RESTORATION OF FEN PEATLAND UNDER CLIMATE CHANGE

Report to the
Adaptation Sub-Committee of the Committee on Climate Change

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Executive Summary

RESTORATION OF FENLAND PEATLAND UNDER CLIMATE CHANGE.
Graves, A. and Morris, J. 2013.

This exploratory study, drawing on earlier work, aimed to assess the implications of Fen peatland restoration and conservation for the mitigation of carbon emissions, for agricultural production and food security, and for selected ecosystems services. Conclusions are drawn with respect to the study objectives. The conclusions must be treated with caution, being based on high level assessments and many simplifying assumptions. The results are best seen as helping to inform understanding and debate rather than providing singularly robust estimates.

The potential degradation of peatlands and associated loss of soil carbon were estimated for different land use scenarios, relatively high under intensive arable production and low under conservation grassland. This drew on estimates of carbon loss for different land uses previously reviewed by Natural England and estimated rates of peat loss in the Fens of between 10mm and 21mm per year. A method was developed to link temperature and rainfall parameters predicted under P10 (low climate change signal) and P90 (high climate change signal) with predicted peat degradation and carbon loss. A simple function was developed to estimate annual peat loss per year (mm) and associated CO_2 emissions as a function of starting and remaining depth, type of land use and climate change signal. Based on available evidence, the current 2012 mean peat depth in arable areas was assumed to be 0.86 m. The peat decay function was applied to the period 2012 through to 2080, assuming different land use and climate change scenarios. These were compared with predicted emissions from a Business as Usual *Continued Arable* scenario.

The type and value of costs and benefits of different land-use scenarios for peatland management were identified under a changing climate through to the year 2080, with particular reference to agricultural production, farm incomes and carbon emissions. Agriculture net margins for Continued (intensive) Arable production are estimated at about £480/ha in 2012 prices (with a possible range of £270/ha - £1,590/ha), declining to about £30/ha (£-50/ha to £150/ha range) for Degraded (extensive) Arable once peats have wasted away. Peat Restoration (with no commercial farming) gives net margins of about -£105/ha (-£200/ha to -£25/ha range), and Grassland conservation options vary between about -£5/ha for extensive grazing (-£50/ha-to £50/ha range) and £23/ha for semi-intensive grazing (-£50 to £100/ha range).

There appear to be significant differences in carbon emission costs between land uses that are further amplified by climate change. Assuming a steady state, and valuing carbon emissions at DECC's price of £57/t CO_2e generated estimated steady state annual carbon emission costs of £434/ha for deep arable peats and £243/ha for degraded peats, rising to about £1,300/ha and £700/ha respective under the extreme P90 climate change scenario for 2080 (assuming there are reaming peats to degrade). Peat Restoration gave an estimated CO_2 sequestration benefit of about £300/ha/ha for 2012. Peatland Conservation gave an estimated of carbon sequestration benefit of about £40/ha on extensive grassland, and a carbon loss of about £75/ha on semi intensive grassland. It is assumed here that Peatland restoration and Conservation options will be managed to prevent possible carbon losses induced by climate change. This assumption is worthy of further testing.

There appears to be significant differences between Peatland Restoration and Conservation options and the BAU continued arable production, assuming a steady state and measured in terms of the value of agricultural production and carbon emissions only. Peatland restoration shows net benefits for 2012 of about £150/ha, rising to between £330/ha and over £1,000/ha in 2080 depending on the climate change scenario. Peatland conservation options have lower carbon emissions than continued arable, but much lower agricultural output.

Climate change further consolidates the relative advantage of Peatland Restoration and Conservation options over the longer term. Assuming a dynamic state and focussing on the effects on agricultural incomes (valued using the International Food Policy Research Institute (IFPRI) predictions for food price increases) and carbon emissions only (valued using the central estimate of dynamic time series values for carbon provided by the Department of Energy and Climate Change (DECC)), and discounting annual net benefits at 3.5% for the first 30 years and 3.0% from years 31 to 68 between 2012 and 2080, the estimated present value benefit of switching from arable to Peatland Restoration or Conservation with extensive wet grassland is between £40,000/ha and £50,000/ha according to climate change scenario. Switching to semi intensive grassland gives a present value benefit of about £15,000/ha but this falls to £1,000/ha under high climate change.

Peatland Restoration and Conservation land use are associated with other beneficial non-carbon environmental and ecosystem effects. Extending environmental effects of different peatland land use to include allowance for land system costs (estimated here to include GHG and acidification emissions from agricultural production) as well as cultural services provided by different landscape and habitat types, further increase the relative advantage of Peatland Restoration and Conservation scenarios.

Peat soils make an important contribution to agricultural production, especially regarding high value crops. The Target Fenland areas identified here of 20,500 ha account for about 0.4% of the UK's tillage area (5.3 million ha) and less than 0.2% of lowland crop and grassland areas (12.4 million ha, excluding rough grazing). They account, however, for about 0.6% the value of total crop production. The area probably accounts for around 1.5% of each of the total national areas of sugar beet area, potatoes and vegetables grown in the open, and about 0.23% of the national fruit growing area. These estimates are not to be confused with the larger Fenland peatland areas for example that comprise mainly degraded peats of over 133,000 ha, that probably account for about 10% of the national areas given to potatoes, sugar beet and vegetables, or the total East Anglian Fenland area of over 500,000 ha (including all soils) that produce about 37%, 24% and 17% respectively of England's area of vegetables grown in the open, potatoes, bulbs, and flowers.

The withdrawal of the 20,500 ha Target area in the East Anglian Fen would probably not have a major impact on UK national food supply and food security. It is likely that the production of high value cropping would be for the most part made good by substitution of cropping elsewhere. Furthermore, the comparative advantage of peat soils for high value cropping is being lost over time as they are degraded. In response, the production of vegetable and salad crops has, according to farmers, moved to mineral soils supported by spray irrigation.

Future food security, that might become more critical in 30 to 50 years' time, could be enhanced by conserving agricultural peatlands, taking them out of agricultural production now, or farming them extensively, so that they can be returned to intensive agricultural use should the need arise. Thus a conservation strategy would include an option (and an option value) for future 'agricultural reclamation'. The peatland scenarios identified above have potential to do this to varying degrees. The present value of preserving potential for future use in 2062 (50 years hence), ranges between about £4,000/ha and £11,000/ha. When it comes to it, the decision to take up the reclamation option will depend on a reassessment of the relative costs and benefits of arable versus conservation peatland use given prevailing circumstances, economic prices of agricultural production and carbon emissions, and technological possibilities.

Maintaining the option to return conserved peatlands to agricultural use requires that (i) reclamation potential is 'engineered' into restoration projects, (ii) critical drainage and flood defence infrastructure is maintained, (iii) knowledge and skills in the agricultural management of peatlands are maintained and (iv) restoration projects of any significant scale include a 'food security' response strategy. Building in an option value for retaining the agricultural potential peatlands could increase the cost of peatland restoration, but it could help to balance some of the arguments round the ecological restoration - food security debate. It is also likely encourage the development of the sustainable management of peatland farming.

Many assumptions required in the assessment of peatland options for agriculture and climate change reflect gaps in knowledge that could be filled by further research if deemed worthwhile.

There is very clear evidence that current methods of intensive agriculture irrecoverably degrade the very inherent properties of peat soils that gave them comparative advantage for farming in the first place. It therefore seems eminently sensible to take actions to conserve their future. This argument is now reinforced by a much greater appreciation that maintaining the health of peat soils delivers considerable real economic benefits associated with GHG regulation as well as a wide range of other environmental benefits.

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1 Introduction

Many goods and services that flow from peat soils are under threat. In Europe, 100,000km^2 of peatland has been lost and the remainder are at risk[1]. In England, there are about 325,000 ha of remaining deep lowland peat soils (> 0.4m depth) that were formed under waterlogged conditions in fens and raised bogs. These lowland peatlands hese have been widely drained and used for food production, with some 240,000 ha (74%) of remaining lowland peatland under cultivation/temporary grass. An estimated 16% of the peat stock recorded in 1850 in the Fens now remains and much of this will be irreversibly degraded in the next two to three decades[2]. In the Somerset Levels, there has been extensive subsidence and shrinkage estimated to be 1 to 1.5 cm per year, even under extensive grazing regimes[3]. Despite this, peatlands remain an important store of terrestrial organic carbon, which has been sequestered from atmospheric CO_2[4]. Protected and extensively farmed areas of peatlands retain important wetland habitats that are promoted through the UK Biodiversity Action Plan (BAP), agri-environment schemes and other management arrangements[5].

In this context, there is growing interest in the large scale restoration of peatlands in order to provide a range of ecosystem services associated with, for example, the maintenance of stocks of soil carbon and associated reductions in carbon emissions, nature conservation, water resource management and flood control, and recreation.

Peatlands are, however, of strategic agricultural importance, particularly given the prospect of increased global demand for food and uncertainties associated with climate change. In the UK peatlands are an important component of Grade 1 and Grade 2 agricultural land. Here, their agricultural potential critically depends on the management of water regimes, including irrigation intensive drainage, pumping and protection from river and coastal flooding. Although these areas have comparative advantage in intensive agriculture, this strategic role is placed at risk unless measures are taken to conserve peat soils under agricultural management[6].

Peat is the accumulated remains of plant materials formed under waterlogged conditions caused by climate, high groundwater levels or by topographical conditions[7].

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[1] Rawlins, A. and Morris, J. (2009). Social and economic aspects of peatland management in northern Europe:, with particular reference to the English case. *Georderma*, doi:10.1016/j.geoderma.2009.02.022

[2] Oates, R. (2002) Restoring The Fens. The Fens Floodplain Project.

[3] Brunning, R. (2001) Archaeology and Peat Wastage on the Somerset Moors. Somerset County Council.

[4] Bellamy, P.H., Loveland, P.J., Bradley, Murray Lark, R.I. and Kirk, G.J.D. (2005) Carbon losses from all soils across England and Wales 1978–2003. *Nature*, 437, 245-248

[5] Clarke, D. and Joosten, H. (2002) Wise use of mires and peatlands: background and principles including a framework for decision-making. International Mire Conservation Group and International Peat Society, Helsinki.

[6] Defra (2009). Caring for Our Soils: A Strategy for Soils in England Department for Environment, Food and Rural Affairs, London

[7] Burton, R.G.O. and Hodgson, J.M. (1987). Lowland Peat in England and Wales, Special Survey 15. Soil Survey of England and Wales, Harpenden

Soils with more than 50% organic matter by content are defined as peats[8]. Soils with 35-50% organic content may be termed peaty sands or peaty loams depending on the type of mineral content.

The use of peat soils for agriculture has resulted in their degradation and loss, commonly referred to as 'wastage', associated with shrinkage[9], compression, oxidation and other causes such as wind erosion, removal of soil on root crops and accidental burning of dry peat.

Although careful management can help to conserve peats under agricultural use, especially under extensively grazed wet grassland, the restoration and reformation of peat soils generally excludes agriculture.

According to Natural England[10] there are a total of 14,185 km^2 of peatlands in England (1.4 million ha, 11% of England's total land area) of which about 6,800 km^2 are deep peaty soils (Table 1-1). Of these, just over half are mainly upland blanket bogs and the remainder (about 3,250 km^2, 0.33 million ha) are lowland peats comprising mainly fens and raised bogs.

Table 1-1: Area of different peatland types in England (Source: Natural England[11])

Peat Class	Area (km^2)
Deep peat soils	6,799*
Shallow peaty soils	5,272
Soils with peaty pockets	2,114
Total	**14,185**

*Includes 1,922 km2 of lowland wasted peat – a technical term for deep peat that has been substantially degraded following years of drainage and cultivation so that the peat is becomes influenced by underlying mineral material.

Figure 1-1 shows the distribution of peatlands in England. In the lowlands, the deep fen peats are mainly located in the Fens of East Anglia, the Somerset Levels and the Lancashire Mosslands. Lowland raised bogs occur in the West Midlands, Manchester Mosslands, the Somerset Moors, Solway Mosses and parts of the Fens. Shallow peaty soils are mainly associated with wet heaths and grasslands around upland plateaux. Lowland soils with peaty pockets are commonly associated with springline mires and wet valley bottoms. About half of the total area of lowland peat in England is cultivated, and a further 17% is occupied by improved grassland (

Table 1-2).

[8] Burton and Hodgson (1987) *op. cit.*
[9] Hutchinson, J.N. (1980). The Record of peat wastage in the East Anglian fenlands at Holme Post, 1847-1978 AD. *Journal of Ecology*, 68, 229-249
[10] Natural England (2010). England's Peatlands: carbon storage and greenhouses gases. (NE257). Natural England. Peterborough
[11] Natural England (2010) *op. cit.*

Peatland status attributes
Afforested
Bare
Rotationally burnt
Cultivated
Eroded
Extracted
Gripped
Improved
Molinia
Overgrazed
Peat Cutting
Polluted
Undamaged
Removed
Restored
Scrub
Semi-natural non peat forming
Wasted
Wooded

Figure 1-1: The distribution of lowland peatland areas in England (provided by the Natural England)

Table 1-2: Type and Use of lowland peats hectares - England (Source: Natural England[12])

Land use/attribute of peat	Raised bog	Rich fens/reedbeds (deep)	Rich fens/reedbeds (wasted)	Grand Total
Afforested	6159	1086	2321	9566
Cultivated	8749	37369	115033	161151
Improved grassland	5286	21208	26605	53099
Undamaged	338	572	341	1251
Restored	1687	3804	1379	6870
Scrub	802	830	140	1773
Wooded	3631	6882	6959	17472
Semi-natural non peat forming	5233	11164	6599	22995
Total*	**35721**	**95804**	**192205**	**323730**

*
Note that sum of the above does not equal the totals as there is overlap in the above land use and attribute categories and not all the categories are included

[12] Natural England (2010) *op. cit.*

1.1 Aim and Objectives

Focussing on the Anglian Fens, the aim of the study is to assess the implications of the large scale restoration of lowland farmed peat areas in order to reduce carbon emissions and thereby mitigate potential climate change effects associated with their agricultural use. More specifically, the study objectives are:

1. To determine potential degradation of peatlands and associated loss of soil carbon under different land use and climate scenarios
2. To identify the type and value of costs and benefits of different land-use scenarios for peatland management under a changing climate through to the year 2080, with particular reference to agricultural production, farm incomes and carbon emissions.
3. To interpret the findings for policy, particularly regarding food security, rural incomes and employment, the mitigation of and adaptation to climate change, and the provision of other ecosystem services.
4. To identify the implications of alternative peatland restoration options for the management of infrastructure and strategic assets, especially land and water resources, including options to secure future agricultural potential.

1.2 Approach

The following approach was adopted to address the study objectives:

- The study built on, updated and further developed the methods used in a 2010 Study sponsored by Natural England [13] on the **Restoration of Lowland Peatland in England and Impacts on Food Production and Security.**
- Estimates of current land use, cropped areas and livestock numbers in the study area were determined using a combination of Defra Agricultural Census Data (2004 and 2009) and Land Cover Map Data (2000). These were adjusted to allow for reduced areas of set aside since 2010.
- Estimates of agricultural yields, production and economic performance were derived from a range of secondary sources including the Regional Farm Business Survey results, supported by discussion with key informants. Estimates of the economic returns of crop and livestock production to agriculture derived in the earlier 2010 study were updated to 2012 values using Defra agricultural price indices[14] allowing for relative price changes between different crop and livestock outputs and input prices. Other prices were updated using GDP deflators. Real increases in agricultural net margins of 1.4% were assumed to reflect changes in agricultural outputs and input prices through to 2050, based on Defra guidance (with alternative assumptions to test sensitivity of results).

[13] Morris J., Graves, A., Angus, A., Hess, T., Lawson, C., Camino, M., Truckell, I. and Holman, I. (2010). *Restoration of Lowland Peatland in England and Impacts on Food Production and Security*. Report to Natural England. Cranfield University, Bedford.

[14] Defra (2013). *Agricultural prices 2012.* Defra, February 2013

- Carbon emissions due to peat degradation by peat type and land use were based on Natural England[15] estimates for CO_2 emissions only, and exclude CH_4 and N_2O emissions.
- Annual peat wastage rates under different climate change scenarios were derived using historical data on fenland peat wastage rates, and reported effects of temperature change on the rate of peat wastage.
- Carbon prices associated with Green House Gas (GHG) emissions (£/t CO2e) were based on DECC's annual price series through to 2080, expressed in 2012 values, using the low, central, and high values to test sensitivity of results.
- A model was developed to predict the relationship between predicted mean rainfall and temperature conditions for two climate change scenarios (P10 and P90) and likely peat wastage and associated carbon loss and GHG emissions.
- Estimates of environmental emissions by crop and livestock type were drawn from lifecycle analysis[16]
- Existing biodiversity and potential biodiversity outcomes were identified for the Fens
- The the implications of taking land out of agricultural production was reviewed, together with options to return land to agricultural use if required.
- Alternative future scenarios for peatland management were considered that vary in terms of the intensity of agricultural use and the degree of peatland degradation or protection
- The impact of these scenarios on (i) peat loss and carbon emissions, (ii) agricultural outputs and food security, (iii) farm incomes and profitability, and (iv) wider economic benefits and costs were assessed.
- Consideration was given to the type and economic value of other environmental effects associated with peatland management options, notably emissions from agricultural production systems and potential wildlife and landscape benefits
- The economic value of agricultural net margins and GHG emissions were estimated for peatland management and climate scenarios. These were considered as (i) 'steady states' for comparative purposes (ii) as time series of flows discounted at The Treasury's test discount rates through to 2080. Broad estimates of agricultural land system costs and the benefits of cultural services provided by peatland options were also considered.

