measures aimed at sustainable production and commercial viability. The data on these farms give an indication of the impacts of the measures taken both to enhance productivity and ecosystem service delivery. As well as providing evidence on the impacts of different on-farm measures on wildlife, these farms also produce economic information (e.g. farm business accounts) in order to illustrate the economic impacts of these measures on the farm business.

5.2.1 Loddington Estate - Game and Wildlife Conservation Trust (GWCT) farm (Leicestershire)

The Allerton Research and Educational Trust (so named because the Allerton's owned the Loddington Estate) was originally a project on the estate which ran with assistance from the GWCT from 1992. The project became the GWCT's Allerton Project formally in 2006 with the aim of integrating game and wildlife management into modern profitable farming practices. The project has evolved over the past 20 years towards a combination of commercial farming, research, demonstration and community engagement. Wherever possible, the project aims to identify management practices that have multiple benefits for wildlife and ecosystem service provision as well as to enhance productivity. The farm covered 272 hectares (ha) when the project started in 1992, additional land being added in the following three years, creating a farm of 318ha. The farm comprises 253ha of arable land, 29ha of pasture and 18ha of mature woodland. The set-aside area rose to a maximum of 43ha in 1994.

The farm has been managed as a commercial business, primarily producing wheat, oats, oilseed rape and beans. Wheat and oats are grown to Conservation Grade standards, which means that there are restrictions on pesticide use and a specified minimum requirement for wildlife habitat areas. The area of land devoted to habitat management has ranged from 10-15% of the agricultural land area through most of the period, with 19% and 17% of land taken out of production in 1994 and 1995 respectively, mainly as a result of set-aside obligations. Crop production has varied annually with cropped land area and yield, but productivity has remained constant within these annual changes and the farm’s yields and profitability compare favourably with the regional average.

On farm research has been carried out on the different agricultural and wildlife management options shown in Table 5.1. The options have been developed to form part of the farming practice where costs and benefits for farming and wildlife have been identified.

Table 5.1: Management Measures Implemented at Loddington Estate

Management Measure	Rationale
Reduced tillage	To reduce soil compaction, conserve soil moisture and aid plant establishment
Hedge laying and woodland management	To benefit game and wildlife, to provide wood fuel (woodland)
Sediment ponds	Intercept phosphorus in surface water runoff.
Conservation grade cereals (Premium price crops, restrictions on pesticide use and minimum wildlife habitat areas)	To provide better habitats for wildlife and better income
Set-aside management to create beetle banks, grass buffer strips incorporating sediment ponds and wild birds seed mixtures along field edges to provide seed for over-wintering bird species.	To use compulsory set-aside areas most effectively for wildlife and ES benefits including impacts on water quality and pollination

The implementation of these measures had the following impacts:

- The adoption of **reduced tillage** systems reduced wheat yields initially by approximately 5% and grass herbicide costs increased from £20 to £70 per hectare in the early years of adoption, but were controlled by a switch to spring beans. Reduced cultivation costs and a ‘stable’ blackgrass population have seen the net wheat crop margin increase over the plough based system as overall crop establishment costs are typically 20% lower. Yields of spring beans and oilseed rape have shown substantial increases, in part due to conserving soil moisture during dry spring and autumn sowing periods by using a single pass crop establishment system.

- **Sediment ponds** to intercept water from field drains has shown that ponds may intercept 50% of phosphorus lost from land to streams. The mains costs involved are the work of digging ponds, but a benefit can be obtained by re-using the trapped sediment (which contains valuable soil nutrients).

- **Hedge laying and woodland management.** This helps to offset Greenhouse Gas Emissions from the farm business – the majority of which is due to fertiliser use. Areas of woodland not harvested for fuel are particularly important for carbon storage. Woodland harvested for fuel replaces the need for use of fossil fuel on farm. Woodland is also important for pheasants for winter cover and roost sites, and its management has been shown to benefit songbird numbers.

- **Field edge management options.** These showed positive impacts on biodiversity including farmland birds and pollinators. The work on the farm showed that kale, quinoa and a cereal such as triticale or millet provided the best sources of food. Although these crops were advocated as an 'intimate mixture' by early Stewardship schemes, research showed that the crops were best grown as single species strips or blocks so that each could be managed according to their differing agronomic needs and seed production could be optimised to benefit birds. Early Stewardship scheme restrictions on fertiliser use also limited seed yield and the trials suggested an optimum rate of 60kg nitrogen per hectare (N/ha), rather than the 30kg N/ha limit advocated within Stewardship.

5.2.2 *Hope Farm, RSPB Farm, Cambridgeshire*[46]

In 1999 the RSPB purchased Hope Farm in Cambridgeshire a 181 ha conventional arable farm. The farm has been used to develop and trial farming techniques that can produce food cost-effectively and benefit wildlife. The project aimed to do this through the creation of key habitats such as skylark plots, wild bird cover, nectar flower mixtures and floristic grass margins.

Key environmental improvement activities:

1) moved to a 4 year rotation including beans and stubble (from a 3 year – wheat-wheat-oil seed rape);
2) skylark plots;
3) grass buffers;
4) wild bird seed mix;
5) pollen and nectar seed mix;
6) hedge management under ELS, and
7) wet feature management.

These measures produced the following results:

- Hope Farm has increased wheat yields by approximately 1 tonne per hectare since 2000 and maintained profitability. Oilseed rape and field bean yields also compare favourably with similar sized farms in eastern England.
- Hope Farm's Farmland Bird Index has increased by 200 per cent. This rise has been driven by helping species that have declined nationally, such as grey partridge, skylark, linnet and yellowhammer.

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[46] RSPB (2010) Hope Farm Accounts: http://www.rspb.org.uk/forprofessionals/farming/hopefarm/accounts.aspx

- Farmland birds have increased due to provision of a package of agri-environment options designed to increase the area of in-field nesting habitat, winter seed food and insect-rich foraging habitat.
- Hope Farm has been used to find new ways of helping birds to breed successfully on commercial farmland. One example is the skylark plot, which was first trialled at Hope Farm. Two skylark plots per hectare have been proven to boost nesting opportunities for skylarks in areas dominated by winter cereals. It has since been included as an agri-environment option.

5.2.3 Scalability of Loddington and Hope Farm Evidence

The Allerton project farm is located in the central section of the Eye Brook catchment in Leicestershire. This area is reasonably representative of lowland farming conditions in Central and South-eastern England. Hope farm in Cambridgeshire was deliberately chosen as a typical arable farm in its region and has been managed in a manner designed to be replicable on similar lowland farms across Southern and Eastern England. The evidence from these farms is therefore intended to be scalable to a large part of lowland farmland in England.

Evidence for this representativeness is reflected in the further research and demonstration work that the Allerton project has undertaken across the Eye Brook Catchment. Bird survey work has shown similar findings across 34 farms in the catchment compared to Allerton farm, suggesting comparable ecological conditions exist across the catchment. Therefore, activities at Loddington are considered be applicable at a larger scale to a significant area of similar lowland farming across England.

The farms have maintained the profitability of their farming operations at the same time as trialling many of the measures (e.g. pollen strips, hedgerow management) discussed in this investment case. The farms contain a range of cropped and non-cropped habitats typical of lowland farmland in England. They illustrate a range of management measures and farm level combinations of measures aimed at environmentally sustainable production and commercial viability. It gives an indication of the impacts of the measures taken both to enhance productivity and ecosystem service delivery. As well as providing evidence on the impacts of different on-farm measures on wildlife, it produces economic information (e.g. farm business accounts) that illustrate that the economic impacts of these measures are not a significant burden on the farm business, which have continued to operate profitably.

This evidence therefore suggests that the measures demonstrated can be applied at a much larger scale, on similar lowland farms without significant costs to the farm business. The exact scale of ‘similar lowland farms’ is not known exactly, so requires further research.

5.3. Benefits

The investment measures for lowland farmland examined above bring a range of ecosystem service delivery and increases in biodiversity. This section briefly discusses the synergies between these actions, and examines the limited data available on the economic value of these benefits.

5.3.1 Synergies

The synergies between the different natural capital investments in this study are discussed in the technical report (Section 5) and examined in more detail for ‘Integrated Catchment Management: Evidence Base’ Section of this document. All three lowland farmland investments examined may be complementary and synergistic for a whole range of ecosystem services. For example:

- Improving hedges and providing nectar and pollen strips or legume and herb rich grasslands in adjacent fields is likely to result in increases in both food and nesting resources for pollinators and biodiversity.
- Impacts on cultural services may be enhanced by adjacency of hedge and field options.
- Water services are also likely to be enhanced in particular by adjacency of hedges and pollen and nectar strips, providing a larger area for absorption of water and associated sediments at field edges.
- There may also be cost savings from synergistic actions. For example, where pollinator strips are placed next to hedges this may mean that the hedge can then have a lower impact (in terms of shade and potentially water uptake) on adjacent crop productivity. Therefore, the overall costs of these adjacent measures will be less than the sum of their individual costs.