[15] Natural England (2010) *op. cit.*
[16] Williams A G, Audsley E, Sandars D L. (2006). *Determining the Environmental Burdens and Resource Use in the Production of Agricultural and Horticultural Commodities*. Final Report to Defra, Project IS0205, Cranfield University and Defra (accessible via www.agrilca.org)

2 The East Anglian Fen Study Area

The area commonly described as the East Anglian Fens cover a total 130,000 ha (Figure2.1). Within this area, and for the purposes here, there are about 33,500 ha of remaining deep peats. Of the latter, about 20,500 ha lie within the Natural England's Target Areas for the Anglian Fens set within the aspirational freshwater Wetland Vision for England[17]. This 20,500ha area is shown in Figure 2.2 by overlaying areas marked green (the wetland vision target areas) with the hatched areas (the peat areas). Figure 2.2 also shows that the study area falls within the "The Fens" National Character Area.

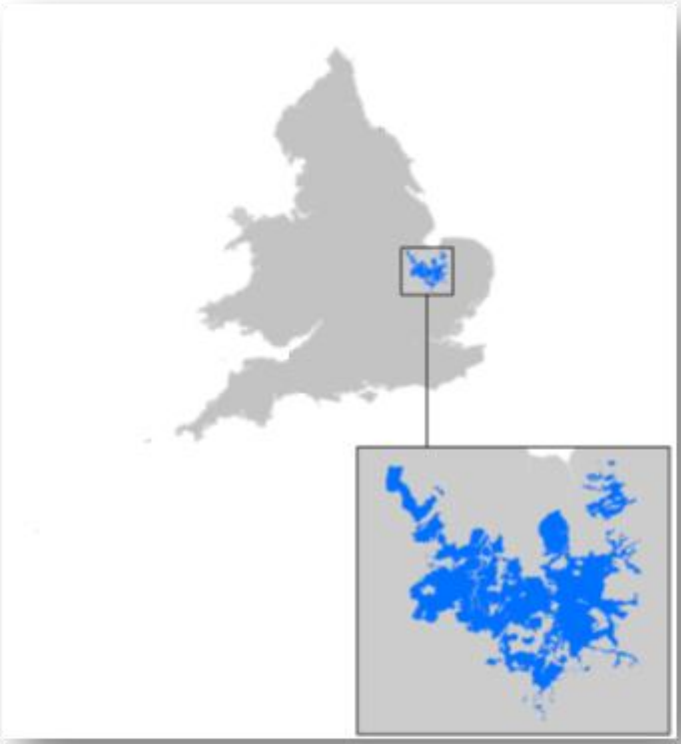


Figure 2-1: The location of the East Anglian Fen study area in England

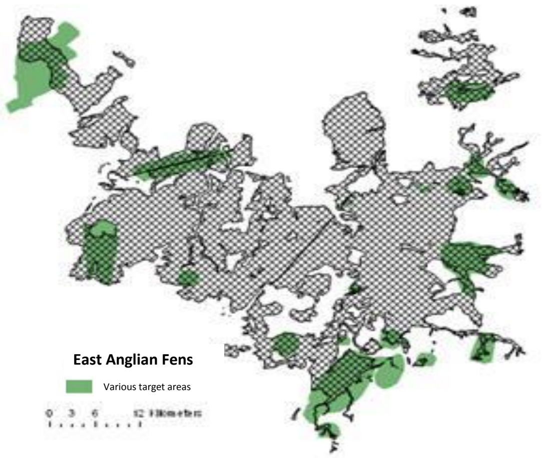
2.1 Existing and Land Use and Farming Systems

Land use information was obtained from the Land Cover Map 2000 (CEH, 2000) and Defra Agricultural June Census statistics 2004 as interpreted by the AgCensus project[18] were obtained. The 2km AgCensus gridded layer for England for 2004 was overlain against the peatland data for the East Anglian Fens and the data in each AgCensus 2km grid cell was weighted according to the proportion of that cell in the peatland area and aggregated

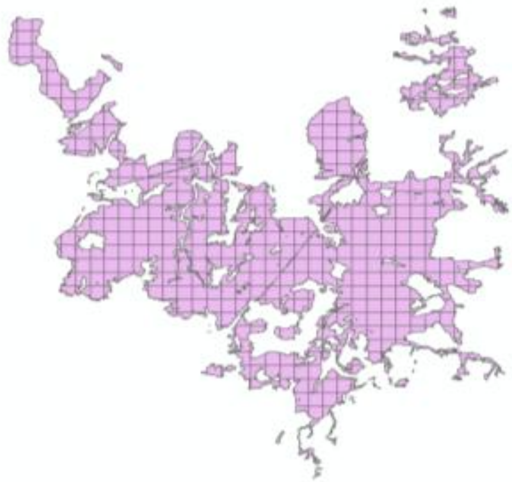
[17] The Wetland Vision: http://www.wetlandvision.org.uk/ (Accessed 26/06/2013)
[18] AgCensus: http://edina.ac.uk/agcensus/description.html (Accessed 26/06/2013)

(Figure 2.2c). These data were corroborated against Defra 2009 June Census data. The results indicate that the 2004 land use estimates provide a reasonable estimate of crop areas and livestock numbers Some minor adjustments were made to allow for the reduced areas of fallow and set aside land in the post 2008 period of globally high agricultural prices. For the purpose of updating the analysis to 2012, some further minor changes in land use in the study area were made to reflect this continued trend, as discussed below.

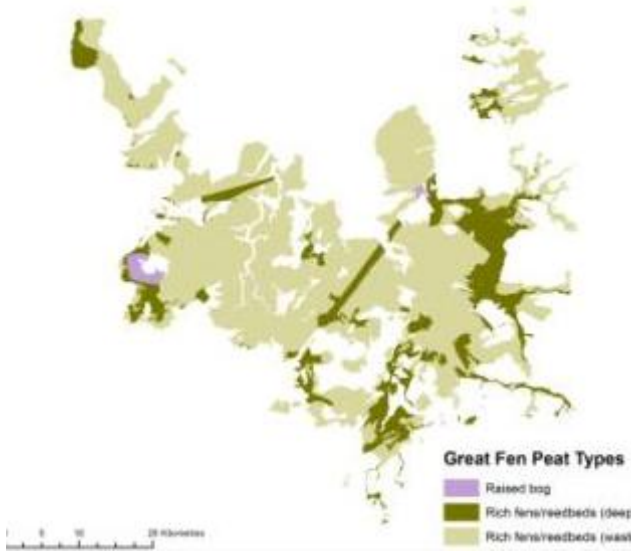
a: "Natural England Restoration Target Areas"



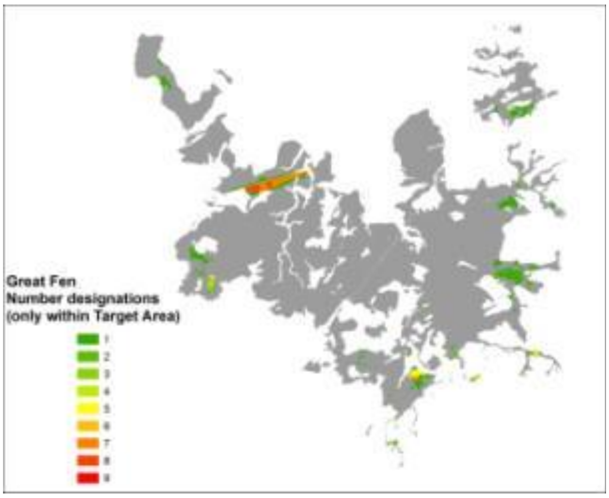
b: AgCensus 3km grid data



c: East Anglian Fens Peat types



d: Number of land designations



e: Agricultural land classification

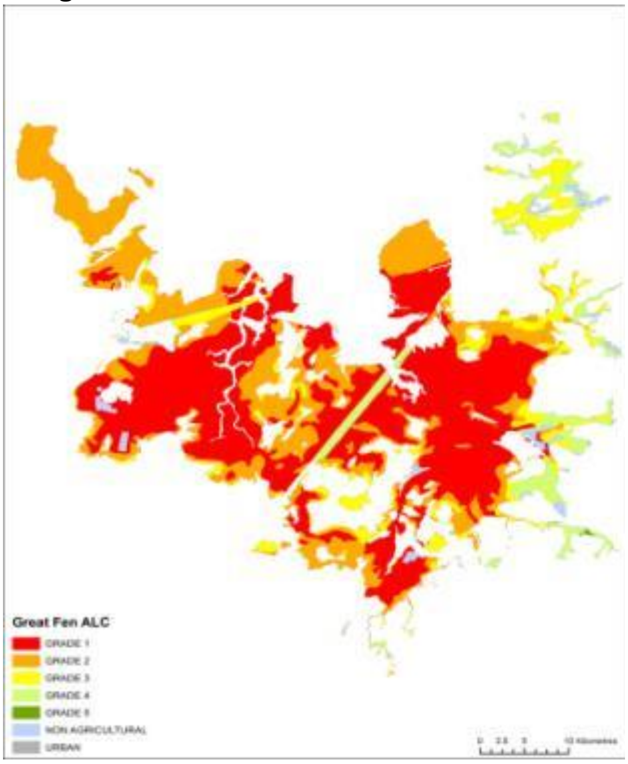


Figure 2-2: Various data used in the analysis of the East Anglian Fens, including: a) The Target Areas (shaded) for peatland restoration (hatched), b) the AgCensus data overlay, c) the deep peat type, d) the number of designations, and e) the agricultural land classification.

Information on the productivity and financial performance of farming systems in peatland areas was obtained from secondary sources, notably Defra statistics, the Regional Farm Business Surveys[19,20,21,22,23] and farm management pocket books[24,25,26] supplemented by personal contact with farmers and their representatives in the study areas.

According to agricultural census data, Fenland farms are characterised by relatively intensive arable farming systems, mainly general cropping farms, and some small scale specialist horticultural and fruit farms (Table 2-1). Arable farms in the Fens account for 60%

[19] Crane, R. and Vaughan, R. (2010). *Farm business survey 2008/09: Horticulture in England*. Rural Business Research at the University of Reading.
[20] Lang, B. (2010). *Farm business survey 2008/2009: crop production in England*. Rural Business Research at Cambridge, University of Cambridge.
[21] Lang, B. (2004). *Report on farming in the Eastern counties of England 2003/04*. Rural Business Research at Cambridge, University of Cambridge.
[22] Wilson, P. and Cherry, K. (2010). *Analysis of gross and net margin data collected from the farm business survey in 2006/07 and 2007/08*. Rural Business Research, University of Nottingham.
[23] Farm Business Survey. (2012). *Region Reports*. Rural Business Research University of Nottingham. Nottingham. http://www.farmbusinesssurvey.co.uk/
[24] Nix, J. (2009). *The John Nix farm management pocketbook: 40th edition*. The Anderson Centre, Leicestershire.
[25] Nix, J. (2012). *The John Nix farm management pocketbook: 43rd edition*. The Anderson Centre, Leicestershire.
Robertson, P. and Wilson, P. (2010). *Farm business survey 2008/09*: dairy farming in England. Rural Business Research, University of Nottingham.
[26] ABC (2009) *The Agricultural Budgeting and Costing Book*. Agro-Business Consultants: Nov 2009. Melton Mowbray

of farms by number and over 90% of the farmed area. The area contains regionally high levels of root crops production (potatoes and sugar beet), 'vegetables grown in the open' (notably carrots, onions and beetroots) and salad crops (lettuce, celery, leeks, calabrese) as well as other high value crops on specialist horticultural and fruit farms. Much of this high value cropping is irrigated and served by pumped drainage.

Table 2-1: Farming in the East Anglian Study Areas

	The Fens Peat Lands				
Robust Farm Type	**Number of Holdings**	**Total Area (ha)**	**% of holdings**	**% of area**	**Av farm size ha**
Cereals	290	25,532	21%	24%	88
General Cropping	512	74,384	37%	69%	145
Horticulture	38	816	3%	1%	21
Dairy	5	195	0%	0%	
Grazing Livestock (Lowland)	93	2,096	7%	2%	23
Mixed	32	2,129	2%	2%	
Other Types	420	2,618	30%	2%	6
Others (suppressed identity)	0	0	0%	0%	0

Source: Defra agricultural census.

2.1 Peatlands and Agricultural Land Grade.

The distribution of Agricultural Land Grades in the study areas is shown in Figure 2-2f. Under controlled drainage, large areas of peatlands are classed as Grade 1 (Table 2-2), supporting intensive arable production, often with ground-fed summer irrigation. The classification of Grade 1 and 2 in the Fens is critically dependent on pumped drainage. It is important to note that ALC grade reflects a capability under a prevailing land management regime that may change, such as land drainage. The classification of land could also be affected by environmental conditions, such as climate change.

Table 2-2: Percentage of total peatland in different Agricultural Land Classification Grades for the Study Area

	East Anglian Fens
Total areas surveyed (ha)	132,131
Grade 1	49%
Grade 2	34%
Grade 3	8%
Grade 4	6%
Other	3%
Total	100%

2.2 Financial Performance of Farming Systems

The profitability of farm businesses in the Fens varies according to type and size. Data are available for Fenland farms in East Anglia from the Regional Farm Business Survey up to 2009, after which Fenland farms are not separately distinguished in the results for the region.

Table 2-3 (part a) shows financial returns for cereal and general cropping farms in the Fens, and for specialist horticultural in England during the period 2007-9 inclusive, derived from Farm Business Survey results[27,28,29]. Net margins (based on Management and Investment Income) here include charges for family labour and land based on typical rents even though farms may be owner occupied. They exclude subsidies such as annual receipts under the Single Payment Scheme that, depending on historical entitlements, can range between £180 and £220/ha on eligible land. Arable farms gave net returns over the period 2007-2009 of about £200/ha to £250/ha (in 2012 prices), rising to over £600/ha on the top performing general cropping farms with root crops. The lowest performing quartile of general cropping fenland farms, many of which are located on degraded 'skirt' soils, barely broke even during the period.

Data were obtained for selected farms for the 2011/12 for the East Anglian region as a whole, including a sub sample of fenland farms that was not separately identified due to small numbers (Table 2-3, part b). Net margins in this relatively wet year averaged about £200/ha to £250/ha (excluding land ownership or rental costs) on arable farms, and about £700/ha for horticultural holdings. Extensive lowland grassland (non-dairy) did not manage to recover full costs on average. These estimates provided a reality check for the estimates of net margins used in the assessment of peatland options.

[27] Crane, R. and Vaughan, R. (2010). *Farm business survey 2008/09: Horticulture in England*. Rural Business Research at the University of Reading.
[28] Lang, B. (2010). *Farm business survey 2008/2009: crop production in England*. Rural Business Research at Cambridge, University of Cambridge
[29] Lang, B. (2004). *Report on farming in the Eastern counties of England 2003/04*. Rural Business Research at Cambridge, University of Cambridge

Table 2-3: Financial performance indicators for different farm types in (a) the Fens and (b) the East Anglian region as a whole [30,31,32,33,34]

Part a: Representative Financial Performance (£/ha) by Farm Type , 2007-2009*

	The Fens				All England
	Cereals	General cropping			Hortic
Average of 2007-9 at current prices	All farms	All farms	Bottom quartile	Top quartile	Mainly outdoor veg**
Av size ha	190	250	220	180	95
Gross Output	920	1459	1263	1944	12003
Variable Costs	290	457	541	492	5097
Gross Margin	630	1001	722	1452	6906
Fixed Costs ***	463	789	875	870	6472
Net margin	167	214	-153	582	434
2012 prices ****					
Infl adjusted gdp	187	240	18	652	486
Infl adjusted agric prices	202	259	32	704	525
Inflation 2008 to 2012:	gdp index	1.12		ag price index	1.21

Source : FBS - Lang, 2010; Crane and Vaughan, 2010; Robertson and Wilson, 2010
*averaged over 2007/8 and 2008/9 years at current prices , ** 2009 only
*** including rents/land charges
**** using ONS gdp deflators and Defra agricultural price indices

Part b: Representative Financial Performance (£/ha) by Farm 2011/2012 East of England

	Mainly cereals	General cropping	Horticulture	Lowland grassland
Sample size	81	65	56	18
Gross output	1141	1253	8552	526
Costs				
variable	443	504	4843	206
fixed (including land)	515	668	3256	324
Total costs	958	1172	8099	530
Gross Margin	698	749	3709	320
Net margin	183	81	453	-4
Land costs	65	125	256	40
Net margin excl land	248	206	709	36

Source: Regional Farm Survey: Agriculture in the East of England, 2011/12

Data are available for the East of England farms that include some Fen farms
Separate data for Fen farms are not available for 2011/12.
Sample data are not available for Fen farms on deep peats

[30] Nix, J. (2012). *The John Nix farm management pocketbook: 43rd edition*. The Anderson Centre, Leicestershire.
[31] Lang, B. (2010). *Farm business survey 2008/2009: crop production in England*. Rural Business Research at Cambridge, University of Cambridge.
[32] Farm Business Survey 2011/2012 (2012). *FBS Region Report: East of England*. The Rural Business Unit, University of Cambridge, Cambridge
[33] Wilson, P. and Cherry, K. (2010). *Analysis of gross and net margin data collected from the farm business survey in 2006/07 and 2007/08*. Rural Business Research, University of Nottingham.
[34] ABC (2012) *The Agricultural Budgeting and Costing Book, Agro-Business Consultants*: Nov 2012. Melton Mowbray

The detailed distribution of land use in the study area reflects dominant farming systems (Table 2-4). Cropping accounts for about 90% of the farmed area. In the most intensive areas, especially on remaining deep peats, cereals act as a 'break' crop, facilitating rotations of potatoes, vegetables and salads. Here, cereals may account for only 30% of the cropped area. Cereals tend to increase in importance as peat soils have degraded over time and the land loses its advantage for high value cropping. Some of this high value cropping has switched to sand and silty soils, with irrigation. Much of the production of field-scale vegetables is now large scale, benefiting from specialisation in crop production and marketing. Farmers overcome constraints imposed by rotation requirements on vegetable crops, notably potatoes and carrots, by seasonal 'renting' from other farmers. There is much contracting of specialist services such as cultivations and harvesting, and in some cases complete production.

Table 2-4: Agricultural Land Use (including woodland) for the Study Areas (source Defra statistics)

	East Anglian Fens		
	2004 and 2009 Census		2012 estimate
	whole	target	Excluding set aside
Farmed areas (ha)	34,889	20,500	20,500
wheat	38.5%	35.8%	40,2%
barley and other cereals	3.5%	5.6%	3.6%
peas and beans (comb)	6.4%	5.1%	6.7%
oil seed rape	2.9%	3.2%	3.0%
sugar beet	11.7%	9.3%	12.3%
potatoes	8.3%	7.1%	8.7%
other veg in open	5.3%	4.7%	5.5%
linseed and oth arable	1.0%	1.3%	1.0%
maize	0.0%	0.0%	0%
fallow and SAS	7.4%	9.4%	0%
horticulture	6.3%	5.9%	6.9%
fruit	0.2%	0.2%	0.2.%
nursery stock/flowers	0.3%	0.4%	0.4%
Total crops	91.8%	88.1%	88.3%
forage crops	0.2%	0.3%	0.3%
grassland pp	4.4%	5.8%	5.8%
grassland temp	1.1%	1.9%	1.9%
rough grazing (pr)	1.4%	1.4%	1.4%
Total grass	7.1%	9.4%	9.4%
woodland	1.0%	2.3%	2.3%
Total %	100.0%	99.8%	100%

Grassland is less than 10% of the farmed area In the Fens. There is little dairying: most livestock comprise suckler cows producing beef calves and the fattening at grass of 'store' cattle of different ages, some of them by itinerant graziers (Table 2-5). Average livestock units (Lu) per ha are about 0.7-0.9 Lu/ha, typical of extensive grassland farming under conditions of poor agricultural drainage or grasslands purposely managed for conservation.

Table 2-5 Distribution of Livestock Units by Livestock type in the Regional Peatland Areas

	East Anglian Fens
Dairy and dairy replacements*	3%
Suckler beef cows	34%
Cattle of various ages	53%
Sheep: ewes and lambs	10%
	100%
Average stocking rates Lu/ha	0.9

*usually a ratio of 4:1 Lu for dairy cows to replacement young milk cows, although this is higher where replacements are produced for sale.

The aforementioned information on farming systems and land use has been used in the assessment of options on peatlands.

2.3 Land use and peats: the effects of agricultural degradation

As referred to earlier, the agricultural use of peatlands results in its degradation over time, mainly due to drainage and cultivation for crop production. Usage for permanent grassland can conserve peatlands providing wetness is maintained. However, the removal of vegetation through grazing and hay/silage cutting, and the extraction of materials for thatching and fuel, limit the further formation of peat soil. Conditions conducive to peat formation are likely to limit land use to extensive summer grazing.

Evidence suggests that peat wastage in arable farming ranges between 10mm and 30 mm per year[35], highest where ploughing and power harrowing (to achieve fine seedbeds and bury crop residues) and intensive drainage (to control water levels and facilitate machinery travel) are practiced in support of large scale field vegetable production. Within assessment of recent peat wastage in the Fens and Humberhead peatlands, Holman (2009) and Holman and Kechevarzi (2010) used values of 10 mm to 21 mm/year, depending on peat thickness and land use[36]. Among agricultural land uses, peat wastage is likely to be least under extensively managed, mainly summer grazing of permanent pasture, where water levels are maintained at a relatively high level for most of the year.

[35] Holman IP (2009). *An estimate of peat reserves and loss in the East Anglian Fens*. Unpublished report for the Royal Society for the Protection of Birds

[36] Holman IP and Kechevarzi C (2010). *An estimate of peat reserves and mineralisation in the Humberhead peatlands*. Unpublished report for the Royal Society for the Protection of Birds.

In the East Anglian fens, where more than 60% of remaining peats are now less than 1 m thick[37] with an average depth of 70 mm, this suggests a remaining life under arable farming of between 25 to 50 years, and considerably less on thinner peats. Discussions with farmers and their representatives in the Fens indicated that they do not contest the principle that arable farming on peat soils results in their degradation. There is, however, much debate on the actual longevity of remaining arable peatlands, and the likely efficacy of measures to reduce the rate of loss. The view widely held by those who earn their livelihoods through peatland farming is that peat soils offer comparative advantage in specialist arable farming, even though eventually this capability will be exhausted.

[37] Holman IP (2009) *op. cit.*

3 Impact of Peatland Restoration on Agriculture, Food and Ecosystem Services

This section considers alternative land use scenarios for Fen peatlands and the implications for agriculture, food security, carbon emissions and a range of ecosystem services. The economic implications of the scenarios are assessed in terms of both steady state values as well as the present value of benefits and costs discounted over the period 2012 to 2080.

3.1 Land use Scenarios

Although peatland soils have comparative advantage for intensive high value cropping, they are liable to continued degradation with consequences for long term yields and the sustainability of farming systems, especially under conditions of climate change. Their degradation is also associated with release of soil carbon, further contributing to global warming and climate change. Thus, while their agricultural usage makes an important contribution to national food supply, this capability and the viability of intensive farming systems on peats are potentially at risk in the longer term.

In this context, a number of future land use scenarios are considered for peatlands in the study areas.

For the Target Areas the scenarios are:

(i) *Baseline BAU - Continued Arable Production* – Current agricultural land use with degradation over time and associated changes in farming systems and performance. This requires no surface inundation and water levels managed at mean depths of at least 0.5m throughout the year,.

(ii) *Degraded Arable Peatland* –wasted peats exposing underlying mineral soils that would not be suitable for intensive arable farming[38]. Soils liable to seasonal water logging, requiring field (and pumped) drainage to control water levels to 0.5m

(iii) *Peatland Restoration* - No agricultural use to allowpeat forming vegetation. This may involve frequent, possibly long duration flooding and standing water, with near surface water table levels throughout most of the year.

(iv) *Peatland Conservation I* –extensive grazing in accordance with Biodiversity Action Plan (BAP) priorities, may also include wet woodlands. This involves surface flooding and standing water in winter and high water tables during winter spring and autumn, managed to about 0.2m from the surface, to allow summer grazing and some hay making from May through to early September

[38] Evidence from the Fens shows that many areas of degraded peatlands comprise so-called 'skirt' soils that are now occupied by extensive arable farming of cereals and oils seeds rather than intensive arable cropping with potatoes and vegetables. Much depends on underlying soil types. On peats lands overlying sands, continued intensive cropping may be possible with additional investment in irrigation and higher annual inputs and costs. On peats over clays, intensive mechanised arable cropping is probably infeasible, and extensive arable production will require additional investment in drainage.

(v) *Peatland Conservation II* – semi-intensive grazing to reconcile farming and peatland conservation objectives. This involves high winter water tables and short duration winter flooding, with water tables managed to about 0.4m from the surface to allow grazing and silage making from April through to October.

Peatland restoration and conservation options can be assessed against the counterfactual of Continued Agricultural Production. However, as explained below, this scenario will convert over time to the Degraded Arable Peatland scenario depending on the initial depth of peat and the annual rate of loss.

The incremental effect of these scenarios relative to the counterfactual on the following:

(i) national food production and national food security
(ii) rewards and incentives to land managers
(iii) carbon stocks and emissions, valued using DECC carbon prices
(iv) other environmental emissions and ecosystem services

Budgets were constructed using a spreadsheet facility for each of these scenarios, allowing for changes in cropping patterns and grassland management options (land use cover), crop yields, livestock type and stocking rates. The methods used follow those reported elsewhere for the appraisal of wetlands options[39, 40, 41]. Net margins were derived for major types of agricultural land use. These include charges for all labour including unpaid family labour. They exclude any charges for land, whether rent or mortgage payments , because the purpose is to determine the value-added per ha, before rents. They also exclude annual single farm payments (currently about £200/ha for eligible land), that is land previously used for crops and livestock that received direct subsidies.

3.2 Scenario Analysis for Target Areas

Arable Land use: the counterfactual

The Fen peatland Target Areas comprises about 20,500 ha, of which about 30 % are deep peats of at least 1 m in thickness. A total extended area of 34,900 ha has been identified for potential restoration by Natural England in the Fens[42].

Table 3-1 contains the results of scenario analysis for the Fen peatlands (see Appendix B for details). Under the *Baseline Continued Agricultural Production Scenario,* under current circumstances, the overall aggregate annual value of agricultural output in the Fen Target

[39] Posthumus H., Rouquette, J.R., Morris, J., Gowing, D.J.G., Hess T.M.˙ (2010). A framework for the assessment of ecosystem goods and services; a case study on lowland floodplains in England. *Ecological Economics*, 65, 151-1523.
[40] Morris, J., Bailey, A.P., Lawson, C.S., Leeds-Harrison, P.B., Alsop, D., and Vivash, R. (2007). The economic dimensions of integrating flood management and agri-environment through washland creation: a case from Somerset, England. *Journal of Environmental Management* 88: 372-381, (2008).
[41] Morris, J., Gowing, D., Mills, J. And Dunderdale, J. (2000). Reconciling agricultural economic and environmental objectives: the case of recreating wetlands in the fenland area of eastern England. *Agriculture, Ecosystems and Environment*, **79**, 245-257.
[42] Natural England (2010) *op. cit.*

Areas is estimated at £69 million assuming all are capable of supporting intensive arable farming with a net margin of £9.6 million, equivalent to about £3,500/ha gross output and £480/ha net margin (excluding rent, other receipts and income). (It is noted that additionally farmers receive single farm payments of about £200/ha on land previously eligible for production subsidies). Land use and the profitability of farming vary considerably reflecting the condition of peat soils and the texture of underlying soils where peats are degraded.

Table 3-1: Agricultural Gross Output and Net Margins by Scenario for Fen Peatlands (£, 2012 prices)

		Gross Output £'000	Net Margin £'000	Gross Output £/ha	Net Margin £/ha	Range (NM) +/- £/ha
Target Area (ha)	20029					
Baseline continuation		69,000	9,600	3,490	479	270 to 1590
Degraded arable peats		26,100	545	1,300	27	-50 to 100
Peat restore		1,000	-2100	50	-105	-200 to -25
Peat conserve I -wet grass		7,280	-940	365	-5	-50 to 50
Peat conserve II - grass		16,590	470	830	23	-50 to 100
some rounding						

In the most intensively farmed deep peat areas, high value cropping of potatoes, vegetables and salad crops can account for over 60% of the total farmed area. These individual crops can achieve annual net margins (after charging average fixed costs) of £1,800 to £2,500 per ha. For an average year in rotation with cereals, this generates a net margin about £450 to £500 per ha, given that other crops such as cereals, which do not give high yields on peat soils, have relatively low net margins. There is much sub-contacting of land and production to avoid the restrictions imposed by rotations on any one farm.

Continued arable production will degrade the remaining peat soils, at the annual observed rate of about 10mm to 30mm. Thus, at current rates, it is likely that the majority of the remaining peats will become 'wasted' over the next 30 to 100 years, depending on current depths and usage. Drier and hotter summer conditions under climate change will exacerbate this process as considered below.

The rate of deterioration of peat soils can be arrested by soil conservation measures such as minimum tillage and retained water levels to avoid drying and wind generated 'blow-outs'. But peatland vegetable farming is characterised by intensive ploughing to bury trash, power harrowing to give a fine seedbed, and lowered water levels to support machinery travel. Measures such as laser levelling of fields to remove hollows and aid soil water management, controlled water levels and soil moisture, and machinery 'tramlines' to reduce machine trafficking can reduce the rate of soil loss but not eradicate it. The potential of the land once peat is wasted depends on (i) the cropping potential of the underlying mineral soils and (ii) the need for additional investment, especially land drainage and/or irrigation

Under the *Degraded Arable Peatland* scenario it is assumed that peats have wasted to leave heavy clay marl or 'skirt soils and cropping is limited to cereals and oil seeds, possibly with sugar beet.

Here soils are difficult to work and typically subject to poor drainage. Gross Output is about 40% of that of intensive arable production on deep peat, at about £1,100 to 1,400/ha with net margins just above break-even, within a range of £-50 to £100/ha.

Under this scenario, the comparative advantage of the peats is lost, but more than this, in some areas farming will be relatively disadvantaged by poor soil and drainage conditions. Additional investments required in land drainage, at about £2,500/ha (about £200/ha/year at 5% real interest rates over 20 years) will probably not be financially attractive, especially to the large institutional land owners in the Fens that let land to tenant farmers. Thus, much will depend on the type of underlying soils and the need for additional drainage investments. On peats over sands or silts, continued high value cropping may be feasible, supported by irrigation, but the extent of this area is not currently known

Thus, the counterfactual against which peatland restoration or conservation options can be compared is either (i) continued intensive agricultural production at £479/ha net margin or where continued use leads to complete peat wastage (ii) degraded arable peats at about £27/ha net margin. As explained, continued arable production will eventually lead to complete loss of peat.

Thus, in the longer term, the net cost of withdrawing arable land from production is likely to decline as arable cropping becomes commercially marginal. The implications of the rate of degradation of peats for the viability of alternative land use are considered later.

Peatland Restoration and Conservation Options

Under the *Peatland Restoration Scenario*, arable land is converted to wet fen and peat forming vegetation. Farming is not commercially viable in the absence of other income streams such as single farm payments or agri-environment receipts. Some stock may be grazed to assist in habitat management biodiversity, as currently at the National Trust Wicken Fen, at a reported net cost of about £50/ha[43]. Evidence from the extension of Wicken Fen indicates that additional capital costs are relatively low, involving minor modifications to drainage systems and some plantings of fen vegetation. The biggest capital expense is fencing if required to retain grazing livestock. A total capital cost of about £575/ha is assumed here, which when amortised over 50 years gives an annual cost of about £23/ha. Annual management costs (including drainage rates) are estimated at £82/ha, excluding any revenues from external graziers used probably on half the area to control vegetation (assumed to be self-financing). This gives an equivalent annual cost of £105/ha (Appendix D). The costs of developing other facilities such as visitor and

[43] *Pers. comm.* Mr Chris Soans: Estates Manager, Wicken Fen, Cambs

recreational attractions are excluded here, although a non-use value for a restored peatland SSSI is considered below.

Thus, under this *Peatland Restoration* Scenario, the net cost is the loss of annual net margin from continued farming, which could either be about £585/ha or £145/ha, depending on whether the current land use or a degraded counterfactual is used. For the currently most productive areas, the net cost would probably be about £1,300/ha.

The *Peatland Conservation I Scenario* involves the universal adoption of wet grassland in accordance with local BAP priorities. An equal mix of extensive grazing (zero fertiliser) with hay cutting in some cases, raised water levels and species rich pastures are assumed, with stocking rates typically 0.5 grazing livestock units per ha or less. In the Fens, this will mainly involve suckler cows and fat cattle. Gross output declines to about 10% of its current level for the Target Areas, at about £365/ha and a net margin just below breakeven, ranging from about £-50 to £50. This option would deliver regional BAP targets and retain a farming presence in the landscape. It would require agri-environment or other payments for environmental services to make it commercially attractive to farmers. There could be opportunities to increase farm income by marketing 'environmentally assured' livestock products.

The *Peatland Conservation II* scenario involves the conservation of remaining peats under a moderately intensive, mainly beef grassland regime. This assumes a mix of grassland regimes with chemical fertiliser ranging from about 25 kgN /ha through to 150 kgN/ha for grazing and silage making systems respectively. It assumes that sufficient livestock and livestock management skills are available in the region, something that would need to be built up. Gross output is about 25% of that of intensive arable at around £830/ha, with net margins at about £23/ha, similar to that of arable on degraded peats. This system could deliver a range of environmental benefits, although it is also noted that livestock systems can generate relatively high environmental burdens, especially regarding GHG emissions[44].