5.3.2 Economic Data

Market data on the prices that consumers actually pay to secure a good or service in a real market can be used to value the benefits associated with lowland farmland natural capital restoration where possible. For example in the catchment investment case (see 'Integrated Catchment Management: Evidence Base' Section of this document) some avoided costs as a result of improved catchment management are valued. However, much of the available evidence for valuing ecosystem service flows is based on economic valuation methods which are applied in the context of (non-market) unpriced benefits provided by natural capital assets. Notably, these methods estimate welfare values (e.g. they measure benefits in terms of consumer surplus), typically in terms of individuals' willingness to pay (WTP) for environmental goods and services.

5.3.3 Non-market valuation

The benefits of lowland farming policy measures that protect and improve natural capital, such as agri-environment and wildlife management schemes, have been estimated through several willingness-to-pay studies.

Christie et al. (2006) study considers improvements to the biodiversity across the counties of Cambridgeshire and Northumberland. Using choice experiment approach, they estimate that households are willing to pay £34.40 to £71.15 to move habitats from continued decline to 'habitat restoration' and £61.36 to £74 for habitat re-creation. A contingent valuation approach estimates WTP bids for various biodiversity conservation activities, through agri-environmental schemes (£74.27), habitat re-creation (£47.49 to £54.97) and preventing development loss (£36.84 to £45.30). The results provide support for policies, such as species Biodiversity Action Plans, which specifically target rare, unfamiliar species. In the Cambridgeshire model, WTP is £115 for a move from continued decline to stopping decline and 'ensuring recovery'.

Of particular relevance to lowland farming is the value for improving *familiar species* from continued decline. This relevance based on the assumption that the majority of farmland species are currently and/or previously widespread species with some familiarity to the general public (at least amongst older generations). However, it should be noted that familiar species occur in habitats other than farmland. In the Cambridgeshire model, the outcome 'protecting rare familiar species only' was valued at £35.65/yr, whilst protecting 'both rare and common familiar species' had an implicit price of £93.49/yr. In the Northumberland sample, the two levels of protection had similar implicit prices (£90.59/yr and £97.71/yr).

The Northumberland result does not reflect the scale effects one would expect (i.e. protecting more species should have higher WTP). However, these values all illustrate a significant positive WTP for conserving familiar species, which are assumed to include widespread species typically occurring in lowland farmland. Based on an estimated 23 million households in England in 2013 (DCLG, 2010), a value of £95 per household is equivalent to approximately £2.2bn per year. This assumes that the willingness to pay values estimated in Cambridgeshire and Northumberland are more widely representative of the UK. Cambridgeshire was chosen as a predominantly intensively arable area that supports low levels of biodiversity, while Northumberland was chosen to represent an area with high levels of biodiversity and a lower intensity of land use. Average GDPs per capita in Cambridge and Northumberland are representative of the average GDP per capita in England.

GHK (2011) estimated the benefits of Sites of Special Scientific Interest (SSSIs) in England and Wales. A choice experiment was used to estimate of the public's willingness to pay to support SSSI management. It identified a value of £956 million annually to secure the current benefits delivered by SSSI funding and specifically for acid grassland (£54m or £682/ha), lowland calcareous grassland (£33m or £914/ha) and neutral grassland (£12m or £642/ha). The public was WTP a further £769 million for the delivery of the additional ecosystem services if favourable condition for all sites was achieved and specifically for acid grassland (£31m or £399/ha), lowland calcareous grassland (£17m or £469/ha) and neutral grassland (£8m or £436/ha). These grassland types are what is classified as semi-natural grassland in Section 3. They are not directly relevant to the low-input improved grassland improvement measures discussed in that Section, but do indicate that the public values grassland conservation. However, it should be noted that this study relied on professional judgement to fill evidence gaps and valued a complex environmental change, so there are significant uncertainties in the interpretation of its results.

Boatman et al. (2010) estimated the wildlife and landscape benefits of Environmental Stewardship in England. Contingent valuation and choice experiment methods were used estimated willingness to pay for the quantity of Environmental Stewardship in 2013 (when it was envisaged that the scheme would reach target uptake) of £22.41/household/yr on average in England. Based on an estimated 23 million households in England in 2013, this is equivalent to approximately £0.5bn per year.

eftec (2006) performed contingent valuation study to estimate the WTP across the six regions with Severly Disadvantaged Areas of £49 to £105/household/year for a change from a 'worst case' to a 'best case' scenario. Scenarios included:

- "Environment-agri" where the same amount of Less Favoured Area scheme (which provides income support) still exists, but is targeted more towards achieving environmental goals;
- "Environment only" where the LFA scheme disappears, but existing support is maintained, and
- "Abandonment-intensification" where upland support (£27m/yr) is withdrawn entirely and many farms dominated by poorer, higher ground, farming would be completely abandoned.

The studies by Christie et al. (2006) and Boatman et al. (2010) are most relevant to the lowland farmland investment measures considered here. Their valuations are proportionate to the benefits they reflect: Boatman's value of £22/household/yr are around a quarter of the Christie value (around £90/household/yr. The goods valued by Boatman (farmland wildlife and landscape environmental stewardship outcomes) are a subset of the outcomes valued by Christie (conservation of rare and widespread familiar species) which do not only relate to farmland.

Aggregating from these studies gives an estimate for the value of conserving wildlife on farmland in England, and of familiar species, of approximately, £0.5bn, or some proportion of £2.2bn, per year. These studies both examined landscape scale conservation measures (county benefits to county residents and England benefits to England residents, respectively), and therefore do not encounter problems in scaling up the values. However, these are very crude estimates of the values of improvements in lowland farmland ecosystems, of which the three measures for grasslands, hedgerows and pollinators, examined in this analysis, are but one, albeit fairly substantial, part. As a result the values have not been inflated to current prices, as this would not improve their accuracy – the broad conclusion is that they indicate values for improvements to lowland farmland ecosystems of around £0.5m/yr, or around £12bn over 50 yrs (using HMT standard discount rates).

5.3.4 *Management Costs*

There is an important distinction between the non-market values discussed above and the opportunity cost of land management practices, as reflected in agri-environment payments (e.g. for hedgerow maintenance/ restoration, buffer strip creation etc.). Whilst these are based on market values, they are not a measure of the benefits delivered by restoration of natural capital, but rather of the benefits (income) foregone.

Table 5.2 summarises upland and lowland agri-environment scheme payment rates in England in 2013. It should be noted that these payments rates may be revised in transition to the new environmental stewardship scheme. Nevertheless they give a recent indication of the opportunity costs of actions.

Table 5.2: Agri-environment scheme payments in England

Scheme	Standard Payment (2013)	Management options payment	
Entry Level Scheme (ELS) (NE, 2013b)	£30/ha/yr (£8/ha/year on land parcels of 15 ha or more above the Moorland Line).	Management actions come with points. Points target must be reached for ELS.	
Uplands ELS	£62/ha/yr (£23/ha/yr on land parcels of 15 ha or more above the Moorland Line)	Points target must be reached. Some supplementary action available at £5/ha	
Organic Entry Level Scheme (OELS)	£60/ha/yr Organic conversion aid payments are £175 per ha (improved land for the first two years) and £600 per ha (top fruit orchards for the first three years).	Points target must be reached	
Uplands OELS	£92/ha/yr	Points target must be reached	
Higher Level Stewardship (HLS) (NE, 2013c)	Dependent on management options	Hedgerow restoration including laying, coppicing and gapping up	£7/m
		Hedgerows planting	£5/m
		Management of field corners	£400 ha
		Floristically enhanced grass buffer strips (non-rotational)	£485 ha
		Enhanced wild bird seed mix plots (rotational or non-rotational)	£475 ha
		Unharvested, fertiliser-free conservation headland (rotational)	£440 ha
		Cultivated fallow plots or margins for arable plants (rotational or non-rotational)	£440 ha

Source: NE (2013b; 2013c)

The two measures shaded grey are those most relevant to the hedgerow and pollinator strips, respectively. The costs of the measures for low-input improved grasslands were identified in that invest case at approximately £460 per ha.

The overall scale of the costs for these lowland farmland investments depends on the extent of improvements identified. As context, the UK BAP Costings (GHK, 2010) identified UK habitat action plan costs of approximately £107 million per year for hedgerows and £35 million per year for arable field margins, between 2010 and 2020. It also identified a further £197 million per year for widespread species in England (many of which are in lowland farmland). This suggests total costs for delivering lowland farmland BAP actions of up to £300 million per year in England.