Other options for agricultural land use include the introduction of bio-energy crops such as willow and miscanthus. These options, because they involve cultivations, removal of vegetation, use of heavy machinery and lowered water levels especially for harvest periods, are unlikely to lead to peat formation but could, with appropriate soil management, deliver similar peat conservation outcomes to those of the semi –intensive grassland options. The potential for conservation oriented bio-energy cropping on peat soils is worthy of further study.

3.3 Summary of the Financial Implications of Land Use Change in Peatlands

The foregoing analysis suggests that taking arable land out of production involves a loss of net margin, that is value-added, of about £480/ha year given typical cropping patterns at the landscape scale. There would be a net loss of about £1,000 - £1,500/ha on the most intensively farmed areas where vegetable and salad cropping approach 60% of the area. (All

[44] Williams et al (2006) *op. cit.*

these estimates exclude land charges (rents and mortgages) and exclude receipts under the Single Payment Scheme which can be about £200/ha on eligible land).

Degradation of arable peats removes their comparative advantage for potatoes and vegetable cropping, and depending on the underlying soil conditions, continued arable cropping will probably just about breakeven assumed continued relatively strong commodity prices. Investments in field and possibly arterial drainage would be needed to retain their potential for arable, mainly cereal and sugar beet, production.

The conservation of peatlands under wet grasslands, with very low stocking rates, would probably fail to breakeven and would require continued supplementary payments to retain farmer interest. Semi intensive grassland farming, with moderate levels of chemical and organic fertiliser, could offer a commercially feasible peatland ‘conservation and carbon storage’ option, with modest returns of -£50/ha to +£100/ha. This would require high standards of management in order to meet environmental objectives.

3.4 Economic Implications of Land Use Change in Peatlands

While the foregoing analysis considers impact of land use change on the financial value of output value–added from a financial perspective, viewed through the eyes of farmers, the implications for the national economy could be different. Defra advises two possible approaches to economic assessment of changes in agricultural land use, of the kind associated with flood and coastal defence investments that have relevance here. One involves displacements, the other complete land loss.

Displacement effects

Regarding displacement, it is likely that, in the event of curtailing arable production on Fenland peats, high value crops such as potatoes, vegetables and salad crops would relocate to other areas and soils. Indeed this has been happening for some time as peatlands have deteriorated. These crops have moved onto lighter more manageable soils, usually requiring overhead irrigation. The same farm businesses are often involved, through either land purchase or contract farming, using established production and marketing capabilities. This relocation of high value crops usually involves the displacement of wheat.

Thus from an economic perspective the net loss could be expressed in terms of loss of value added from wheat production, plus any additional costs of relocation, such as investments in production or marketing infrastructure, such as drainage, irrigation and storage. At current average yields (8.8t/ha) and prices (£150/t), net margins on winter wheat are about £100/ha (excluding Single Payments). Therefore, a very approximate estimate of economic cost associated with displacement of crops from peatlands is £100/ha, plus additional costs of production infrastructure (such as irrigation installations and crop storage) at about

£100/ha/year. Thus, an 'economic' assessment of displacement gives about £200/ha/year [45] for land use that switches to other areas as a result of Fenland restoration.

Land Lost from Agriculture

Where land is completely withdrawn from agriculture, for example by 'restoring' it to wet fen, the prevailing market prices for agricultural land, adjusted to remove any effect of subsidies, can in theory reflect the present value of future value-added from farming that are foregone as a result. Defra use this approach to assess the economic 'cost' of abandoned agricultural where a severe increase in flood risk renders farming infeasible.

Discussions with land agents in the study areas suggested current land prices of around ranging from £21,000/ha for Grade 1 and 2 land to about £9,000/ha for poor quality grassland. Much depends on location, access and drainage condition. Arable land that comes with abstraction licences can command higher prices, sometimes as much as an extra 20% -25%. Land prices in East Anglia increased by over 30% in the period 2010 to 2012 inclusive, partly reflecting improved farming prospects but also a decline in other investment opportunities.

Removing the present value of single farm payments requires market prices to be adjusted downwards by about £600/ha according to Defra guidance (Table 3-2). Thus, a high level estimate of Grade 1 land taken out of agriculture for peatland restoration in the Fens is about £20,000/ha (given that 88% of land in the target areas is Grade 1 and 2). This provides an alternative estimate of the 'opportunity cost' of land taken out of agriculture to that provided by the net margin approach used above. By the same token, taking peatland out of intensive farming and 'conserving' it as semi intensive grassland, is associated with a reduction in the asset value of land (in terms of the value of agricultural production foregone) of about £13,000/ha (£20,400 - £7,400).

Another approach to the value of lost output from farming is to express the capital value of land as an equivalent annual series of profits. Amortising adjusted land value over 50 years at 3.5 % gives an average equivalent annual value for arable land in the Fens of between £700/ha and £860/ha (£20,000 at 3.5% discount rate over 50 years) (Table 3-2). This probably overestimates the current profitability of all but the most intensively farmed land. It may however reflect the value of farm land at the margin to farms that can achieve economies of scale by increasing farm size through land acquisition. Thus, using this method, the loss of value-added from agricultural land used for peat restoration is equivalent to about £800/ha /year. This is higher than the estimate provided by the net margin approach for intensive arable farming at £479/ha (excluding land costs) in Table 3.1 above (although approaching the range in net margins that might apply with a predicted 40% increase in agricultural commodity prices by 2050). This is consistent with the

[45] This approach is used by Defra in the appraisal of flood risk management investments see Chapter 9 in: Penning-Rowsell E, Johnson C, Tunstall S, Tapsell S, Morris J, Chatterton J, and Green C, (2005) *The Benefits of Flood and Coastal Risk Management, A Manual of Assessment Techniques*. Flood Hazard Research Centre, Middlesex University, Enfield, London

commonly held view that agricultural land prices tend to overstate the earning potential of land in agriculture because they are influenced by many other factors than farming profitability. In this case, however, given predictions about relatively strong prices for agricultural commodities in future, the current high land prices and the valuations implied appear to reflect the high strategic value of agricultural land in the Fens.

Table 3-2: Estimated Economic Value of Agricultural Land based on ALC Grade and Market Prices and Equivalent Annual Value

	Fens % by area	Capital value (2012 prices)		Equivalent Annual value (50 years at 3.5%)
		Market price £'000/ha	Adjusted value* £/000ha	£/ha
ALC Grade				
1	49	21-22.5	20.4-21.9	£890
2	39	21-22.5	20.4-21.9	£890
3	8	17-18.5	16.4-17.9	£720
4	6	12.4-13.4	11.8-12.9	£510
5	3	8.0-9.0	7.4-8.4	£340
Average (weighted)	100	20.8-22.4	20.2-21.7	£850

Sources : Smiths Gore (2013)[46] and Savills (2012) [47]

*Less £600/ha to allow for present value of Single Payments . Grade 4 and % grassland may be in receipt of HLS stewardship payments requiring further reduction in net value of about £600-£700/ha

3.5 The contribution of the Peatland Target Areas to food production and food security

Peat soils make an important contribution to agricultural production, especially regarding to high value crops (Table 3-3). The Target Fenland area identified here of 20,500 ha account for about for about 0.3% of the UK's lowland crop and grassland areas (12.1 million ha, excluding rough grazing) and about 0.56% the value of total production. It accounts for around 2.5% of each of the total national areas of sugar beet area, potatoes and vegetables grown in the open, and about 0.23% of the national fruit growing area. These estimates are not to be confused with the larger peatland study areas of which the Target Areas are part. The total Fenland peat area for example, including now degraded peatlands of over 133,000 ha, probably accounts for about 10% of the national areas given to potatoes, sugar beet and vegetables. According to NFU (2008)[48], using Defra Statistics, the total East Anglian Fenland area of over 500,000 ha (including all soils), produces about 37%, 24% and 17% respectively of England's area of vegetables grown in the open, potatoes and bulbs and flowers.

[46] Smiths Gore (2013). *Review of English Farmland Market*. October December 2012, Smithsgore: Peterborough
[47] Savills (2012). *Market Survey Agriculture Land*. Savills Research UK Rural. 2012.
[48] NFU (2008). *Why Farming Matters in the Fens*. National Farmers Union: London

Table 3-3: Agricultural Production for the UK (2007-9) and Peatland Target Areas

Proportion of national production: UK - Peatlands in Target Areas average values for 2007-09						
	UK National			P		
	area	prod	value	Fens		
Ouputs	ha	tonnes 000	000£	area	prod	value
Wheat	1,908,000	14,942	1,719,707	0.80%	0.85%	0.88%
Barley	1,030,000	5,997	686,410	0.20%	0.20%	0.17%
Oil Seed Rape	620,341	2,011	506,081	0.42%	0.46%	0.43%
Peas for harvesting dry	25,000	102	14,000	3.66%	3.50%	3.82%
Field beans	144,000	541	75,000	0.64%	0.68%	0.68%
Sugar Beet	121,000	7,568	204,000	2.76%	2.56%	2.76%
Potatoes	144,211	6,044	698,568	1.77%	2.20%	2.66%
Fresh veg grown in open	120,000	2,551	1,075,000	1.39%	2.62%	1.75%
Hortic	170,000		2,441,000	1.24%		1.62%
Fresh fruit	28,000	410	528,000	0.23%	0.46%	0.21%
Other non food	85,711		1,108,000	0.15%		
Total crops	4,623,000		6,781,800	0.68%		1.19%
Total Grass	11,506,000			0.03%		
milk production			3,128,000			0.01%
meat production			5,138,000			0.05%
Total dairy and livestock			8,266,000			0.03%
Total Agriculture	12,100,000		14,996,700	0.29%		0.56%

Note:

hortic and fruit value lifted by 1.5 to allow for wholesale market: farm gate prices for national valuation
field veg adjusted by same uplift factor, area: value, as potatoes

Notes:

1 The areas, yields and values for the UK are an average taken from years 2007; 2008; 2009
2 Wheat and barley are figures for both winter and spring varieties
3 value of production is at market prices basis, as quoted in Agriculture in the UK, hortic and veg prices adjusted for market - farm gate price differences
4 Peas for harvesting dry and field beans are for stockfeeding
5 Field vegetables use the classification in Agric UK. It includes, cabbages, cauliflowers, carrots, lettuces, mushrooms, peas and tomatoes
6 Potatoes includes early and maincrop
7 Horticulture includes other field vegetables (seee note 5), plants and flowers, orchard fruit & soft fruit
8 Non-food crops include bulbs and nursery items
9 Fruit includes Orchard fruits (including non-commercial orchards) and soft fruit
10 Meat production includes cattle and calves, pig meat, sheep meat, poultry meat
11 Total crops includes all arable crops and also includes oats, rye, fibre crops, linseed and hops
12 Total grass includes temporary grass, permanent grass and rough grazing

The withdrawal of the 20,500 ha Target area in the East Anglian Fens would probably not have a major impact on UK national food supply and food security. It is likely that the production of high value cropping would be for the most part made good by substitution of cropping elsewhere. Furthermore, the comparative advantage of peat soils for high value cropping is being lost over time as they are degraded. In response, the production of vegetable and salad crops has, according to farmers, moved to mineral soils supported by irrigation. Although the area of production of these crops has declined in total, the relocation of cropping is evident in the significant increase in abstraction licences for sprinkler irrigation on mineral soils[49].

[49] *Pers. comm.* Dr Keith Weatherhead, Cranfield University

Although the scale of the peatland restoration considered here would probably not make a major impact on total food production now, projections for global food demand and supply suggest that that food security might become more critical in 30 to 50 years' time. In this respect, peatland strategies could give more priority to maintaining capacity for future food production and less to meeting current food needs (because they can be met by other means).

Thus, future food security could be enhanced by conserving agricultural peatlands, taking them out of agricultural production now, or farming them extensively, so that they can be returned to agricultural production should the need arise. Thus a conservation strategy would include an option (and an option value) for future 'agricultural reclamation'. The peatland scenarios identified above have potential to do this to varying degrees.

Maintaining the reclamation option will however require that (i) reclamation potential is 'engineered' into restoration projects, (ii) critical drainage and flood defence infrastructure is maintained, (iii) knowledge and skills in the agricultural management of peatlands are maintained and (iv) restoration projects of any significant scale include a 'food security' response strategy. Building in an option value for retaining the agricultural potential peatlands could increase the cost of peatland restoration, but it should help to balance some of the arguments round the ecological restoration - food security debate. It is also likely encourage the development of the sustainable management of peatland farming.

3.6 Ecosystems Services from Peatlands under different Scenarios

Peatlands provide a range of environmental benefits, often referred to as 'ecosystem services', in addition to agricultural outputs. These vary in accordance with the use of peatlands. Generally, there is a trade off between their use for agricultural production and the generation of ecosystems services and associated benefits and costs.

Environmental Emissions of Peatland Scenarios

Data on environmental emissions associated with different crops and livestock systems were derived from lifecycle analysis[50]. Emission values per unit output (tonnes of crop and livestock products) were produced and expressed per ha according to crop yields and stocking rates (see Appendix B).

Emission quantities eg GHG (CO_2e) and acidification potential, were produced and then multiplied by unit values from published sources (Table 3-4). Carbon was valued as at a 2012 price of £57/t CO_2e for non-traded carbon in accordance with DECC guidance 2010[51]. The adjusted time series value for traded and non-traded carbon values are shown for selected years in Table 3-5. The full series is shown in Appendix E. As agriculture falls outside the EU emission trading scheme, the non-traded values for carbon were used here.

[50] Williams et al (2006) *op. cit.*

[51] DECC (2010) *Carbon Valuation*. Department of Energy and Climate Change. https://www.gov.uk/carbon-valuation (Accessed 26/06/2013)

Research literature was used to value the non-market cultural services of peatlands under different land uses as shown in Table 3-4 and reviewed in Morris et al, 2010, expressed in 2012 prices. These proportions were applied to land under different categories of use under each of the scenarios.

Table 3-4: Valuation data used for analysis of selected non-market ecosystem costs and benefits

Economic data:		
GHG value	£57	£/t CO_2
Ammonia	£1,933	£/t
Nox	£879	£/t
VOCs	£1,643	£/t
Sulphur Dioxide	£1,525	£/t
Cultural value: non SSSI general farm land	£95	£/ha/year
Cultural value: forest/woodland	£152	£/ha/year
Cultural value: SSSI	£812	£/ha/year

*emissions values based on Williams et al (2006)[52]; cultural values from various sources reported in Jacobs (2008)[53], 2012 prices

Table 3-5: Carbon time series values provided by DECC (2010) and corrected to 2012 values for selected years 2012 to 2080

	Traded values			Non-traded values		
	Low	Central	High	Low	Central	High
2012	7	14	18	29	57	87
2020	19	30	36	33	66	97
2030	38	76	114	38	76	114
2040	74	147	220	74	147	220
2050	109	217	326	109	217	326
2060	130	289	448	130	289	448
2070	131	327	524	131	327	524
2080	116	332	548	116	332	548

Estimating Carbon Loss from Fenland Peats under alternative Land Use Scenarios

The annual per hectare GHG flux (t CO_2e) from different types of peatland under different types of land use were taken from data reviewed by Natural England[54] (Table 3-6). In order to develop a relationship between the rate of peat depth loss over time and a rate of CO_2

[52] Williams et al (2006) *op. cit.*
[53] Jacobs (2008). *Environmental Accounts for Agriculture*. Final report submitted to Defra. 175 pp.
[54] Natural England (2010) *op. cit.*

emissions from peat, the data in Table 3-6 exclude the CH_4 and N_2O emissions associated with peat loss (and gain) that were aggregated into the values reported by Natural England[55], since these act independently of the rate of peat depth loss or gain. The updated values were provided by the Adaptation Sub-Committee of the Committee on Climate Change[56].

As noted previously, it was assumed that the cultivated and temporary grass emission values should be used for the Baseline Arable Production scenario, the Undamaged values should be used for the Peatland Restoration scenario, the Restored values should be used for the Peatland Conservation I scenario. However, for the purposes of this study, the data value reported for improved grassland under deep fenland (18.22 t CO_2/ha/yr) was considered too high for the conservation orientated semi-intensive beef system envisaged in the Peatland Conservation II scenario, and the value reported for Improved grassland under Blanket bog/Raised bog (8.61 t CO_2/ha/yr) was used instead.

Table 3-6: The GHG emission (t CO_2) from different peatland types under different land uses (Source: Natural England)

	Blanket Bog/Raised bog	Fen peatland deep	Fen peatlands wasted
Cultivated & temporary grass	22.42	22.42	4.85
Improved grassland	8.61	18.22*	
Afforested	2.49	2.49	
Restored	-3.56	-3.56	
Undamaged	-5.34	-3.56	

* For the purposes of this study, the data value reported for improved grassland under deep fenland (18.22 t CO_2/ha/yr) was considered to be high for the semi-intensive beef system envisaged in the Peatland Conservation II scenario, and the value reported for Improved grassland under Blanket bog/Raised bog (8.61 t CO_2/ha/y) is used instead.

There are few data associated with peat wastage under different climate change scenarios. For the purposes here, relationships were therefore developed using a range of simplified assumptions.

Firstly, data for future climates were taken from the UK climate projections (UKCP09[57]) for the East of England[58] in which the fenlands are located, for 2020, 2050, and 2080. The UKCP09 projections have been developed with low, medium, and high level emission scenarios and within each of these, 10%, 50%, and 90% probability levels. Data for the low emission 10% probability level (P10) were used to give the lower boundary of future climate change and data for the high emission 90% probability level (P90) were used to define the upper limit of climate change. The mean annual relative change in temperature (^{o}C) for

[55] Natural England (2010) *op. cit.*
[56] *Pers. comm*. David Thompson and Ibukunoluwa Ibitoye, Adaptation Sub-Committee of the Committee for Climate Change
[57] UKCP09: http://ukclimateprojections.defra.gov.uk/
[58] UKCP09 East of England data: http://ukclimateprojections.defra.gov.uk/21712

2020, 2050 and 2080 was taken from the winter and summer mean temperature (Table 3-7).

Temperatures are predicted to increase under all climate change scenarios in the long-term future (Table 3-7). The P10 probability scenarios, which are in effect a low probability scenario, show that the rise in mean temperature will be within the range 1.35°C to 2.2°C of current temperatures in 2080, under low and high emissions respectively. However, the P90 scenarios for 2080 suggest an increase in temperature of between 4.35°C and 6.6°C of current temperatures, depending on whether emissions are low or high respectively emission

Table 3-7: The relative increase in temperature for the low and high emission scenarios under P10, P50, and P90 probability scenarios for 2020, 2050, and 2080.

2020s	**Low emissions**			**High emissions**		
	P10	**P50**	**P90**	**P10**	**P50**	**P90**
Winter mean temperature (°C)	0.5	1.3	2.1	0.5	1.3	2.2
Summer mean temperature (°C)	0.7	1.5	2.6	0.5	1.4	2.5
Mean change in relative temperature (°C)	0.6	1.4	2.35	0.5	1.35	2.35
2050s	**Low emission P10**			**High emission P90**		
	P10	**P50**	**P90**	**P10**	**P50**	**P90**
Winter mean temperature (°C)	0.9	2	3.1	1.1	2.2	3.4
Summer mean temperature (°C)	1	2.4	4	1.2	2.5	4.3
Mean change in relative temperature (°C)	0.95	2.2	3.55	1.15	2.35	3.85
2080s	**Low emission P10**			**High emission P90**		
	P10	**P50**	**P90**	**P10**	**P50**	**P90**
Winter mean temperature (°C)	1.4	2.6	4	2	3.7	5.7
Summer mean temperature (°C)	1.3	2.7	4.7	2.4	4.5	7.5
Mean change in relative temperature (°C)	1.35	2.65	4.35	2.2	4.1	6.6

Carbon mineralisation is dependent on a range of factors, such as soil temperature, vegetation, microbial activity, and peat chemical characteristics. A range of factors, such as higher temperatures, lower or fluctuating water tables, a dominant vegetation of vascular plants, in particular grasses, contribute to high carbon mineralisation rates.

Data reviewed by Blodau (2002)[59] suggest that under normal peat temperatures, CO_2 emission increases by two to threefold for every 10°C increase in temperature. This suggests that for every one degree increase in temperature (°C) there is approximately a 30% increase in CO_2 emission and this relationship was used as a multiplier that could be used to quantify how the peat emissions described by Natural England (Table 3-6) would respond to the temperature increases described by the climate projections for 2020, 2050, and 2080. It should be noted that for the purposes of this project, it was assumed that restored and undamaged peat would not be affected by climate change, and that as long as water levels and land use were correctly managed, should be peat forming under P10 and P90 climate change scenarios at the same rate as under the current baseline[60].

[59] Blodau, C. (2002). *Carbon cycling in peatlands - A review of processes and controls*. *Environmental Reviews* 10, 111-134.
[60] *Pers. comm.* David Thompson, Adaptation Sub-Committee of the Committee for Climate Change

The predicted rates of carbon loss by land use and climate change scenario are shown in Table 3-8. The Baseline 2012 draws on Natural England's estimates of peat loss by land use and provides a counterfactual against which future climate change scenarios can be compared. The annual rates of peat loss increase according to the degree of climate change.

For the purpose of analysis, the Peatland Land use scenarios used here have been ascribed to particular Natural England land use categories and associated estimates of peat degradation. It is noted that the Restoration Scenario used here is assumed to be equivalent to the Natural England 'Undamaged' case, with potential for peat formation, whereas the Conservation I (wet grassland) used here is taken to be equivalent to Natural England's Restoration case. The associated rates of peat degradation are considered appropriate in terms of the expected rates of degradation and emissions from Fen peatlands under alternative uses. The Conservation II semi intensive grassland option considered here, involving measures to conserve peat, is considered to be less damaging to peat than the Improved Grassland category used by Natural England, with peat loss rates about half way between the Restoration and Arable Scenarios used here[61].

(It is noted that Natural England's estimates for relatively small carbon loss on Fenland peats are the same for 'Restored' and 'Undamaged' categories.)

[61] The estimates of rates of loss were checked against other data sources allowing for estimated peat loss, bulk densities under different land use, carbon content of soils, and the fate of carbon emissions (including carbon to atmosphere). These corroborated reasonably well, although it is noted that there is considerable variation in circumstances and uncertainty in the estimates.

Table 3-8: The 2012 baseline peat emissions data and the estimated emissions scenarios for 2020, 2050, and 2080 developed for P10 and P90 probability ranges (t CO_2)

Year 2020									
	2012 baseline			P10 Climate Change Scenario			P90 Climate Change Scenario		
Peat land use based on Natural England classes (peatland Land Use Scenarios shown in brackets)									
	Blanket Bog/Raised bog	Fen peatland deep	Fen peatlands wasted	Blanket Bog/Raised bog	Fen peatland deep	Fen peatlands wasted	Blanket Bog/Raised bog	Fen peatland deep	Fen peatlands wasted
Cultivated & temporary grass (Arable)	22.42	22.42	4.85	26.46	26.46	5.72	38.23	38.23	8.27
Improved grassland (Conservation II semi intensive grassland)	8.61	8.61		10.16	10.16		14.68	14.68	
Afforested	2.49	2.49		2.94	2.94		4.25	4.25	
Restored (Conservation I extensive grassland))	-3.56	-3.56		-3.56	-3.56		-3.56	-3.56	
Undamaged (Restoration)	-5.34	-3.56		-5.34	-3.56		-5.34	-3.56	

Year 2050									
	2012 baseline			P10 Climate Change Scenario			P90 Climate Change Scenario		
	Blanket Bog/Raised bog	Fen peatland deep	Fen peatlands wasted	Blanket Bog/Raised bog	Fen peatland deep	Fen peatlands wasted	Blanket Bog/Raised bog	Fen peatland deep	Fen peatlands wasted
Cultivated & temporary grass (Arable)	22.42	22.42	4.85	28.81	28.81	6.23	48.32	48.32	10.45
Improved grassland (Conservation II semi intensive grassland)	8.61	8.61		11.06	11.06		18.55	18.55	
Afforested	2.49	2.49		3.20	3.20		5.37	5.37	
Restored (Conservation I extensive grassland))	-3.56	-3.56		-3.56	-3.56		-3.56	-3.56	
Undamaged (Restoration)	-5.34	-3.56		-5.34	-3.56		-5.34	-3.56	

Year 2080									
	2012 baseline			P10 Climate Change Scenario			P90 Climate Change Scenario		
	Blanket Bog/Raised bog	Fen peatland deep	Fen peatlands wasted	Blanket Bog/Raised bog	Fen peatland deep	Fen peatlands wasted	Blanket Bog/Raised bog	Fen peatland deep	Fen peatlands wasted
Cultivated & temporary grass (Arable)	22.42	22.42	4.85	31.50	31.50	6.81	66.81	66.81	14.45
Improved grassland (Conservation II semi intensive grassland)	8.61	8.61		12.10	12.10		25.66	25.66	
Afforested	2.49	2.49		3.50	3.50		7.42	7.42	
Restored (Conservation I extensive grassland))	-3.56	-3.56		-3.56	-3.56		-3.56	-3.56	
Undamaged (Restoration)	-5.34	-3.56		-5.34	-3.56		-5.34	-3.56	

3.7 Land use by Land Use Scenario

The distribution of different peat types, as developed by Morris et al (2010)[62] in the Fen peatlands is shown in Table 3-9. Analysis of the data shows that the largest proportion of the land (79%) is classified as wasted peat, with 20% still considered to be deep peat, and 1% classified as blanket bog.

Table 3-9: Area and proportion of different peat types in the Fen peatlands

	Blanket Bog/Raised bog	Rich fens/reedbeds (deep)	Rich fens/reedbeds (wasted)
Area (ha)	1493	26519	104120
Proportion (%)	1%	20%	79%

Table 3-10 shows the distribution of land use by scenario for which estimates of agricultural production, carbon emissions and other environmental outputs are derived.

Table 3-10: The proportion of land under each type of land use assumed for each scenario on Fen peatlands

Land Use Scenario	Natural England Peat land use category (Land use scenario in brackets)	Blanket Bog/ Raised bog	Fen peatland deep	Fen peatlands wasted
BAU Continued arable and arable degradation	Cultivated & temporary grass (Arable)	88%	88%	88%
	Improved grassland (Semi-intensive grass)	5%	5%	5%
	Afforested	2%	2%	2%
	Restored (Extensive grass)	5%	5%	5%
	Undamaged (Restored)	0%	0%	0%
Conservation II Semi intensive grassland	Cultivated & temporary grass (Arable)	0%	0%	0%
	Improved grassland (Semi-intensive grass)	80%	80%	80%
	Afforested	0%	0%	0%
	Restored (Extensive grass)	20%	20%	20%
	Undamaged (Restored)	0%	0%	0%
Conservation I Wet grassland	Cultivated & temporary grass (Arable)	0%	0%	0%

[62] Morris J., Graves, A., Angus, A., Hess, T., Lawson, C., Camino, M., Truckell, I. and Holman, I. (2010). *Restoration of Lowland Peatland in England and Impacts on Food Production and Security*. Report to Natural England. Cranfield University, Bedford. 167pp.

	Improved grassland (Semi-intensive grass)	0%	0%	0%
	Afforested	0%	0%	0%
	Restored (Extensive grass)	100%	100%	100%
	Undamaged (Restored)	0%	0%	0%
Peat restoration	Cultivated & temporary grass (Arable)	0%	0%	0%
	Improved grassland (Semi-intensive grass)	0%	0%	0%
	Afforested	0%	0%	0%
	Restored (Extensive grass)	0%	0%	0%
	Undamaged (Restored)	100%	100%	0%

3.8 Estimated value of agricultural production and GHG emissions by peatland scenario

Table 3-11 shows the estimated value per hectare per year (in 2012 prices) of agricultural production and GHG emissions associated with loss of carbon from peat soils for alternative peatland management and climate scenarios. Estimates are given as annual values for the years 2012, 2020, 2050 and 2080 assuming the land use scenarios are in full operation. Table 3-11 also shows the difference in the net combined value of agricultural production and soil carbon GHG emissions (£/ha) between alternative peatland management scenarios and the BAU case. The estimates in Table 3-11 use 2012 prices for agricultural production and GHG emissions throughout with no adjustment for possible changes in real prices over time (this is considered later in the non-steady state analysis).

The BAU *Baseline Continued Agricultural Production scenario*, with ongoing peatland degradation, produces a net value for agriculture and carbon GHG for status quo climate scenario of £45/year. The cost of soil carbon loss per year increases over time relative to BAU due to strengthening climate change effects. For example, the cost of soil carbon loss is estimated at £1,297/ha for year 2080 under the P90 climate change scenario.

Degraded arable peatland generates a net annual cost of -£216/ha for 2012 and current climate conditions. Land will switch from the intensive arable BAU case to this extensive arable scenario once peats have become degraded, at which point soil carbon loss declines.

Peatland Restoration generates a net benefit of £199/ha mainly associated with formation of soils and soil carbon accumulation. It is assumed here that peat formation is the same under all climate scenarios, although rates of accumulation could be lower under the long term P90 scenario[63].

[63] There is some uncertainty about the way that restoration options would be impacted by climate change. Available data suggest that soil carbon loss would be greater on arable and intensively managed grasslands under more extreme climate change scenarios, notably regarding higher temperatures and potential water deficits. The assumption here, however, is that restored sites would be managed to avoid climate change induced carbon loss, especially by maintaining soil wetness. This could involve additional costs and soil water deficits may arise in some periods with consequences for soil formation and carbon storage..

Peatland Conservation I using extensive grazing systems generates a positive ecosystem benefit of £38/ha due to modest rates of soil carbon accumulation. As with the Restoration case, it is assumed here that land would be managed to support modest rates of peat accumulation under all climate scenarios, although rates of accumulation could be lower under the long term P90 scenario. *Peatland Conservation II* involving semi grassland generates an overall net ecosystem cost of -£52/ha, reflecting moderate carbon loss.

Table 3-11: Steady state per hectare non-market value of selected ecosystem costs and benefits associated with changing land use and climate in Fen Peatlands

	Year	2012	2020	2020	2050	2050	2080	2080
	Climate Scenario	Status quo	P10	P90	P10	P90	P10	P90
BAU Baseline	Agric net margin (£/ha)	£479	£479	£479	£479	£479	£479	£479
Intensive arable	GHG cost (£/ha)	£434	£512	£741	£558	£937	£610	£1,297
	Net value (£/ha)	£45	-£33	-£262	-£79	-£458	-£131	-£818
Degraded arable peats	Agric net margin (£/ha)	£27	£27	£27	£27	£27	£27	£27
Extensive arable	GHG cost (£/ha)	£243	£287	£415	£313	£524	£342	£725
	Net value (£/ha)	-£216	-£260	-£388	-£286	-£497	-£315	-£698
Peatland Restoration	Agric net margin (£/ha)	-£105	-£105	-£105	-£105	-£105	-£105	-£105
	GHG cost (£/ha)	-£304	-£304	-£304	-£304	-£304	-£304	-£304
	Net value (£/ha)	£199	£199	£199	£199	£199	£199	£199
Peatland Conservation	Agric net margin (£/ha)	-£5	-£5	-£5	-£5	-£5	-£5	-£5
Extensive wet grassland	GHG cost (£/ha)	-£43	-£43	-£43	-£43	-£43	-£43	-£43
	Net value (£/ha)	£38	£38	£38	£38	£38	£38	£38
Peatland Conservation	Agric net margin (£/ha)	£23	£23	£23	£23	£23	£23	£23
Semi intensive grasslan	GHG cost (£/ha)	£75	£90	£133	£98	£171	£108	£239
	Net value (£/ha)	-£52	-£67	-£110	-£75	-£148	-£85	-£216
Relative to BAU								
Degraded arable peats	Net value (£/ha)	-£262	-£227	-£126	-£207	-£39	-£183	£120
Peat restore	Net value (£/ha)	£154	£233	£461	£278	£658	£331	£1,017
Peat conserve I	Net value (£/ha)	-£7	£71	£300	£117	£496	£169	£856
Peat conserve II	Net value (£/ha)	-£97	-£33	£152	£4	£310	£46	£601

The lower part of Table 3-11 shows the incremental effects of land use change from the BAU extrapolated into the future. The *Restoration* of peatlands to peat forming vegetation could generate extra benefits of around £150/ha/yr for the 2012 status quo scenario to over £1,100/ha/yr under long term extreme climate scenarios compared with the Baseline of continued agricultural production.

A switch to *Peatland Conservation I* under extensive grassland systems more or less breaks even for the 2012 status quo case but gives positive net value of around £70/ha/yr to £170/ha/yr for future low (P10) climate change scenarios, and much more for high (P90) climate change scenarios. The semi intensive grazing *Conservation Option II* slows down but does not eradicate peat loss such as that there is an overall loss of around £100/ha/year relative to BAU for the 2012 status quo climate scenario. However, this option more or less breaks even with BAU for future low climate change scenarios, but offers a net gain for high (P90) climate change scenarios.

3.9 Estimated net value of peatland scenarios including environmental costs of agricultural land systems and benefits of cultural service

Estimates were derived for other, non-soil carbon environmental aspects of peatland management options, namely: (i) 'land system' emissions of non-soil related GHG (including those linked to use of fuels and fertilisers) and acidification effects (ammonia and sulphur); and (ii) the provision of land based cultural services with particular reference to biodiversity, landscape and amenity (excluding that associated with formal provision of recreation services such as visitor centres).

These estimates were combined with those of agricultural production and soil carbon GHG emissions (reported above) to provide a broad indication of the wider environmental costs and benefits associated with alternative peatland management options (Table 3-12). Land system costs are based on LCA data and unit rates for valuation (as explained earlier). They reflect differences in the intensity of farming, especially as this affects energy use and emissions, including those from livestock.