Alternatively, the costs of managing the extent of the respective natural capital assets in England identified in the preceding Sections can be crudely estimated from the figures in Table 5.2:

- For the majority of the 154,000km of lines of trees on lowland farmland that were formerly hedgerows, restoration at £7 per metre would cost up to £1bn.
- Improved grasslands cover 22% of the land area (approximately 2.8m ha), part of which is low-input. If measures were taken on 0.5 million ha of low-input improved grassland, this would cost £230m/yr, or £5.6bn over 50 yrs.
- Arable and horticultural land occupies 30% of England (approximately 3.9m ha). Cereals account for 51% of the arable land in Great Britain. Estimating the average national field size to be 12 ha suggests that there are 400 000 km of cereal field edges in the UK. If all such boundaries included a 6m managed margin, some 200,000 ha of land would be brought into sensitive management[47] At £486 per ha, this would cost £97 million/yr, or £2.4bn over 50 years.

These calculations indicate costs of £100s millions to implement investments in hedgerows, low-input improved grasslands and pollinator strips on a widespread basis. These figures should be regarded as approximate estimates for a number of reasons. Firstly, they represent average costs across a range of farm types and conditions across England. Secondly, costs to farmers will vary depending on the circumstances of the farm business and exogenous factors such as global food prices. Finally, agri-environment payments rates have previously included an element of ‘incentive’ (i.e. profit) and therefore data on past spending (e.g. on hedgerows) may overestimate the costs involved.

5.3.5 Appraisal of Agricultural Subsidy Options

Adopting farm measures to enhance natural capital means adjusting farm business objectives for the production of multiple benefits. Maintaining food production would still be the main objective, but marginal changes in production systems can have large benefits for the state of natural capital and levels of other ecosystem services. Achieving these changes will require redirection of public funding, from within the existing subsidies to agriculture, to compensate farmers for the opportunity costs of enhancing natural capital.

The Rural Development Programme for England (RDPE) is the mechanism through which the European Union’s Common Agricultural Policy (CAP) Pillar 2 funds are distributed. Evidence on outcomes associated with RDPE has been used to estimate the benefits associated with transferring funds from support for agricultural production (known as Pillar 1) into measures that target environment outcomes (known as Pillar 2) during the 2014 – 2019 budget period (2011 prices) (Defra, 2013).

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[47] http://www.nebiodiversity.org.uk/biodiversity/habitats/farmland/cerealmargins/default.asp

Benefits of spending under Pillar 2 encompass economic, environmental, and social benefits, across the existing funding streams in the programme. Estimates of the benefits of increased Pillar 2 spend were made by taking the benefit:cost ratio estimates for each of the funding streams of the programme and multiplying by the relevant estimate of cost in each scenario. An implicit assumption of this methodology is that Pillar 2 spending offers constant returns to scale.

The costs of delivering the RDPE programmes, including administration (public and private) are subtracted from the benefits figures in order to generate a net benefit. Table 5.3 shows the benefits of increased spending under Pillar 2 by transferring funds to it from Pillar 1. It should be noted that these benefits are over and above the benefits of the do minimum 1% transfer.

Table 5.3: Benefits of Pillar 2 Funding Allocation Options, 2014 - 2019

Option		Funding transferred from Pillar 1 to Pillar 2 (£m)	Gross benefits of additional Pillar 2 spending (£m)	Estimated totals costs, including admin costs (£m)	Net benefits of transferred (£m)
9% transfer		1,215	2,615 – 2,885	1,076 – 1,294	1,349 – 1,809
15% Transfer		1,889	4,762 – 5,089	1,767 – 2,040	2,760 – 3,322

Note: In order to avoid double counting, the revenue costs of the production lost as a result of the transfer are not taken into account in these benefit figures. The costs and benefits are presented together in Table 5.4 below. Source: Defra (2013a).

For comparison, the total costs of the lowland farmland investments discussed in this paper over five years (2014-2019) are a one-off investment of up to approximately £1bn in hedgerows, and approximately £1.6bn for the field margin and grassland investments (total £327m/yr).

Table 5.4 summarises the costs and benefits of transferring funding from Pillar 1 to Pillar 2. The benefits are those additional net benefits generated as shown in Table 5.3. The costs of reducing Pillar 1 arise from a small reduction in agricultural production, which has a present value (PV) of £100m over the same five year appraisal period (2014-2019). These costs will be overestimated as they are compared to a baseline of no transfer and are lost revenue figures unadjusted for cost of sales. The transferred funding itself is not counted as a cost or benefit in either calculation.

Table 5.4: Costs and Benefits of Pillar 2 Funding Allocation Options, 2014 – 2019

Option	Scenario	Benefits of Pillar 2 spend (£m PV)	Costs of transfer - lost production (£m PV)
1	9% transfer	1,349 – 1,809	67
2	15% transfer	2,760 – 3,322	100

Note: Costs are estimated as lost production (i.e. revenue). However this is an over- estimate of the actual costs of the transfer as farmers would save the resource costs of this production. For each of the transfer scenarios there are options for how the funding is allocated between different schemes within Pillar 2. The benefits presented in this table are the range of the central benefit estimates for each of those different options. Further sensitivity analysis is available in the RDPE impact assessment. Source: Defra (2013a).

The PV of the benefits of increasing the transfer to 15%, net of the cost of delivering and administering the RDPE programmes, were £1,410m – £1,510m. The costs of this transfer are a small reduction in agricultural production, which has an estimated PV of approximately £100m. This analysis suggests that transfer of spending to Pillar 2 has a benefit:cost ratio of over 10.

6. CONCLUSION

The evidence covered has focussed on three examples of potentially widespread actions to protect and improve natural capital in lowland farmland in England: 1) Hedgerow enhancement, 2) Pollinator strips on field margins, and 3) Changes to low-input improved grassland management.

Site and farm-scale evidence show that these actions provide a range of ecosystem service benefits, including:

- Supporting farmland biodiversity, including pollinators;
- Pest control within arable systems;
- Sequestration and storage of carbon;
- Regulation of the quality and quantity of water runoff, and
- Landscape.

These services are provided by a variety of mechanisms. For example, water quality may be improved by both minimising chemical applications and providing features which can buffer more productive areas, e.g. pollinator strips or hedgerows. The extent of benefits for different ecosystem services is very complex to assess. For example, providing pollinator strips will increase biodiversity, and would be likely to lead to positive population growth for a suite of insect pollinators in agricultural land. However, other conditions like the availability of nesting sites for such pollinators (e.g. bees) would influence whether there is an increase pollination services and this may depend on presence of hedges and associated basal habitats.

At a landscape scale a significantly enhanced understanding is required of how actions to protect and improve lowland farmland natural capital will best deliver biodiversity and ecosystem service goals in a cost effective manner. This needs to balance both understanding of current costs and benefits of actions in the farm production system, and also future impacts on the ecosystem, including those relating to risks and non-linear responses. For example, impacts of plant diseases such as ash die back or changes in cropping patterns are likely to have profound impacts on delivery of ecosystem services from agricultural landscapes. Designing management actions that will help to provide landscapes which are resilient to such change is vital. Greater diversity of tree species and better hedgerow condition can therefore mitigate risks to hedgerow services as a result of tree disease.

The available evidence suggests that funding widespread measures to improve lowland farmland natural capital could have substantial costs, as shown in Table 6.1. However, evidence from commercial demonstration farms discussed in Section 5.2 suggests that such measures can be implemented without compromising farm profitability.

The benefits from these measures would be a substantial part of the overall benefits expected from agri-environment measures, of which they are a part, which have an estimated PV of £12bn. These costs and benefits are not for the same sets of actions so cannot be directly compared, but appear to be of a similar order of magnitude. Both the costs and benefits evidence identified are averages, and are expected to vary substantially with local conditions.

This caveat also applies to recent appraisal of policy options to transfer funding from support for agricultural production to agri-environment and other rural development spending. However, the available evidence suggests that the significant benefits of the latter (estimated at over £1bn) would exceed the costs of lost agricultural production (approximately £100m) over the next 5 years.

Table 6.1: Summary of Impacts of Three Potential Lowland Farmland Investments in Natural Capital

		Grasslands	Hedgerows	Pollinator Strips
Costs		Unit costs of livestock reduction £120-460/ha. On 0.5m ha of grassland = £230m/yr. PV of £5.6bn.	Unit cost £7/m. Cost of improving up to 154,000km of former hedge-row has PV of up to £1bn.	Unit cost to create strips arable field margins = £485 per ha. For 0.2m ha = £97m/yr. PV of £2.4bn
Benefits		Part of overall benefit from agri-env measures with PV of £12bn. Based on valuation studies for outcomes of agri-env schemes in England (all measures covered).		
Key non-monetised benefits		Benefits to farm of improved forage quality, lower synthetic fertiliser costs. Benefits of some (especially regulating) ecosystem services: retained soil carbon, water regulation, pollination.	Pest control in arable systems. Unclear which benefits are reflected in valuation estimates: climate and water regulation, pollination and aesthetic services will all increase.	Option value/ resilience of pollination services. Pest control in arable systems. Benefits of some (especially regulating) ecosystem services.
Time period		Results of interventions observed within 4 yrs.	Results of rejuvenation observed within 1-5 years. Restoring woody structures 5 – 10 years.	Results of rejuvenation observed within a year.
		PVs over 50yrs at HMT discount rates.		