There is considerable uncertainty about the estimates of the value of cultural services that are based here on estimates derived from research literature of 'willingness to pay' for broad habitat categories such as grassland conservation sites (SSSI) and farmed grasslands and arable areas. For this reason the estimates of value for cultural services should be treated cautiously and as broad indicators of the differences between peatland options. It is assumed here that the value of these additional items does not vary with climate scenario, and neither, with respect to cultural services, does it vary with the scale of provision. In reality this may not be the case.

Taking this broader perspective Table 3-12 shows that, for the assumptions made, continuing agricultural production results in a net cost of about £100/ha per year for the current 2012 situation, rising to a cost of between about £230/ha and £1,000/ha in 2080 depending on climate change scenario, all in 2012 prices.

Once degraded, carbon emissions are lower, but so is agricultural productivity: degraded arable net costs are about £300/ha for 2012, rising to between £400/ha and £800/ha by 2080 depending on the degree of climate change. Restoration to peat forming vegetation generates a net benefit of about £1,000/ha under all scenarios (for the assumptions made). Extensive wet grassland has potential to deliver substantial environmental benefits, but net margins from agriculture are negligible, requiring (and justifying) agri-environment payments to deliver habitat and landscape outcomes. Combined net benefits are stable across all scenarios at about £700/ha. Here farming is mainly providing environmental benefits, including carbon storage. Semi intensive grassland farming produces low but positive farm incomes, but some peat wastage and relatively high emissions associated with livestock farming, result in a net cost of about £100ha for the current situation, rising to between costs of £200/ha and £30/ha by 2080 according to degree of climate change.

Table 3-12: Summary of Agricultural net margins, GHG costs, land system costs and cultural services benefits by land use and climate scenarios for Fen peatlands

	Year	2012	2020	2020	2050	2050	2080	2080
Fenland scenario	Climate scenario	Status quo	P10	P90	P10	P90	P10	P90
BAU Baseline	Agric net margin (£/ha)	£479	£479	£479	£479	£479	£479	£479
Intensive arable	GHG cost (£/ha)	£434	£512	£741	£558	£937	£610	£1,297
	Land system cost (£/ha)	£276	£276	£276	£276	£276	£276	£276
	Cultural services benefit (£/ha)	£129	£129	£129	£129	£129	£129	£129
	Net value (£/ha)	-£102	-£181	-£410	-£227	-£606	-£279	-£966
Degraded arable peats	Agric net margin (£/ha)	£27	£27	£27	£27	£27	£27	£27
Extensive arable	GHG cost (£/ha)	£243	£287	£415	£313	£524	£342	£725
	Land system cost (£/ha)	£235	£235	£235	£235	£235	£235	£235
	Cultural services benefit (£/ha)	£145	£145	£145	£145	£145	£145	£145
	Net value (£/ha)	-£307	-£350	-£478	-£376	-£588	-£405	-£788
Peatland Restoration	Agric net margin (£/ha)	-£105	-£105	-£105	-£105	-£105	-£105	-£105
	GHG cost (£/ha)	-£304	-£304	-£304	-£304	-£304	-£304	-£304
	Land system cost (£/ha)	£25	£25	£25	£25	£25	£25	£25
	Cultural services benefit (£/ha)	£812	£812	£812	£812	£812	£812	£812
	Net value (£/ha)	£986	£986	£986	£986	£986	£986	£986
Peatland Conservation	Agric net margin (£/ha)	-£5	-£5	-£5	-£5	-£5	-£5	-£5
Extensive wet grassland	GHG cost (£/ha)	-£43	-£43	-£43	-£43	-£43	-£43	-£43
	Land system cost (£/ha)	£127	£127	£127	£127	£127	£127	£127
	Cultural services benefit (£/ha)	£812	£812	£812	£812	£812	£812	£812
	Net value (£/ha)	£723	£723	£723	£723	£723	£723	£723
Peatland Conservation	Agric net margin (£/ha)	£23	£23	£23	£23	£23	£23	£23
Semi intensive grasslan	GHG cost (£/ha)	£75	£90	£133	£98	£171	£108	£239
	Land system cost (£/ha)	£292	£292	£292	£292	£292	£292	£292
	Cultural services benefit (£/ha)	£238	£238	£238	£238	£238	£238	£238
	Net value (£/ha)	-£106	-£121	-£165	-£130	-£202	-£140	-£271
BAU	Net value (£/ha)	-£102	-£181	-£410	-£227	-£606	-£279	-£966
Relative to BAU								
Degraded arable peats	Net value (£/ha)	-£205	-£169	-£68	-£149	£18	-£126	£177
Peat restore	Net value (£/ha)	£1,088	£1,167	£1,396	£1,213	£1,592	£1,265	£1,952
Peat conserve I	Net value (£/ha)	£825	£904	£1,133	£950	£1,329	£1,002	£1,688
Peat conserve II	Net value (£/ha)	-£4	£60	£245	£97	£404	£139	£695

The general result of including land system costs and cultural services is to further draw out the differences in net value between the peatland options. Land system costs are relatively high for arable farming and semi intensive livestock compared with the peatland restoration option and peatland conservation involving extensive grassland. Furthermore, cultural services are much higher for restoration and extensive grassland systems than for more intensively farmed peatlands. In broad terms, inclusion of land system costs and cultural services as defined here *increases* the extra net value of Peatland Restoration and Peatland

Conservation 1 (extensive grassland) over the BAU case by about £850/ha/yr. While this is not considered a robust estimate, it indicates that peatland restoration is likely to deliver other net benefits beyond that associated with carbon storage alone, particularly in terms of cultural services.

3.10 Present Value of Agricultural and Ecosystem Services by Land use and Climate Change Scenarios

The aforementioned changes in land use and environmental outcomes, especially carbon emissions, were considered as a series of costs and benefits over the period 2012 to 2080. Estimated net flows of predicted benefits and costs over the future 68 year period were discounted at the Treasury recommended discount rates of 3.5% up to 2052 and 3% beyond that. A number of other assumptions were made in addition to those concerning land use and climate change scenarios, namely

- Carbon £/t CO2e prices were set at (i) low, (ii) central and (iii) high values (expressed in 2012 price) based on DECC guidance,
- Agricultural commodity prices were set at (i) fixed 2012 prices (based on averages over the period 2008 to 2010 and adjusted to 2012 prices using Defra agricultural price indices 2010 to 2012) and (ii) rising in real terms (expressed in 2012 prices) from 2012 by 1.4 % annually in accordance with IPFRI forecast[64] for international agricultural prices. It was assumed that real agricultural commodity prices lead to equivalent real increases in net margins.
- Carbon loss from peat soils was estimated using (i) a linear rate of degradation and (ii) an negative exponential rate of degradation with marginally greater reduction in carbon stock in early years.

Thus 12 possible sets of variables were considered, applied to five land use options. For the purpose of presentation here, the central case is assumed. This is considered to be:

- the central carbon price,
- a 1.4% annual increase in agricultural net margins, and
- the non-linear rate of carbon degradation

Thus, future flows of agricultural benefits, carbon emissions and other ecosystem service flows were estimated according to land use and climate change use over the period to 2080 (Table 3-13, Figure 3-1). Arable land use assumes either continued intensive arable production on remaining deep peats or, where these become wasted due to carbon loss, a switch to arable on degraded peats and associated reduction in agricultural benefits. For the purposes here it is assumed that intensive arable (with a net margin of £479/ha) is obtained on peats of more than 0.4m depth, that degraded arable (with a net margin of £27/ha) occurs on degraded peats of less than 0.1m depth, and that an intermediate net margin of £253/ha is obtained on peats of between 0.4m and 0.1m depth. The rates of carbon loss are assumed to vary according to the remaining depth; more rapid loss for

[64] IFPRI (2007). *Food security and climate change. Challenges to 2050 and beyond*. International Food Policy Research Institute, Issue Brief 66 December 2010. 8pp.

greater depths. The year hence in which peats switch to intermediate and degraded conditions varies according to land use and, in the cases of arable and semi-intensive grassland, the degree of climate change.

For the central assumptions, there is a net present value cost of about £33,000/ha for continuing agricultural production on existing peatlands accounting for agricultural net returns and soil GHG costs only. The present value of GHG costs exceed agricultural benefits by more than three times (Table 3-13). This scenario incorporates a switch to less intensive farming as peat soils run out. Allowance is made for reductions in subsequent carbon emissions once this occurs. The P10 and P90 climate change scenarios hasten the speed of degradation, thereby decreasing the PV benefits from agriculture and increasing the PV cost of carbon losses relatively.

The PV of net benefits for Restoration and Conservation options are also shown. The present value of agricultural net benefits and soil GHG costs only for Peatland Restoration is about £10,500/ha, assumed to be constant under different climate scenarios equivalent, although there is a possibility that the rate of carbon sequestration will be reduced as explained earlier. Peatland Conservation involving semi intensive grassland gives a net present value cost for agriculture and soil GHG of about £17,000/ha, doubling to over £36,000/ha costs for the P90 climate scenario.

Accounting for land system costs and cultural service benefits widens the differences in present value between the peatland management options. Overall present value costs rise by about £12,000/ha for continued agriculture, whereas the present value of benefits rises by about £12,000/ha and £16,000/ha for restoration and extensive grassland conservation options respectively. Present value costs increase by about £9,000/ha on semi- intensive grassland conservation due to lower cultural service benefits and higher land system costs associated with livestock emissions.

It is noted that the estimates of land system costs could be moderated downwards if the displacement effects are taken into account. Switching fat livestock production into the Fens could substitute for future production that would otherwise occur elsewhere.

A sensitivity analysis was undertaken for the baseline scenario to identify the switch values for net margins and carbon prices (see Appendix F). The switch values for a given input was taken to be the relative value for that input at which the NPV of the land use system would provide no benefit (NPV = 0). The switch values for the baseline BAU (continued agriculture) net margin was 21%, indicating that the annual net margin of agriculture under this scenario would have to increase by 21% to compensate for the cost of carbon emitted from the loss of peat. For the semi-intensive grassland system, this value was 141%.

The switch value for carbon price was estimated to be - 77% for the baseline BAU (continued agriculture) scenario indicating that the price of carbon (here taken to be the central DECC values) would have to decrease by 77% for the cost of emitting carbon to be equivalent to the benefit provided by agriculture. For the semi-intensive grassland system, this value was - 97%.

Table 3-13: Estimated Net Present Value of Benefits and Costs of Alternative Land Use and Climate Change Scenarios in the Fens: Central carbon price estimates, central agricultural price forecast, and non linear peat degradation function, 2012 - 2080 (£/ha, 2012 prices).

	BAU continued arable	Peat Restoration	Peat Conservation	
			Extensive grass	Semi intensive grass
Baseline: status quo				
Agricultural income (a)	14524	-2062	-98	860
GHG gas cost for peat loss (b)	47142	-12579	-12579	18104
Combined Agric and GHG (peat) (c=a-b)	-32618	10517	12481	-17243
Land system cost (d)	16128	1366	6832	15706
Cultural services benefit (e)	3666	23160	23160	6789
Net benefit (f=c-d+e)	-45080	32311	28809	-26160
P10:				
Agricultural income	12283	-2062	-98	860
GHG gas cost for peat loss	52624	-12579	-12579	22730
Combined Agric and GHG (peat)	-40342	10517	12481	-21869
Land system cost	16128	1366	6832	15706
Cultural services benefit	3666	23160	23160	6789
Net benefit	-52804	32311	28809	-30786
P90:				
Agricultural income	9141	-2062	-98	860
GHG gas cost for peat loss	46608	-12579	-12579	37317
Combined Agric and GHG (peat)	-37467	10517	12481	-36456
Land system cost	16128	1366	6832	15706
Cultural services benefit	3666	23160	23160	6789
Net benefit	-49929	32311	28809	-45373

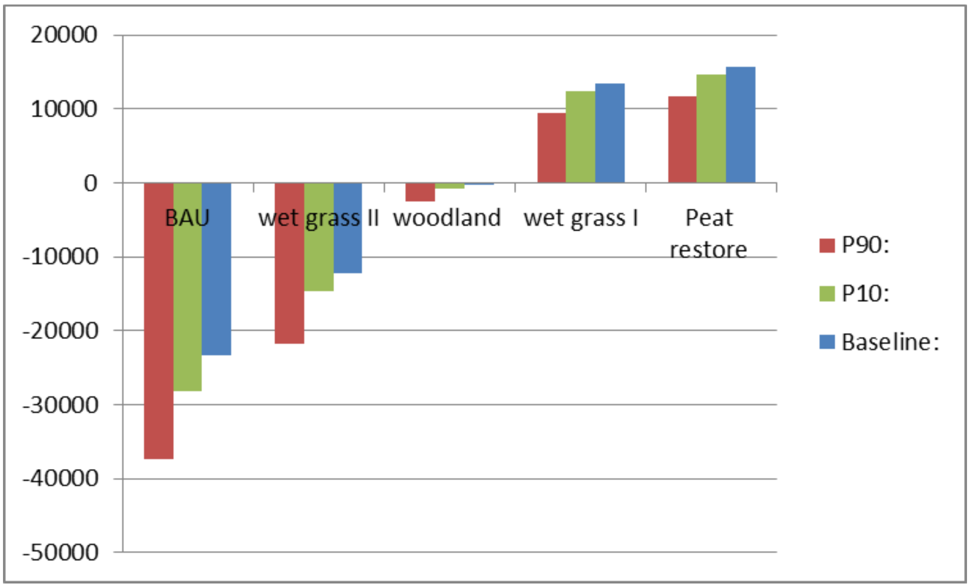


Figure 3-1: Estimated net present value (£/ha 2012 prices) by Land use and Climate Change Scenarios Scenario

3.11 Estimated Incremental Net Present Value of Fen Restoration and Conservation Peatland Options

Table 3-14 shows the change in the present value of net benefits (£/ha, 2012 prices) of switching from continued arable production on Fen peatland to alternative scenarios.

Table 3-14: Change in Net Present value (£/ha, 2012 prices) of Land use Scenarios for Fen peatlands relative to the Business as Usual Arable Land Use: Central carbon price estimates, central agricultural price forecast, and non-linear peat degradation function, 2012- 2080 (£/ha, 2012 prices).

	Peat Restoration	Peat Conservation	
		Extensive grass	Semi intensive grass
Baseline: status quo			
Agricultural income	-16586	-14622	-13663
GHG gas cost for peat loss	-59721	-59721	-29038
Combined Agric and GHG (peat)	43135	45099	15375
Land system cost	-14761	-9296	-422
Cultural services benefit	19494	19494	3123
Net benefit	77391	73889	18920
P10:			
Agricultural income	-14345	-12381	-11422
GHG gas cost for peat loss	-65204	-65204	-29895
Combined Agric and GHG (peat)	50859	52823	18473
Land system cost	-14761	-9296	-422
Cultural services benefit	19494	19494	3123
Net benefit	85115	81613	22018
P90:			
Agricultural income	-11203	-9239	-8280
GHG gas cost for peat loss	-59187	-59187	-9291
Combined Agric and GHG (peat)	47984	49948	1011
Land system cost	-14761	-9296	-422
Cultural services benefit	19494	19494	3123
Net benefit	82240	78738	4556

For the assumptions made, switching land from agriculture to the *Peatland Restoration* or extensive grass *Peatland Conservation I* option gives an extra PV net benefit of over £40,000/ha rising to about £50,000/ha attributable agricultural net benefits and GHG costs for alternative climate scenarios. Including land system costs and cultural services adds a further £30,000/ha or so of additional benefits.

Switching to semi-intensive grassland generates an extra present value benefit of about £15,000/ha for the base climate scenario, but this falls to about £1,000/ha for the high climate change (P90) scenario. Benefit estimates increase by about £2,500/ha if land system and cultural services are included.

There is considerable uncertainty in these estimates such that they must be treated cautiously. They are indicative values about which there is considerable variation. They are also not complete. These estimates exclude other environmental costs and benefits such as those associated with diffuse pollution to water and contribution to flood control respectively. The magnitude of these environmental effects, both positive and negative, are likely to vary considerably according to local conditions, such that generalised estimates are difficult and potentially misleading without more detailed assessment.

The estimates derived here do however indicate the potential scope for reconciling agricultural and environmental objectives in peatlands. It is noted that conventional agricultural production systems generally results in an overall negative environmental burden[65]. Conserving remaining peatlands could prove economically more efficient given that continued use generates relatively high environmental burdens compared to other farmed areas.

1.3 Income Distribution effects

The different peatland scenarios result in different flows of revenue, expenditure and net income to farmers with potential knock-on effects into other sectors supplying services to farmers and acquiring products for processing and/or sale. Estimates of income and employment multiplier effects in the agricultural sector derived in studies in the UK Reviewed in Hill (2009) are relatively high, typically between 1.5 and 1.8 respectively with considerable variation between farming sub-sectors[66]. Thus, £1 extra income in farming can generate a further £0.50 income elsewhere in the economy, and one extra job in agricultural produces about 0.8 jobs elsewhere. The overall aggregate effect of reduced agricultural production depends on the extent to which that lost in the Fens is made good by increased production elsewhere: the displacement effect (see below).

A switch to peatland restoration or conservation options would result in a reduction in agricultural net income (as defined here, excluding land charges) of about £450/ha/yr to £500/ha/yr, depending on land use. Peatland conservation grassland options are unlikely to be commercially viable for farmers and would require compensatory payments to reflect the opportunity cost of withdrawal from arable farming. The payments would be justified against the environmental benefit of reduced GHG emissions and enhanced cultural services.

[65] Jacobs et al, 2008. *Environmental Accounts for Agriculture*. Final report submitted to Defra. 175 pp.
[66] Hill, B. (2009) *The Role of Agriculture and Farm Household Diversification in the Rural Economy of the United Kingdom*. TAD/CA/APM/WP20091/Final. Organisation for Economic Cooperation and Development, Paris.

3.12 Possible effects of changes at the landscape scale

Water regime management

Discussions were held with senior engineers with permissive powers for managing flood risk and regulation of winter and summer flows in the Fens. The surface water system operates at two main levels: The Environment Agency and area specific Land Drainage Commissioners take responsibility of the main river system, major arterial works and large scale pumping stations. Discussions suggested that Peatland Restoration/Conservation options would not result in changes to regional flood risk management capital works and operations, especially as this relates to the protection of property and critical infrastructure. For the most part the target areas fall within larger areas drained areas require continued water management services, as evident in the case of the Great Fen Project and Wicken Fen areas.

A number of Internal Drainage Boards (and Local Governments) have permissive powers to regulate the lowland surface water system. The switch to Fenland Restoration, it was thought, would require retention of land drainage infrastructure and associated capital works, although there might be some modest (possibly 20%) reduction in pumping costs associated with retained water levels). Much depends on the juxtaposition of restored and farmed Fenland. In some cases additional capital works may be required to hydraulically separate the two areas.

The creation of wet fen is predicated on the availability of summer water to retain high ground water levels. (Water is commonly transferred into peat areas for surface and sub irrigation for cropping in summer). It may be necessary to secure water for Fenland creation by means of ‘farm scale’ reservoirs of the kind currently being installed in the Easter Region for intensive cropping. Investment costs could be about £2/m^3 assuming clay lined reservoirs, possibly as much as £1,000 to £2,000/ha served depending on water needs, although they could be engineered as part of wetland development[67]. These additional investments for water supply could apply equally for wet fen restoration or continued arable production.

Continued agricultural production will lead to further peat shrinkage and new investments in drainage infrastructure including new pump stations may be needed to maintain agricultural benefits. Where peat loss exposes clay subsoils, remedial investments in land drainage of £2,500/ha to £3,000/ha may be required, equivalent to about £50/ha/year (amortized at 3.5% over 30 years).

For the purposes here, ongoing drainage and irrigation costs (where relevant) have been included in the fixed costs estimates for arable and grassland farming. Drainage costs (minor works and annual operations and maintenance) have been included for peatland operation. Major investments have not been considered in this exploratory assessment.

[67] Morris, J., Weatherhead, E.K., Knox, J., Daccache, A., and Kay, M.G. (2013). *An updated assessment of the economics of on-farm irrigation reservoirs*. Final Report (May 2013). Defra funded project FFG1112: Efficient supply of water for agriculture. Cranfield University, Bedford

Other land management cost:

The costs of land management for peatland options involving agricultural management are included in the estimates of fixed costs and net margins. As previously explained, a total average costs at £105/ha per year for Peatland Conservation.

The peatland restoration and conservation options may be eligible for high level agri-stewardship agreements delivering specific environmental outcomes. The costs of implementing these are not separately accounted for here, although some broad estimates of cultural service benefits are identified for each land use option. Current Fenland restoration projects attract a lot of volunteer assistance, where presumably the benefits of volunteering exceed the cost of time committed. Large scale restoration may exhaust the pool of available volunteers.

The existing Fen restoration projects include visitor centres and provide research and education facilities. The additional costs and benefit of these developments and services are not included here.

Strategic assets: retaining options on future land use

Peats currently of 0.9m depth (the mean depth) would be degraded within 50 years under P10 and P90 climate change scenarios. Conserving them now would theoretically make them available for agricultural use should the need arise in 50 years time, when otherwise they would not be available. The option value of this future use value can be assessed in different ways as shown in Table 3-15.

The stock value of agricultural land can be assessed in terms of the market value of land, as discussed previously. The present value of ALC Grade 1 land secured for use in 50 years hence is £3,800/ha at 2012 market prices and £6,200 assuming a 1% annual real increase (above inflation) in land. If a trebling of agricultural real land prices is assumed, equivalent to an annual real increase of 2.2% as occurred over the period 1960/63 to 2008/2010 in the UK, the present value of the retained land stock is £11,400/ha. Other valuation assumptions based on loss of value of high grade land or loss of agricultural net margins range between £2,000/ha to £7,000/ha. The assumption here that land brought back into production would degrade at the same rate as if it was used now. There may however be new technological possibilities in future that reduce degradation rates.

Stronger climate change effects in themselves would serve to reduce the present value of land stock values because the remaining life of peats would shorten. Conversely, however, climate change and other possible market effects could increase the relative value of agricultural production in future.

Table 3-15: The Present Value of Maintaining the Stock of Agricultural Peats for use 50 years hence.

(£/ha, 2012 prices) Basis for estimating option value	Adjusted Current Value £000/ha	PV of capital value arising in 2063 (50 years hence)*	PV assuming 64% real increase in agricultural land prices (1% real increase per year)	PV assuming 300% real increase in agricultural land prices (2.2% real increase per year)+	Assumptions
ALC Grade 1	£21,000	+£3,800	+£6,200	+£11,400	Assumes asset value of ALC 1 land secured and available in year 50, otherwise lost
Difference between ALC 1 and ALC 5	£13,000	+£2,300	+£3,800	+£6,900	Assumes incremental asset value of ALC1 land secured and available in year 50, relative to poor quality arable land at £21k/ha -£8k/ha
Capital value of net margins from farming	£11,100	+£2,000	+£3,300	+£6,000	Assumes 50 year flow of agricultural net benefits from ALC 1 on deep peatlands compared with degraded peat, £479/ha -£27/ha per year = PV £11.1k (occurring 50 years hence) x 0.18 discount factor year at 3.5%

*Discount factor: 0.18 year 50 at 3.5% discount rate. Agricultural land prices increased by about 300% in real terms between 1960-1962 and 2008-2010 adjusted by GDP deflator

Thus, future food security could be enhanced by conserving agricultural peatlands; taking them out of agricultural production now, or farming them extensively, so that they can be returned to intensive agricultural use should the need arise. Thus a conservation strategy would include an option (and an option value) for future 'agricultural reclamation'. The peatland scenarios identified above have potential to do this to varying degrees. The present value of preserving potential for future use in 2080, assuming that continued use now would otherwise lead to complete peat wastage by then, ranges between £3,800/ha and £11,4000/ha (Table 3-15). When it comes to it, the decision to take up the reclamation option will depend on a reassessment of the relative costs and benefits of arable versus conservation peatland use given prevailing circumstances, economic prices and technological possibilities.

Maintaining the reclamation option requires that (i) reclamation potential is 'engineered' into restoration projects, (ii) critical drainage and flood defence infrastructure is maintained, (iii) knowledge and skills in the agricultural management of peatlands are maintained and (iv) restoration projects of any significant scale include a 'food security' response strategy. Building in an option value for retaining the agricultural potential peatlands could increase the cost of peatland restoration, but it should help to balance some of the arguments round the ecological restoration - food security debate. It is also likely encourage the development of the sustainable management of peatland farming

4 Conclusions

This exploratory study, drawing on earlier work, aimed to assess the implications of Fen peatland restoration and conservation for the mitigation of carbon emissions, for agricultural production and food security, and for selected ecosystems services. Conclusions are drawn with respect to the study objectives. The conclusions must be treated with caution, being based on high level assessments and many simplifying assumptions. All numerical estimates must be regarded as indicative and are best considered as a range rather than as any single estimate. In reality, there is considerable variation and uncertainty. Critically the analysis rest on a number of (i) key technical assumptions regarding the productivity of farming, the degradation of peat soils and the fate of carbon emissions and (ii) key economic assumptions regarding the relative value of agricultural commodities, carbon emissions to atmosphere, other environmental burdens, and the value of selected ecosystem services. The results are best seen as helping to inform a debate rather than providing singularly robust estimates.

The potential degradation of peatlands and associated loss of soil carbon were estimated for different land use scenarios, relatively high under intensive arable production and low under conservation grassland. This drew on estimates of carbon loss for different land uses previously reviewed by Natural England and estimated rates of peat loss in the Fens of between 10mm and 21mm per year. A method was developed to link temperature and rainfall parameters predicted under P10 (low climate change signal) and P90 (high climate change signal) with predicted peat degradation and carbon loss. A relationship was developed to estimate annual peat loss per year (mm) and associated CO_2 emissions as a function of starting and remaining depth, type of land use and climate change signal. Based on available evidence, the current 2012 mean peat depth in arable areas was assumed to be 0.86 m. The peat decay function was applied to the period 2012 through to 2080, assuming different land use and climate change scenarios. These were compared with predicted emissions from a Business as Usual *Continued Arable* scenario.

The type and value of costs and benefits of different land-use scenarios for peatland management were identified under a changing climate through to the year 2080, with particular reference to agricultural production, farm incomes and carbon emissions. Agriculture net margins for Continued (intensive) Arable production are estimated at about £480/ha in 2012 prices (with a possible range of £270/ha to £1,590/ha), declining to about £30/ha (£-50/ha to £150/ha range) for Degraded (extensive) Arable once peats have wasted away. Peat Restoration (with no commercial farming) has a net margin of about -£105/ha (-£2000/ha to -£25/ha range), and Grassland conservation options vary between about -£5/ha for extensive grazing (-£50/ha-to £50/ha range) and £23/ha for semi intensive grazing (-£50 to £100/ha range).

There appear to be significant differences in carbon emission costs between land uses that are further amplified by climate change. Valuing carbon emissions at DECC's price of £57/t CO_2e for 2012 generated estimated steady state annual carbon emission costs of £434/ha for deep arable peats and £243/ha for degraded peats, rising to about £1,300/ha and

£700/ha respective under the extreme P90 climate change scenario for 2080 (assuming there are reaming peats to degrade). Peat Restoration gave an estimated CO_2 sequestration benefit of £300/ha for 2012. Peatland Conservation gave an estimated of carbon sequestration benefit of about £40/ha on extensive grassland, and a carbon loss of about £75/ha on semi intensive grassland. It has been assumed here that Peatland restoration and Conservation options will be managed to prevent possible carbon losses induced by climate change. This assumption is worthy of further testing.

There appears to be significant differences between Restoration and Conservation options and the BAU continued arable production, measured in terms of the value of agricultural production and carbon emissions only. The *Restoration* of peatlands to peat forming vegetation could generate extra benefits of around £150/ha/yr for the 2012 status quo scenario to over £1,100/ha/yr under long term extreme climate scenarios compared with the Baseline of continued agricultural production.

A switch to *Peatland Conservation I* under extensive grassland systems more or less breaks even for the 2012 status quo case but gives positive net value of around £70/ha/yr to £170/ha/yr for future low (P10) climate change scenarios, and much more for high (P90) climate change scenarios. The semi intensive grazing *Conservation Option II* slows down but does not eradicate peat loss such as that there is an overall loss of around £100/ha/yr relative to BAU for the 2012 status quo climate scenario.

Extending environmental effects of different peatland land use to include allowance for land system costs (comprising GHG and acidification emissions from agricultural production) as well as cultural services provided by different landscape and habitat types, increases the relative advantage of Peatland Restoration and Conservation scenarios.

Discounting the expected benefits and costs of peatland management options and climate change scenarios over the period 2012 to 2080 further consolidates the relative advantage of Peatland Restoration and Conservation options. Focussing on the effects on agricultural incomes and carbon emissions only (and allowing for real price increases in agricultural commodities and carbon prices), the estimated incremental benefit of switching from *Continued Agricultural Production* to *Peatland Restoration* or *Peatland Conservation I* with extensive wet grassland is about £40,000/ha rising to £50,000/ha under the highest climate change scenario.

Extending environmental effects of different peatland land use to include allowance for land system costs (estimated here to include GHG and acidification emissions from agricultural production) as well as cultural services provided by different landscape and habitat types, further increases the relative advantage of Peatland Restoration and Conservation scenarios.

Peat soils make an important contribution to agricultural production, especially regarding high value crops. The withdrawal of the 20,500 ha Target area in the East Anglian Fen would probably not have a major impact on UK national food supply and food security. It is likely that the production of high value cropping would, for the most part, be made good by substitution of cropping elsewhere. Furthermore, the comparative advantage of peat soils for high value cropping is being lost over time as they are degraded.

Although the scale of the peatland restoration considered here may not have a major impact on total food production now, projections for global food demand and supply suggest that food security might become more critical in 30 to 50 years time. Thus, future food security could be enhanced by conserving agricultural peatlands, taking them out of agricultural production now, or farming them extensively, so that they can be returned to intensive agricultural use should the need arise.

The preceding analysis required a number of assumptions that critically affect the results and interpretations obtained. It is predicated on assumptions about future agricultural and carbon prices about which there is considerable uncertainty. There is also considerable uncertainty about the rates of peatland degradation under conditions of climate change and the efficacy of measures to reduce soil carbon loss. Many of these assumptions reflect gaps in knowledge that could be filled by further research if deemed worthwhile.

Broadly, however, there is very clear evidence that current methods of intensive agriculture irrecoverably degrade the very inherent properties of peat soils that gave them comparative advantage for farming in the first place. It therefore seems eminently sensible to take actions to conserve their future. This argument is now reinforced by a much greater appreciation that maintaining the health of peat soils delivers considerable real economic benefits associated with GHG regulation as well as a wide range of other environmental benefits.

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Appendix A: Peat emission data developed for NPV calculations

Annual data are needed to calculate the NPV associated with the potential services flows of different uses of the fenland peat. In particular it was necessary to determine how the depth of peat might change over time in order to determine at what point in time it would disappear. A range of assumptions were made regarding this and there is inevitably high uncertainty associated with the calculations.

The annual change in temperature was developed from the data in Table 3-7 above using second order polynomial equations to describe the relationship between year and relative temperature change (°C) (Figure A- 1:).

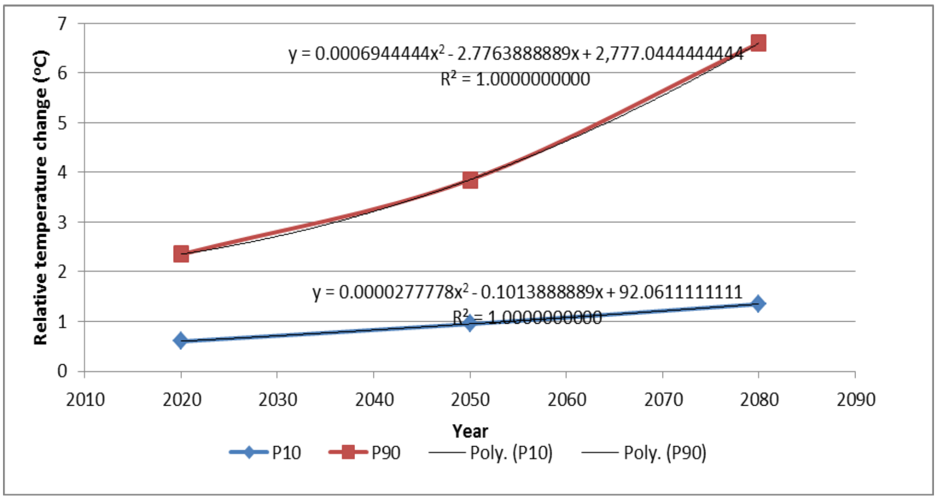

Figure A- 1: The relationship between year and relative temperature change as developed from the UKCP09 projects described in Table 3-7.

In order to determine how long the fenland peat might last given an annual rate of degradation, a starting peat depth needed to be defined. This was developed by taking measured peat depth data from Burton and Hodgson (1987)[68] as developed in Holman (2009)[69] (Figure A- 2).

[68] Burton and Hodgson (1987). *op. cit.*
[69] Holman IP (2009) *op. cit.*

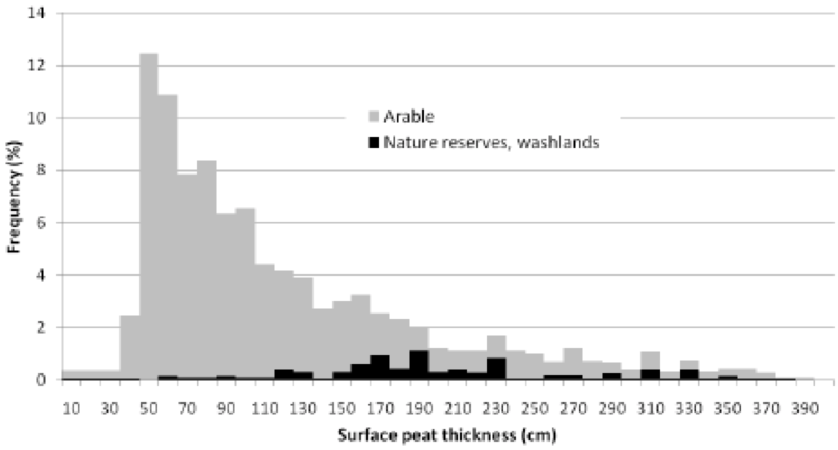

Figure A- 2: Distribution of peat thickness for "Nature reserves, washlands", and "Arable" peats developed by Burton and Hodgson (1987)[70] and described by Holman (2000)[71].