This evidence suggests that measures to protect and improve lowland farmland natural capital need to be targeted to where they provide greatest benefits for a range of ecosystem services in order to outweigh their costs. More evidence is needed on the spatial variation in the balance between the costs and benefits of these actions. However, evidence that representative of lowland farmland across much of England suggests such actions could be undertaken at a large scale.

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INTEGRATED CATCHMENT MANAGEMENT: EVIDENCE BASE

SUMMARY

- *A range of actions in the other investment cases examined (particularly in lowland farmland, and for peatlands, woodlands and wetlands) can improve water (quality, quantity and flood hazard) regulating services in a catchment. In addition to investment in these actions, investment in coordinating them can deliver additional benefits as part of integrated catchment management.*
- *A governance process to undertake coordination, in addition to the individual actions, requires additional resources and hence it is the focus of this investment case.*
- *Coordination of these actions has strong potential synergies, it can also benefit biodiversity and habitat connectivity, landscape, recreation and soil condition.*
- *Evaluations of exemplar projects suggest positive economic returns, and the approaches they demonstrate are being taken up in surrounding catchments.*

Investment: Coordinated implementation of actions (existing/potential adjustments to rural land uses) to manage water regulating services in a catchment.	
Baseline: A range of issues (diffuse pollution, soil compaction causing rapid runoff) are compromising water regulating services in catchments. Coordination of efforts should not be left to goodwill, or assumed to be covered by individual investment budgets.	
PV of costs: £100ks - £ms per catchment.	**PV of benefits:** £millions of benefits/ avoided costs per catchment.
Monetised costs: Governance to coordinate actions and farm planning, capital works.	**Monetised benefits:** Avoided flood damage/ protection expenditure. Reduced water treatment costs.
Non-monetised impacts: Opportunity costs of reduced production from land used for catchment measures. Some biodiversity and cultural benefits. Soil retention.	
NPV: N/A	**Time period:** Results of interventions observed within 1-5 yrs.
Key assumptions: Governance structures are able to agree coordinated implementation of actions in a catchment.	
Additionality: Extensive actions are underway (e.g. Catchment Sensitive Farming Initiative), but more are needed for Water Framework Directive (WFD) delivery. Costs and benefits of individual actions involved may not be additional, but their coordination in catchments brings additional benefits (synergies), and costs (admin).	
Synergies/conflicts: Significant synergies, involving coordination of actions in other potential investment cases (peatland, woodland, farmland, wetlands).	
Impact on natural capital assets: Retention of soil and improvement to ecological communities in catchments. Improvement to water resources.	
Scale of impacts: Potentially large – values of water resource improvements will diminish little with increases in the number of catchments. Exemplars are being scaled up to surrounding catchments, but	

impacts are catchment-specific. The Environment Agency’s current WFD proposals (consultation opened October 2014) identify beneficial additional agricultural measures in over 50% of catchments.
Distribution: Costs to land use activities, particularly agriculture, potentially compensated by payments from water customers and/or taxpayers (but contradicts polluter pays principle).
Uncertainties: Potential effects of increased frequency of intense rainfall, due to climate change and hence future benefits to manage these effects. Urban land use can be relevant, but is not considered.

Example: Cornwall Rivers Project (CRP)

The Cornwall Rivers Project, run by the Westcountry Rivers Trust, provided advice and grants to farmers and landowners in order to support environmentally sensitive farming practices, as well as enterprise diversification. The project took a catchment scale approach to respond to the degradation of natural ecosystems, changing land-use practices to address this whilst also improving the efficiency of agricultural practices (e.g. one farmer was persuaded to move from growing fodder beet to growing grass to reduce the risk of soil runoff and to save costs). Activities relevant to the management of natural capital included under-sowing, bi-cropping, buffers along watercourses, managing banksides and changing applications of fertilisers and pesticides. A partial valuation of benefits was made, before the project was fully completed. This estimated a benefit:cost ratio of over 4:1 (using a 10-year time horizon and the Green Book’s 3.5% discount rate) and included an increase in annual on-farm income.

1. INTRODUCTION

This case study examines investments in improved management of catchments. Catchments are areas of land which can be delineated by the extent to which rain or snow that fall reach a common water body and may incorporate a range of land use types. Improvement of water regulating (quality, quantity and flood hazard) services in catchments may incorporate a range of different activities across these different land use types, depending also on topography, soils and other factors. Integrated catchment management can also benefit biodiversity and habitat connectivity, landscape, recreation and soil condition.

For integrated catchment management the combination of activities affects the final delivery of services. The actions discussed as potential interventions in several other investment cases can all potentially contribute in different ways to catchment management, namely:

- Farmland - hedgerow management, pollinator strips, grassland management;
- Woodland;
- Peatland, and
- Wetlands.

However, potential management actions are not limited to measures included in the investment cases above. For example, the Belford flood attenuation project (see Section 2.1) involves installation of small embankments to intercept peak rainfall. In fact, given that all land area is within a catchment, all natural capital (except for marine systems) may be subject to restoration options. Although the primary services aimed at through catchment approaches are to do with water, in many cases positive impacts on service delivery may occur for all service types (e.g. improved agricultural production, increases in carbon sequestration, improved access). The case studies described below involve different combinations of actions, but also require governance to coordinate them across a catchment, based on interpretation of local evidence on the best solutions in a particular area. So while individual actions can be assessed, evaluation of the effectiveness of integrated catchment management investments is also likely to require an evaluation of the governance framework that coordinates how they have taken place.

The potential importance of governance structures around catchment investments mean that the outcomes of catchment management are difficult to predict. Furthermore, there are large uncertainties in the evidence of the impacts of actions. For example at the 2014 CIWEM conference (Helen Dunn, pers com, November 2014), speakers highlighted the variability reported in the literature on how woodland creation reduces catchment flood peaks, from <5% to over 50%. This means that integrated catchment management approaches need to be assessed on a case by case basis, and this is reflected in the approach taken by the Environment Agency in developing its River Basin Management Planning proposals for delivery of Water Framework Directive (WFD) objectives)[48].

Therefore, it is hard to predict the impacts of measures, particularly in terms that allow comparisons to alternative approaches. For example, the Belford case study (see Section 2.1) involves actions with relatively modest costs (approximately £100k's for capital works, with low

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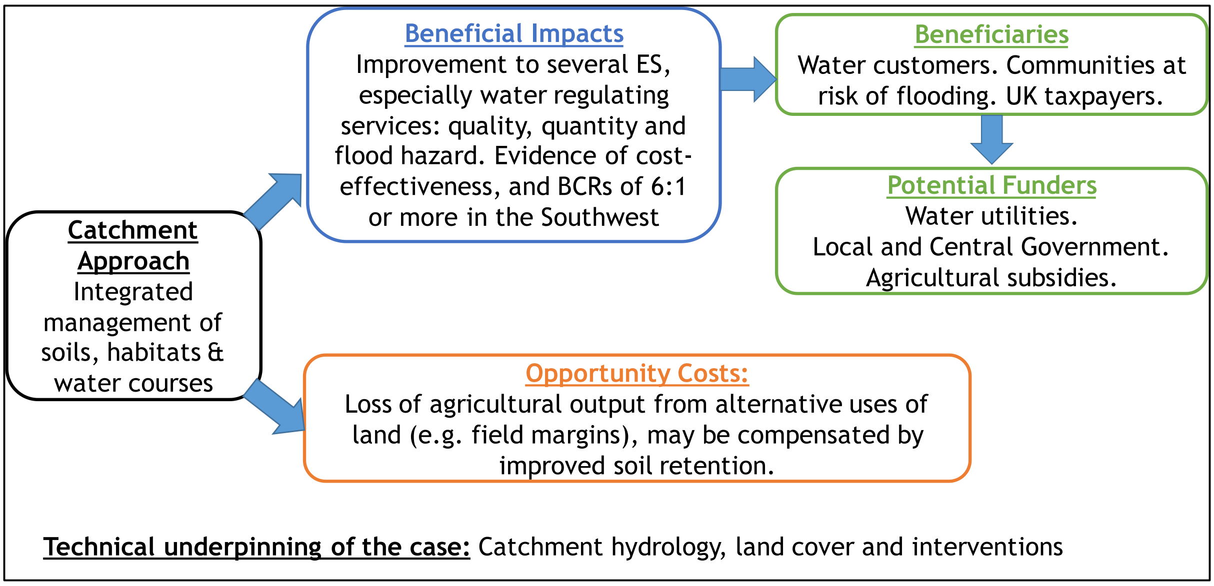
[48] Consultation opened in October 2014, see: https://consult.environment-agency.gov.uk/portal/ho/wfd/draft_plans/consult

ongoing maintenance costs), compared to alternative investments in engineered solutions costed at £4m. However, the effects of these different approaches are hard to compare in order to evaluate cost-effectiveness.

Figure 1.1: Integrated Catchment Management Value Chain



Catchment Approach
Integrated management of soils, habitats & water courses

Beneficial Impacts
Improvement to several ES, especially water regulating services: quality, quantity and flood hazard. Evidence of cost-effectiveness, and BCRs of 6:1 or more in the Southwest

Beneficiaries
Water customers. Communities at risk of flooding. UK taxpayers.

Potential Funders
Water utilities.
Local and Central Government.
Agricultural subsidies.

Opportunity Costs:
Loss of agricultural output from alternative uses of land (e.g. field margins), may be compensated by improved soil retention.

Technical underpinning of the case: Catchment hydrology, land cover and interventions

2. CATCHMENT MANAGEMENT CASE STUDIES

This Section summarises published information on three catchment management projects, from Belford in Northumberland, and The Cornwall Rivers Project which was subsequently expanded into the third example: the Upstream Thinking project. The examples illustrate different approaches to catchment management in terms of purpose, scale, institutional arrangements and outcomes.

2.1 Belford

In 2007 the Northumbria Regional Flood Defence Committee funded a catchment management project in Belford. The aim was to apply innovative approaches to catchment management to slow and reduce the runoff in the catchment, thereby avoiding potential flooding incidents and reducing the impacts of dissolved nutrients on water quality downstream. This is an interventionist approach to managing water quality and quantity at the catchment scale. The scheme was funded by the EA's North East Local Levy, and stakeholder consultation was held throughout the Catchment Systems Engineering process.

On-line and off-line pond features, which involve either a bund across the river or a bund adjacent to the river that excess water spills into, were installed in order to slow the runoff from farmland. In order to slow the flood peak and divert it on to the floodplain, large woody debris was installed in woodland. Greater roughness was provided by planting shrubs and pinning timber to the woodland floor, and in some areas, bands of willow have been trialled across watercourses. In order to determine the location of flow pathways and potential storage areas, the Farm Pond Location Tool, or Farm PLOT, was used. These measures aim to control runoff in order to reduce the risk of flooding during extreme events, in doing so they reduce the risk of soil erosion. They also regulate runoff under day-to-day conditions, thereby increasing retention of sediment and reducing flows of particulates and nutrients into surface water bodies.

2.1.1 Costs and Benefits[49]

The traditionally engineered flood defences (the baseline scenario) for Belford are estimated to have cost around £4 million. The capital and maintenance costs of the measures installed in the catchment are estimated to be of the order of £tens of thousands to £100,000[50], and therefore an order of magnitude lower than tradional approaches. However, it should be noted that in order to manage increased risks of flooding due to climate change, the catchment and traditional methods of managing flood risk may be both be needed, rather than being alternatives in this context.

The area of land occupied by the catchment management structure has an opportunity cost. Work in Belford contributed to the conclusion (Quinn et al. 2007a, cited in Wilkinson et al 2010), that if between 2-10% of the surface area of the catchment is used for runoff storage and mitigation features, then the properties of a catchments runoff regime can be radically altered. This proportion of land is not necessarily taken out of production – while it would store water during

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[49] Source of cost and benefit information: http://www.parliament.uk/documents/post/QuinnPOST.pdf

[50] Based on costs of £10-300 per meter for bunds of different types (Wilkinson et al 2010). Bunds are typically 10's of meters in length at most and therefore cost between £100's-£1,000's each normally. Typically 10's of bunds may be deployed within a small catchment (The Belford Burn catchment is 6km^2), allowing capital costs to be estimated in the region of £50,000 - £100,000, or around £10,000 per km^2. It should be noted that maintenance of features is important to retain their flood storage capacity over time (e.g. by removing silt).

flood conditions it could be available for lower intensity farming (e.g. livestock grazing) during normal weather conditions. The retention of silt in the bunds requires resources to be deployed to remove this to retain its flood attenuation capacity. However, as well as costs for this action, it can have benefits to farming by providing a source of fertile soil.

Benefits of the catchment techniques include the following:

- Storing and slowing run-off in the catchment to reduce the risk of flooding in Belford.
- Storing water in ponds on fields accumulates sediment picked up by overland flows which can be returned to the farmer's fields.
- Creating wetlands on some of the ponds provides improved water quality, a new habitat for wildlife, and overall increased biodiversity of the catchment
- Farmers have seen improved yields from crops grown where field ponds have been created.

The benefits listed above were not monetised, though the change in volume capacity of catchment areas was assessed using the Pond Network Model.

2.1.2 Scalability

Due to the uptake of similar runoff management projects in other areas to mitigate future flooding, there is evidence that this approach could be undertaken on a wider scale. Other areas which have adopted a runoff management approach in Northumbria include Netherton, Dyke Head, Powburn, Hepscott, and Nafferton Farm. This indicates that those initiating these schemes believed that the beneficial results observed in Belford can be replicated in other catchments, and thus that similar measures can be used at a larger scale (across further catchments with similar characteristics). The only monetary data available for the catchment is the potential cost of using traditional methods to mitigate flooding (which may be partially avoided as a result of the catchment approach implemented) and therefore feature as a cost saved (benefit). The relevance of this cost saving at other sites depends on the similarities of catchments (e.g. geography and size of the catchment).

2.2 Catchment Management Case Study: Cornwall Rivers Project[51]

The Cornwall Rivers Project (CRP), run by the Westcountry Rivers Trust, provided advice and grants to farmers and landowners in order to support environmentally sensitive farming practices, as well as enterprise diversification. The project was designed in order to respond to two problems:

1. The threat to the riverine environment in Cornwall as a result of degradation of natural ecosystems, due to a variety of activities; and
2. Changing land-use practices which do not adequately support the agricultural sector.

Its primary aim was rehabilitation of the key rivers and their catchments across the areas while bringing improvement in the economic viability of local rural communities. The project tackled these two problems in a linked and integrated catchment scale approach that simultaneously promoted environmental improvement and economic benefits. Its methods were based on provision of advice and grants to farmers and landowners to support environmentally sensitive farming practices. These practices led to enterprise diversification that generated increased farm income

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[51] Based on an evaluation by Le Quesne (2005).

and improved environmental quality. Parallel to this, riparian projects sought to directly improve environmental quality and access to fisheries, leading to increased economic benefits to the region.

The project ran from January 1, 2002, to December 31, 2004. The project was based on methods that were used by the Westcountry Rivers Trust's *Tamar 2000 SUPPORT* and *Taw/Torridge Westcountry Rivers* projects, which proved to be successful. Additionally to this, the CRP led "*riparian projects sought to directly improve environmental quality and access to fisheries, leading to increased economic benefits to the region*" (Le Quesne, 2005, p.4).

2.2.1 Costs and Benefits

An economic evaluation assessed the economic impacts of the CRP, including overall costs (see Table 2.1) and benefits (see Table 2.2) from the project. It must be noted, though, that the economic assessment took place before the CRP was fully completed (data was collected for the report in October 2004). The assessment used a 10-year time horizon and the standard Green Book (2003) 3.5% discount rate.

Table 2.1: Costs of the component elements of the CRP (£, 2005).

Project element	Total Project Cost (£)
Preparation of 612 integrated land management and farm business plans, including the preparation of comprehensive farm practice information sheets	819,000
Farm business contributions towards the implementation of farm business plans	309,000
The contribution of £176,000 and administration of 239 grants to farmers for riparian improvement works	609,000
Establishment and maintenance of Angling 2000 scheme	67,000
Delivery of community projects including demonstration sites, education, etc.	136,000
Total	**1,940,000**

Source: Le Quesne, 2005, p.8.

The average cost of delivery of each of the integrated land management and farm business plans was £1,338 per farm. On farm benefits make up approximately three-quarters of the quantified benefits. The project was received well overall, with 97% of customers and 100% of other stakeholders giving a positive rating to the quality of the team.

Analysis of benefits was summarised underthree categories: direct, on-farm benefits; benefits from improved quality and access to angling; and indirect, off-farm benefits (Table 2.2).

A CBR is not provided due to the fact that the majority of benefits are not quantified. Non-quantified benefits include reduced forms of pollution, and the reduced external costs from soil loss. Of the benefits quantified, the economic evaluation estimates a net present value of £9,224,000. Although the assessment could only partially assess benefits, they exceeded the estimated of quantified costs.

Table 2.2: Summary of Quantifiable Economic Impacts of the Cornwall Rivers Project

	Benefits(£)
Agricultural benefits, on-farm	
Reduced soil loss, annual saving	145,260
Improved fertiliser use, annual benefit	337,095
On-farm tourist income, annual benefit	68,010
Additional annual on-farm benefits	287,640
Total annual on-farm benefits	838,005
On-farm benefits, net present value	**7,176,142**
Cost to CRP of delivery of farm plans and farm improvement grants	819,070
Cost to farm business of implementing recommendations	309,000
Total Cost of On-farm benefits	**1,128,070**
Angling 2000 benefits, local economy	
Net annual benefit from Angling 2000	13,636
Net present value of Angling 2000 benefits	116,770
Cost to CRP of establishment of Angling 2000	**33,318**
Benefits of increased number of salmon and sea-trout, local economy	
Annual benefit of increased salmon and sea-trout catches	223,824
Net present valeu of increase in salmon and sea-trout catches	1,916,686
Cost to CRP of generating increased salmon and sea-trout populations	**608,848**
Benefits of reduced diffuse pollution	
Annual reduction in dredging costs, Fowey Harbour	1,666
Net present value of annual reduction in dredging cosdts, Fowey Harbour	14,258

Source: Le Quesne, 2005, p. 10.

Based on this partial valuation of benefits, a benefit:cost ratio can be calculated, with estimated benefits being over 4 times larger (£7.2m:£1.8m) that estimated costs. It is also estimated that annual on-farm income increased more than £1,369 per farm.

2.2.2 Scalability

It is reasonable to assume that similar projects could be implemented in other areas of England with similar characteristics (e.g. relatively steep and high rainfall catchments with a mixture of agricultural practices). Therefore, the measures taken are more likely to be relevant in catchments in north and west England. The development of the Upstream Thinking Initiative (see case study 3) reflects this.

2.3 Catchment Management Case Study: Upstream Thinking

The aim of Upstream Thinking, a project run by South West Water, is to improve water quality in river catchments, in order to reduce water treatment costs. This project looks at what influences water quality and quantity across entire catchments, targeting pressures at their source through improved land management. Part of the project helps farmers and land managers to keep peat soils and natural fertilisers on their land, and funds action to improve water and slurry management, with the aim or reducing the energy, chemicals, and costs needed to treat water in the long-term. This work was undertaken at the catchment scale, working with individual land management and farm business plans. Due to differences in characteristics such as type of farming, and land quality, individual plans have to be tailored towards the specific region where they are to be carried out.

Projects are taking place in the Dartmoor Mires; under the Westcountry Rivers Trust (building on the actions described in case study in Section 2.2: Cornwall Rivers Project); in the Exmoor Mires; the Culm area of Devon (the Working Wetlands project); Wild Penwith; and Otter Valley. Below is a brief summary of the goals of each project:

Dartmoor Mires Project: This project aims to restore Dartmoor's blanket bog, with the goal to improve water supply, increase carbon storage to mitigate the impacts of climate change, and enhance and conserve the habitat for wildlife.

Exmoor Mires Project: The aim of this project is to 're-wet' dried out peat bogs, which will enable the bogs to retain carbon and water. Due to years of peat-cutting and drainage ditch creation, the mires have dried out.

Westcountry Rivers Trust: A land management project which targets landowners. The goal is to improve raw water quality through informing and assisting landowners on the protection of river catchments.

Working Wetlands: This project is being undertaken in the Culm area of Devon, and aims to work with landowners to recreate a 'Living Landscape'. Living Landscapes are the Wildlife Trusts' landscape-scale approach to nature conservation, aimed at restoring, recreating and reconnecting habitats.

Wild Penwith: Another 'Living Landscape' project in the Penwith peninsula (in West Cornwall). This project once again targets landowners with one-to-one farm advisory visits; free training events; and a capital grant award.

Otter Valley: A project which targets land management, through improving raw water quality to reduce treatment costs post abstraction.

2.3.1 Costs and Benefits[52]

It is estimated that by 2015, costs will be 65p per year per customer[53] in the South West Water region. It should be noted that this figure is likely to vary between regions based on differences in in catchment sizes, other influences on water bills, number of customers, and the current state of water catchments.

Evaluation of the capital expenditure in the programme has positive projected benefit to cost ratios (BCR). This, along with the low projected customer costs, is indicative of very good value for money, but BCRs reflecting full (capital and operating) costs have not been published. The benefit cost-ratio does not reflect land-management payments that support ongoing management after the capital expenditure. However, it is hard to determine if such payments are additional, for example because agri-environment schemes are likely to have already been making payments into these catchments before the scheme started.

It should be noted while the projects within the Upstream Thinking initiative are motivated by water resources management, they also produce a range of other benefits. For example, the benefits listed as a result of the Exmoor Mires project include increases in:

- water storage in upland catchments;
- water quality;
- carbon storage (voided carbon losses from dried peat) in the peat soils[54];
- wildlife on the moors;
- recreational enjoyment for moorland visitors;
- forage and water sources for livestock, and
- health of livestock through avoidance of pests and other problems

(Source: Upstream Thinking: A South West Water Initiative, 2014).

2.3.2 Scalability

It is likely the approach taken in the Upstream Thinking Initiative, focussed on entire catchments, could be applied in other river basin districts in regions of England with similar characteristics.

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[52] Cost and benefit information taken from the following website: http://www.southwestwater.co.uk/index.cfm?articleid=8329

[53] South West Water serves an area with 1.6m residents: http://southwestwater.custhelp.com/app/answers/detail/a_id/114/~/what-area-does-south-west-water-serve%3F

[54] Ofwat has also commissioned a project to research and monitor the hydrological and ecological effects of rewetting peatland. This evidence is discussed further in the peatland investment case.

3. POTENTIAL SYNERGIES BETWEEN CATCHMENT MANAGEMENT AND OTHER NATURAL CAPITAL PROTECTION AND IMPROVEMENT MEASURES

The catchment management case studies described above involve coordination of an integrated set of actions in a catchment, to enhance delivery of water regulating and other ecosystem service benefits. Alongside the costs of the actions taken, which may not be additional to other natural capital protection and improvement activities, there are costs attributable to the governance effort required to ensure that integrated catchment management occurs; assessing the types and location of pressures in a catchment and co-ordinating action to target them appropriately.

3.1 Costs of Coordination

This cost is identified in the CRP evaluation as being £1,777[55] per plan for over 600 farm plans. This compares with reported costs of £2,390 per farm for 15,000 farms under the government's Farm Business Advisory Scheme (FBAS) operating at the time. The figures in Table 2.1 suggest that this farm planning process occupies approximately 40% of project costs.

Administration costs associated with expenditures on environmental enhancements were estimated by GHK and eftec (GHK, 2011) in relation to the costs of biodiversity offsets. These are of some relevance to catchment management spending because they involve targeted spend to achieve specific environmental outcomes. However, they may be significantly different, for example because the degree of environmental change, and therefore gross expenditure per area, may be higher for offsets. Evidence cited in GHK and eftec (2011) that is of relevance to catchment management included that:

- The UK BAP costings incorporate a 15% increase in the costs of biodiversity actions to cover administration costs. The 15% figure is based on the average administration cost of agri-environmental schemes (mainly the entry-level scheme). The relatively low costs reflect the standardised (with limited targeting) nature of the entry-level scheme and similar schemes.
- Evidence from the Royal Society for the Protection of Birds based on EU LIFE grants suggests total transaction costs are typically 6% - 30% of the other project costs.
- Data from the Environment Agency (EA) on habitat creation programmes estimated that transaction costs are 30% (reedbed) to 74% (wet grassland) of habitat management costs. The high costs may reflect the high negotiation costs to EA of securing areas of land for habitat works. These costs would be expected to be reduced within an offsets system because the market price provides the incentive for landowners to make areas of land available, so proactive negotiation of deals, as needed by the EA, will not be a factor.

This evidence suggests that the costs of coordinating catchment management actions may be the addition of around 30% to the costs of existing actions within a catchment.

Nature Improvement Areas (NIA) were established in 2012 to encourage coordination of actions to create joined up and resilient ecological networks at a landscape scale. Their total awarded

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[55] Source: L Quesne (2005). Costs inflated to 2014 prices.

funding of £7.5m[56] (approx. £200k per Area per year) is a resource that can only have an impact on natural capital by coordinating larger expenditure more effectively. NIAs are discussed further in Section 3.3.

3.2 Benefits of Coordination: Synergies

The potential for synergies and conflicts between the different natural capital protection and improvement measures considered in this project are discussed in the (see Final Report Section 5]. The analysis in the technical report did not identify any serious conflicts, but stated that catchment management (with a primary focus on water ecosystem services) was a key activity with potential for synergies with the delivery of a range of ecosystem services. The analysis is developed further here by examining the impacts of enhancing natural capital assets for specific ecosystem services and investigating their potential wider impacts. For several individual habitat investments, actions designed for the purpose of enhancing a specific set of ecosystem system services will also result in enhancement of further services. For example, the value of investment in woodlands is mainly related to carbon storage and recreation benefits (see Woodland Investment Case in this document), but well-positioned woodland planting can also play a significant role in catchment management. Research in Upper Wharfedale (North Yorkshire) concluded that a targeted increase of woodland cover by 5.6% could prevent 80% of sediment from entering the river (Lane et al, 2008).

An initial assessment of the extent of synergies across catchments is analysed for four ecosystem services in Table 3.1:

- Regulation of water quality (W.Ql);
- Regulation of water quantity (W.Qt);
- Carbon sequestration and storage (C), and
- Maintenance of biodiversity (BD).

Table 3.1 shows potential synergies between investing in natural capital assets (peatland, lowland farmland, freshwater wetlands, and woodland, i.e. major land use types) and the impacts on the delivery of ecosystem services in catchments[57].

The overall impact of multiple natural capital assets within a catchment (or other landscape area) can be to enhance the overall value of service delivery (such as increasing returns to cultural services related to greater connectivity of habitats for biodiversity associated with contiguous habitats). This impact may be non-linear. The opposite may occur: that the combined value from multiple natural capital assets can be reduced due to diminishing returns. For example, the presence of field margin buffer strips may regulate surface water runoff and therefore reduce the additional runoff regulation benefits of a downslope area of woodland. These factors reflect the need for coordination of effort when deciding the location of actions within a catchment.

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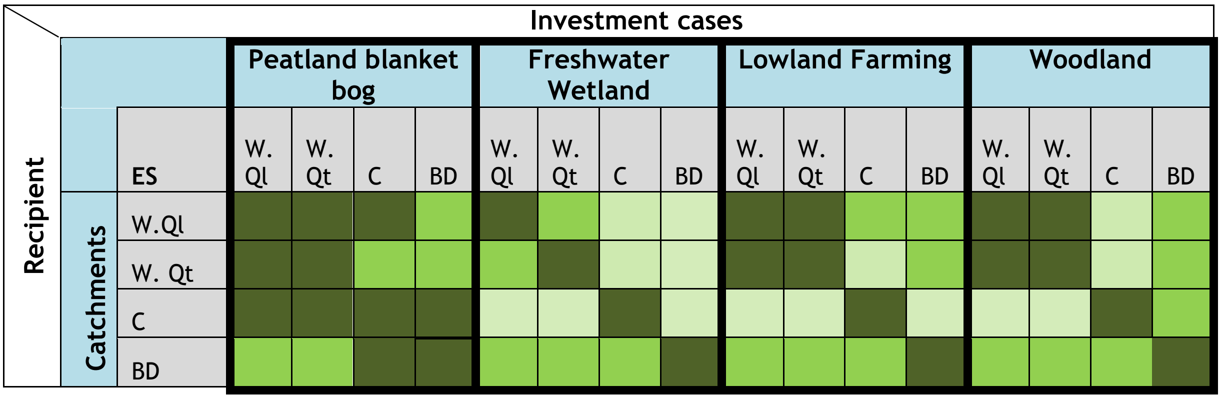
[56] https://www.gov.uk/government/publications/nature-improvement-areas-improved-ecological-networks/nature-improvement-areas-locations-and-progress

[57] The synergy is read by looking vertically down a 'investment case' column for an asset/ecosystem service to a cell of interest and then left across to catchment row to see the 'recipient' ecosystem service. The colour of that cell indicates the potential synergy between the driver and the recipient.

Further explanation of the ratings is provided below the table. The services considered are not limited to water regulation, because achieving multiple benefits (e.g. water and climate regulation) will be necessary to maximise returns to investments.

Any investment to improve a given service will benefit the provision of the service by the catchment. This is shown by 'high' synergy for the same ecosystem service combinations in each investment area (diagonal lines in each investment case box). But for other services, the outcomes of actions are variable. For example, for three of the habitats (peatland blanket bog, lowland farming and woodland), measures to improve water quantity regulation will also prevent sediment loss, and measures to improve water quality regulation will need to slow flows to reduce sediment and nutrient transport, so will improve water quantity regulation. Therefore, investments in water quality and quantity are judged to have a high synergy with one another for each of these habitats. However, this is not the case for wetlands, where measures to regulate water quantity will trap suspended sediment and chemical contaminants. However, wetlands are not expected to prevent soil erosion in the same manner, and can only trap sediments in water that passes through them, so are rated 'medium' synergy.

Table 3.1. Initial assessment of synergies between catchment and other investment cases



			Investment cases															
			Peatland blanket bog				Freshwater Wetland				Lowland Farming				Woodland			
		ES	W. Ql	W. Qt	C	BD	W. Ql	W. Qt	C	BD	W. Ql	W. Qt	C	BD	W. Ql	W. Qt	C	BD
Recipient	Catchments	W.Ql	■	■	■	▩	■	▩	▤	▤	■	■	▩	▩	■	■	▤	▩
		W. Qt	■	■	▩	▩	▩	■	▤	▤	■	■	▤	▩	■	■	▤	▩
		C	■	■	■	■	▤	▤	■	▤	▤	▤	■	▤	▤	▤	■	▩
		BD	▩	▩	■	■	▩	▩	▩	■	▩	▩	▩	■	▩	▩	▩	■

Key		
Extent of Synergy	Rating	Description
High	■	Investment in asset leads to significant impact on ES provision with high certainty
Medium	▩	Investment in asset leads to significant impact on ES provision with low certainty or small impacts with high certainty
Low	▤	Investment in asset leads to small impact on ES provision with low certainty
None	□	Investment in asset leads to no impact on ES provision
ES: ecosystem services; W.Ql: water quality, W.Qn: water quantity, C: carbon sequestration and storage, BD: biodiversity		

The ratings in Table 3.1 are an initial assessment based on the judgement of the study team, and have not been subjected to peer review, or developed from fuller analysis of the literature, which would be desirable if more resources were available. The main points observed in undertaking the analysis are that:

- Single actions within habitats can influence the delivery of multiple ecosystem services (e.g. hedge creation, grip blocking, woodland creation);
- Co-ordination of actions across habitats within a catchment is generally aimed at impacts on water quality or quantity, but may also enhance the delivery of other services, and
- Optimising delivery of multiple ecosystem services within landscape areas may be possible - though there are likely to be conflicts as well as synergies - particularly when production (provisioning services) is concerned. Delivery of ecosystem services at multi-habitat

landscape scales will be dependent on spatial arrangement of habitats as well as temporal factors.

Synergistic relationships shown in Table 3.1 are extremely complex and context-specific, depending on the relative location of different land use types and water bodies within a catchment. However, the initial assessment of synergies in Table 3.1 shows that when investing in each habitat, in addition to the ‘high’ synergy on the diagonal, there are potential further synergies. It is recognised that these relationships can be extremely complex, and this the following is a simplified and high-level view:

- Water quality regulation potentially has medium synergy with water quantity regulation when from freshwater wetlands, and higher synergies from the other three habitats (as described above). It has lower synergies with carbon sequestration and storage, and medium synergy with biodiversity maintenance.

- Water quantity regulation similarly potentially has medium synergy with water quality regulation when provided by freshwater wetlands, and higher synergies from the other three habitats (as described above). It has lower synergies with carbon sequestration and storage, and medium synergy with biodiversity maintenance.

- Actions to maintain Biodiversity potentially have medium synergy with water regulating services, due to increasing variety of vegetation structure and soil condition.

- Carbon management actions have potential high synergy for measures for any of the four services under peatland. It otherwise has lower synergies except for with biodiversity measures from woodland.

4. POTENTIAL SCALABILITY OF CATCHMENT MANAGEMENT APPROACH CASE STUDIES

The three case studies presented in Section 2 identify catchment management actions where economic evaluations suggest a positive return on investments. However, the extent to which these successful catchment approaches can be scaled up is complex, and raises a number of questions:

a) Could the same measures taken in a different catchment achieve the same amount of improvement in ecosystem services?
b) How does the value of a unit of improvement in a given ecosystem service differ in different locations? and
c) How many people benefit from a given improvement in different locations?

The answers to these questions are influenced by geographical location (including topography, existing land uses, and climate) and how that relates to the ecosystem service beneficiaries.

The costs and types of actions required are also likely to vary according to local circumstances within catchments (e.g. land uses, topography). There may also be some economies of scale in the costs of undertaking actions between adjacent sub-catchments.

Catchment initiatives primarily focus on water regulating services (quality and flood attenuation). For these services, in relation to the questions above:

a) The replication of actions at Belford and under the CRT project in their surrounding areas suggest similar environmental improvements can be achieved more widely (see Scalability, below), at least in catchments with similar geographies.
b) The unit value of an environmental improvement in water regulating services is not significantly influenced by activities in other catchments, so is not expected to vary with the number of different catchments implementing them across the country.
c) Total benefits will vary significantly according to the number of people living in the catchment or receiving ecosystem service benefits from that catchment.

Therefore in general, the value of the costs and benefits of catchment management illustrated in the case studies are not expected to vary with scale per se, but are highly dependent on the environmental characteristics and population in (or benefitting from actions in) a given catchment. Therefore, a linear multiplication of benefits from a case study catchment to all similar catchments would not be advised. The remainder of this section examines the evidence on scalability in the case studies and in the EA's planning for the next round of WFD implementation.

4.1 Scalability and Additionality of Case Study Evidence

The three case studies all suggest that the beneficial actions taken could be scaled up and applied more widely:

- In the Belford case, the uptake of similar runoff management projects in other parts of Northumberland to mitigate future flooding suggests the project's actions have more widespread applicability. Other areas which have adopted a runoff management approach in Northumbria include Netherton, Dyke Head, Powburn, Hepscott, and Nafferton Farm. This suggests these approaches are at least applicable in other catchments susceptible to flash floods – i.e. which have significant variations in elevation between lowland and upland areas, relatively small areas of floodplain and high rainfall.

- The Cornwall Rivers Project noted that it is feasible to assume that similar projects could take place in regions incorporating catchments with comparable characteristics (i.e. undulating high rainfall catchments with a mixture of agricultural practices, including livestock, in the West of England). The success of such an approach would depend on a number of factors including funding to undertake the scheme and the availability of qualified individuals to run project teams. However, the extension of catchment management approaches by South West Water, through the Upstream Thinking Initiative, suggests the approach developed has more widespread applicability, at least within the same region.

- The Upstream Thinking Initiative has organised smaller scale projects taking place in different areas. Such an approach could be undertaken on a larger scale, with tailored sub-projects for each individual region. The estimated costs, though, are likely to differ depending on the region

It is recognised that in addition to the examples cited there are numerous other examples of catchment management initiatives in England. The Catchment Sensitive Farming (CSF) initiative reported that across its 50 priority catchments, some 9,023 farm holdings receiving advice directly (CSF Evidence Team, 2011). This represents 17% of all farm holdings within Priority Catchments (38% by area) and 45% within targeted sub-catchments (62% by area). The ECSFDI Capital Grant Scheme contributed towards £29 million of farm improvements. The Environment Agency's Catchment Restoration Fund approved 42 projects with a combined value of £24.5 million during 2012/13 – 2014/15. Project value ranges from £89k up to £2.1 million[58].

The Ecosystem Markets Taskforce reports that management of the environment at the catchment scale is now widely recognised as an effective and sustainable approach to tackling a range of pollution and flooding sources (Duke et al, 2013). It identified that at the 2009 price review (PR09), water companies in England and Wales committed to investments of approx., £60m in over 100 catchments, many of which were focused on catchments for specific water sources like reservoirs.

However, a forthcoming paper by UKWIR says, "*Despite the potential for multiple benefits, the effectiveness of catchment management is uncertain and the outcomes of schemes are difficult to predict. In particular, there is limited evidence available to indicate what scale of improvement may be achieved by catchment management and over what time-scales. This makes it difficult to judge under which circumstances catchment management might be the most cost-effective management option and there is no clear consensus on whether catchment management is capable of delivering a return on the investment (i.e. a positive cost benefit)*".

Improved evidence is needed to increase the confidence with which we can say there are discernible economic benefits from coordination of actions that improve water regulating services in catchments. This includes projects aiming to improve the condition of upland peatlands, in part motivated by potential improvements in water quality regulating services. These projects are

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[58] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/330464/pb14179-catchment-restoration-fund-report.pdf

estimated to cover 60,000 ha, and are discussed in more detail under the peatland investment case.

4.2 Scalability, Additionality and Synergies

The ability of governance systems to coordinate measures is important in catchment management as the benefits of individual investments are affected by location and the combination of activities that make up the investment. Maximising the positive synergies discussed in Section 3.2 is the purpose of investing in governance that can coordinate actions within a catchment. It is recognised that some activities already provide such coordination in England. In projects like Upstream Thinking there are attempts to take into account other (non-water regulating) ecosystem services in planning of actions within catchment management.

Coordination of actions to protect and improve natural capital is also one of the main motivations behind the Nature Improvement Areas (NIA) established in 2012 to create joined up and resilient ecological networks at a landscape scale. NIAs are each run by a local partnership, with funding provided by the Department for the Environment, Food and Rural Affairs (Defra) and Natural England. Twelve NIAs have been set up in areas that have opportunities to establish and improve ecological networks with potential synergies for outcomes like the condition of waterbodies, flood-risk, carbon storage and people engagement[59]. Their total awarded funding of £7.5m[60] (approx. £200k per Area per year) is a resource that can only have an impact on natural capital if it is used for coordinating larger expenditure more effectively (in other words, a leverage function).

Thus initiatives like the NIAs potentially provide the governance framework and funding required for strategic landscape scale restoration of natural capital for the enhancement of ES delivery. However, they are primarily focussed on biodiversity targets. Monitoring and evaluation of Nature Improvement areas is ongoing.

Management of agri-environment scheme expenditure (like under Environmental Stewardship) and Catchment Sensitive Farming work also attempt to take a broad ecosystem service approach. However, these different coordination mechanisms do not offer complete spatial or ecosystem service coverage and may even overlap. Therefore, they do not provide governance that can fully exploit synergies in the management of natural capital assets within catchments.

The Environment Agency (EA) have been examining catchment management measures as part of their appraisal of packages of options for the current planning of further Water Framework Directive (WFD) implementation in England[61]. The proposals for such measures are currently being consulted on.

Analysis of the EA's database used to develop these proposals gives an indication of the scale at which further catchment management measures could have net economic benefits. The EA's data

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[59] https://www.gov.uk/government/publications/nature-improvement-areas-improved-ecological-networks/nature-improvement-areas-about-the-programme

[60] https://www.gov.uk/government/publications/nature-improvement-areas-improved-ecological-networks/nature-improvement-areas-locations-and-progress

[61] The EA launched a 6-month consultation in October 2014 on draft River Basin Management Plans: https://consult.environment-agency.gov.uk/portal/ho/wfd/draft_plans/consult

quantifies the benefits and costs of the River Basin Management Plan (RBMP) in each individual catchment across England, detailing the type of improvements sought, or the 'measure' undertaken. They use formulae to estimate the benefit-cost ratios (BCR) of potential measures in each catchment. The data therefore gives an indication as to the number of catchments in which the benefits of undertaking different measures outweigh the costs. The analysis is necessarily high-level (in that it cannot take into account all circumstances in each catchment) due to its need to cover all 297 catchments in England. It therefore relies on standardised information developed from catchment sensitive farming scheme knowledge and related tools (such as FARMSCOPER). It is focused on WFD benefits, and due to resource constraints does not fully appraise synergies with other ecosystem service benefits (e.g. landscape, non-water recreation, biodiversity, soil carbon).

Within the EA's database, 270 (91%) of catchments had natural-capital related catchment management measures as part of the package of actions proposed. In three-quarters of these (227, or 76%), agricultural measures were proposed as part of the package of catchment management actions. The percentage is of the number of catchments, so does not represent the proportion of the land area. The most commonly proposed agricultural measures were those to manage surface runoff and drainage, which were part of the proposed package of catchment management measures in nearly half (44%) of all catchments. Field-level management measures for arable soils and for livestock farming were part of the proposed package in approx. 20% of catchments.

Considering the 227 catchments where agricultural related measures were part of the package of proposed measures, in the first round of analysis 27% of those catchments have a BCR less than one (i.e. costs greater than benefits). Therefore, agricultural catchment management actions were part of packages of measures with a BCR greater than one in the majority (73%) of catchments where they were proposed, based on the first round analysis methods. The BCRs under 1 were subject to more detailed analysis, including valuation of a wider range of ecosystem services benefits. This wider valuation made a significant difference, as in all but two of the catchments, the BCR changed from less than one to greater than one.

The EA's proposals on WFD implementation, therefore, include widespread use of further catchment management measures in farming systems. This suggests there is significant potential for further catchment management activity across England, in addition to current activities.

Finally, a number of synergies between coordination of catchment management measures for water regulating services and other investment cases examined in this project should be noted. Actions in the farmland, woodland, peatland and wetland investment cases can all contribute to catchment management. Detailed analysis of the interactions between these measures is beyond the scope of this work. Its complexity should not be underestimated, as catchment impacts depend on local circumstances and conditions, for example, the ability of woodland to reduce flood flows likely to decrease with increasing flood size. As a result, coordination effort should not be left to the goodwill of different agencies or stakeholders, or assumed to be covered by individual investment budgets. Investment in governance to ensure coordination should be specifically allocated in public bodies undertaking actions that contribute to catchment management. Finally, urban catchment management actions are not discussed here, but there are examples of urban river restoration actions reducing flood risks to homes, as well as increasing property prices as a result of providing quality green space.

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