Whilst this data described a range of peat thicknesses for two categories of peat under: i) "Nature reserves and washlands" and, ii) "Arable", Holman (2009)[72] converted this to single average values for three peat thickness classes, 40-99 cm, 100-199cm, and >200cm.

Table A- 1: Average peat thickness for three peat thickness classes for Nature reserves, washlands, and Arable peats developed by Holman (2009)[73] from data from Burton and Hodgson (1987)[74].

Peat thickness class (cm)	Nature reserves, washlands		Arable	
	Frequency (%)	Average peat thickness (cm)	Frequency (%)	Average peat thickness (cm)
40-99	7	79	60	71
100-199	51	166	29	142
>200	42	287	11	278

In order to convert the peat thickness in 1987 (Table A- 1) to a current peat thickness, an annual peat degradation rate was required. The annual rate of loss of peat has been reported in a number of studies and ranges from 0.19 cm per year (Milne et al., 2006)[75] to 2.5 cm per year (Miers, 1970)[76]. Data suggest that annual rates of degradation are higher when peats are thicker, than when they are thinner.

[70] Burton and Hodgson (1987). *op. cit.*
[71] Holman IP (2009) *op. cit.*
[72] Holman IP (2009) *op. cit.*
[73] Holman IP (2009) *op. cit.*
[74] Burton and Hodgson (1987). *op. cit.*
[75] Miers RH (1970). Design of underdrainage based on field evidence in England and Wales. MSc thesis, Newcastle University
[76] Milne, R.; Mobbs, D. C.; Thomson, A. M.; Matthews, R. W.; Broadmeadow, M. S. J.; Mackie, E.; Wilkinson, M.; Benham, S.; Harris, K.; Grace, J.; Quegan, S.; Coleman, K.; Powlson, D. S.; Whitmore, A. P.; Sozanska-Stanton, M.; Smith, P.; Levy, P. E.; Ostle, N.; Murray, T. D.; Van Oijen, M.; Brown, T. (2006). *UK emissions by sources and removals by sinks due to land use, land use change and forestry activities*. Report, April 2006. Centre for Ecology and Hydrology, 278pp. (CEH: Project Report Number C02275).

Table A- 2: Peat wastage rates as reported by Holman (2009)[77].

Peat thickness	Land cover Intensive arable	Intensive grassland	Semi-natural
Deep (> 1m)	2.1	0.8	0.4
Thin (< 1 m)	1.3	0.7	0.1

Under intensive arable use, Holman (2009)[78] suggests rates of 2.1cm yr^{-1} for peats with a depth of more than one metre, and 1.3 cm yr^{-1} for peats with a depth of less than one metre (Table A- 2). Using these values, a relationship was established between the total depth of peat and the rate of annual peat degradation (Figure A- 3). This was then used to find a starting depth for the peat, assuming that the values for arable land developed by Holman (2009)[79] from the data given by Burton and Hodgson (1987)[80]. In order to simplify the analysis, the mean mid value of 142 cm total peat depth was used to represent an average peat depth in the Fens in 1987. It was assumed that the degradation rate of 2.1cm yr^{-1} should be associated with the thick peat commencing at depth of one metre (deep peat), and that the degradation rate of 1.3 cm yr-1 for thin peat should be associated with the midpoint for thin peats, in this case 0.5 m (Figure A- 3).

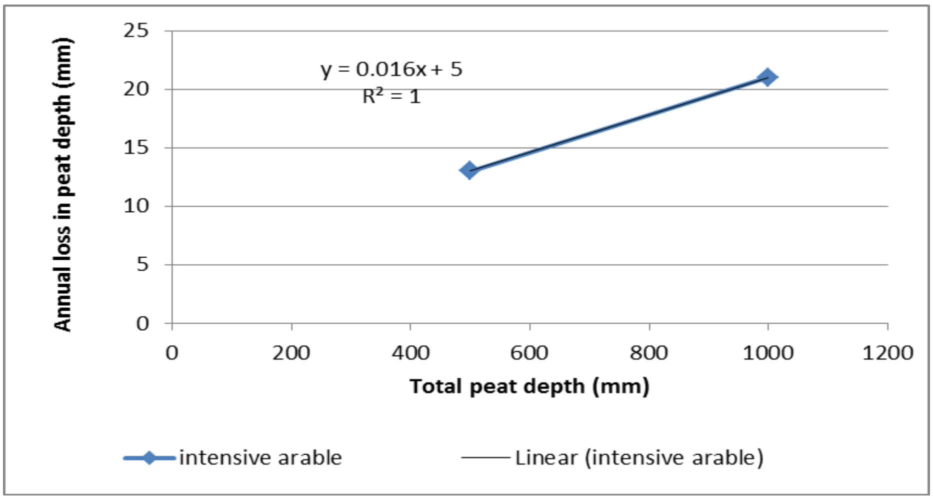

Figure A- 3: The relationship between annual peat wastage rates and total peat depth, developed from data reported by Holman (2009)[81].

Using the linear regression described in Figure A- 3, the current starting depth for 2012 was found to be 0.86 m. This was then used as the starting peat depth for all the land use scenarios used in the NPV calculations. At this depth the relationship in Figure A- 3 suggests an annual peat degradation rate should be approximately 1.88 cm yr^{-1}. Finally, it was

[77] Holman IP (2009) *op. cit.*
[78] Holman IP (2009) *op. cit.*
[79] Holman IP (2009) *op. cit.*
[80] Burton and Hodgson (1987). *op. cit.*
[81] Holman IP (2009) *op. cit.*

further assumed that as the fenlands are mostly under arable cultivation, the CO_2 emission to be associated with this total depth of peat of 0.86 m and the associated annual peat loss of 1.88 cm yr^{-1} should be a value of 22.42 CO_2 ha^{-1} yr^{-1} which was the value initially given by Natural England but modified by the Adaptation Sub-Committee of the Committee on Climate Change to exclude CH_4 and N_20 emissions for arable land use in deep fenland[82]. This was because CO_2 emission (or sequestration) is closely related to a change in peat depth, whereas the CH_4 and N_2O emissions can act independently of this. Using this relationship, an annual emission rate of 1.19 t CO_2 ha^{-1} yr^{-1} for each millimetre of peat depth loss was estimated for arable land use on deep peat. This relationship was then used to calculate the annual peat depth loss of the other land uses, using the annual CO_2 emissions initially reported by Natural England, and subsequently modified to exclude CH_4 and N_20 emissions, by the Adaptation Sub-Committee of the Committee on Climate Change[83]. The effect of annual peat depth change on total peat depth for the baseline scenario, which assumes that the climate in the future is no different to the climate now, is shown in Figure A- 4.

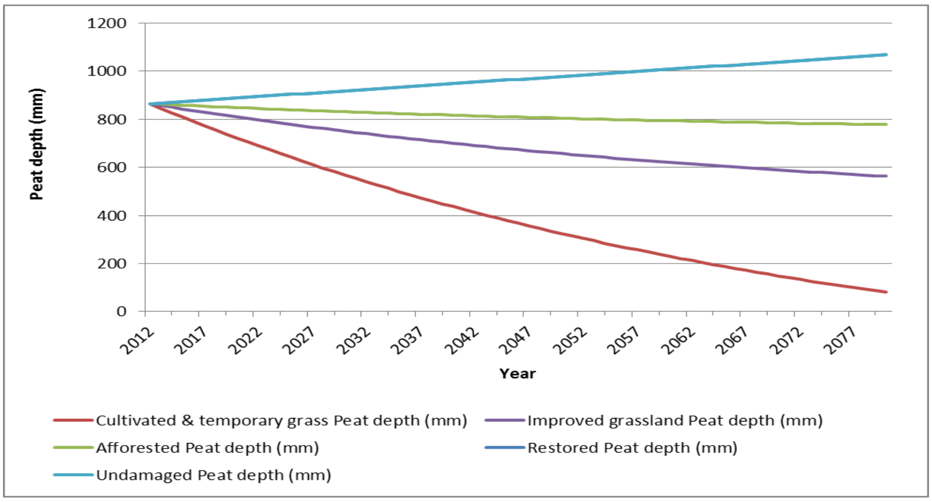

Figure A- 4: Peat depth change under different land uses for the baseline climate scenario.

In order to calculate the impact of global warming on these annual emission rates and the impact of this on annual peat depth loss, the annual temperature changes developed for the P10 and P90 global warming scenarios, as shown in Figure A- 1: were used to develop a series of annual multipliers based on the relationship described by Blodau (2002)[84], that is, that under normal peat temperatures, CO_2 emission increases by two to threefold for every 10^{o}C increase in temperature, suggesting that every one degree increase in temperature (^{o}C) results in approximately a 30% increase in CO_2 emission. The impact of the P10 and P90 scenarios on the rate of emissions of CO_2 from peat given these assumptions is shown in Figure A- 5. There is a marked difference in the expected duration of the peat under these

[82] *Pers. comm*. David Thompson and Ibukunoluwa Ibitoye, Adaptation Sub-Committee of the Committee for Climate Change

[83] *Pers. comm*. David Thompson and Ibukunoluwa Ibitoye, Adaptation Sub-Committee of the Committee for Climate Change

[84] Blodau (2002) *op. cit.*

different climate change scenarios, with the peat remaining for longest under the current baseline, and for shortest under the P90 high emissions scenario.

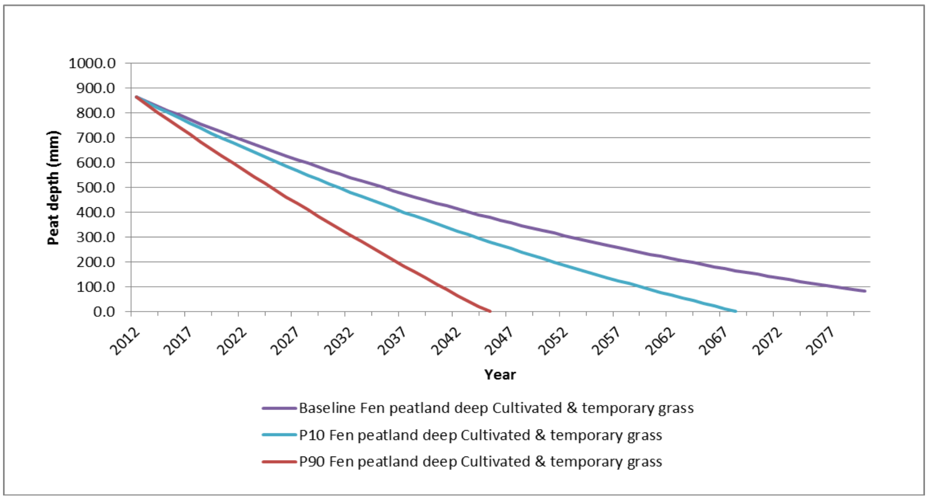

Figure A- 5: Annual peat depth change under arable land assuming the baseline climate and the P10 and P90 climate change scenarios.

It should also be noted that two peat depth loss scenarios have been assumed. The first assumes a constant rate of peat depth loss, and therefore a constant CO_2 emissions rate, irrespective of total peat depth. The second assumes that peat depth loss, and therefore CO_2 emissions rates, decline as total depth of peat decreases. The effect of this for arable land and for the baseline climate change scenario is shown in Figure A- 6. The constant rate of decline predicts a much more rapid loss of peat than the declining rate of annual peat depth loss with decreasing total peat depth.

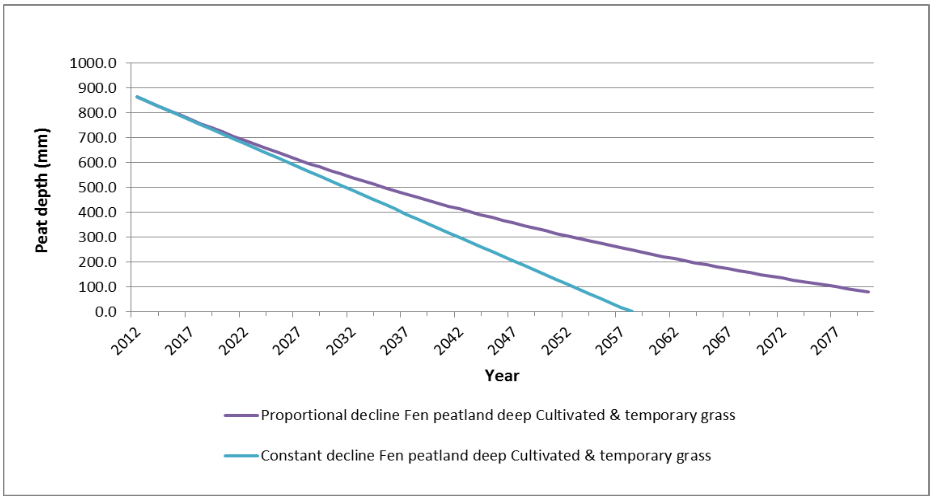

Figure A- 6: Annual peat depth change under arable land assuming the baseline climate scenario for two different assumptions on peat loss rates.

Appendix B: Summary of Production and Net Returns from Farming by Land use Scenario

Fen Peatland

Scenario **BAU Continued Arable Agriculture** | **Scenario:** **Degraded Arable peatlands**

Farmed Areas		Area	Production	Gross Value	Net Value	Farmed Areas		Area	Production	Gross Value	Net Value
% of area		ha	000t	£000‡	£'000‡	% of area		ha	000t	£000‡	£'000‡
Total area		20029						20029			
Total farmed area		20029						20029			
Total arab	90.4%	18102				90%		18102			
	% of arable area						% of arable area				
W Wheat	46%	8254	69.3	8182	179		55%	9956	83.6	8363	216
Sp barley	4%	742	4.4	422	-172		5%	905	5.4	515	-209
Oil Seed Rape	5%	815	2.9	684	12		15%	2715	9.5	2281	40
Peas	4%	724	2.8	424	-97		5%	833	3.2	487	-112
Beans	4%	634	2.5	355	-57		5%	905	3.6	507	-81
Sugar Beet	14%	2516	145.9	4232	530		15%	2715	157.5	4567	572
Potatoes	10%	1774	92.2	12914	3165		0%	0	0.0	0	0
Field Veg	6%	1140	45.6	6842	2235		0%	0	0.0	0	0
Hortic	8%	1430	35.8	17875	2874		0%	0	0.0	0	0
Fruit	0%	72	2.4	2842	91		0%	72	2.4	2842	91
Other (non food) ex(	0%	0	-	-	-		0%	0	-	-	-
Total crops	100%	18102		**68089**	**9621**		100%	18102		**24317**	**567**
Total Gras	9.6%	1927				10%		1927			
milk production*			381	**105**					381	**105**	
meat production			540	**1693**					540	**1693**	
Total dairy and livestock**				**1799**	**-22**					**1799**	**-22**
Total £000				**69888**	**9600**					**26116**	**545**
				£/ha	**£/ha**					**£/ha**	**£/ha**
Total £ per ha				**3489**	**479**					**1304**	**27**

Note: ‡agricultural commodity prices based on average of 2008 to 2010, initially expressed in 2010 prices, totals uplifted to 2012 using Defra agricultural prices series
**gross value based on meat and milk sale prices, excluding depreciation of herd
gross value including depr 1391 £k
Net Value after fixed costs

Other indicators	per farmed ha	total area 000	Other indicators	per farmed ha	total area 000
Labour hrs	61.3	1227.7	Labour hrs	14.9	299.2
Water hamm	5.2	103.8	Water hamm	5.4	108.1
Primary Energy used, GJ	26.3	527.1	Primary Energy used, GJ	18.2	364.1
Global Warming Pot'l, t (100 year) CO2 Equiv	4.3	86.6	Global Warming Pot'l, t (100 year) CO2 Equiv.	3.6	71.3
Eutrophication Pot'l, kg PO4 Equiv.	21.3	425.8	Eutrophication Pot'l, kg PO4 Equiv.	23.1	463.6
Acidification Pot'l, kg SO2 Equiv.	19.6	392.2	Acidification Pot'l, kg SO2 Equiv.	21.1	422.7
Pesticides used, dose ha	8.5	171.1	Pesticides used, dose ha	6.7	135.1
Abiotic depletion, kg antimony Equiv.	13.1	262.0	Abiotic depletion, kg antimony Equiv.	10.2	204.1
Nitrates to Water NO3 kg	31.0	620.2	Nitrates to Water NO3 kg	35.3	707.9

Scenario	Conservation I : Wet Grass (extensive)				
	Farmed Areas	Area	Production	Gross Value	Net Value
	% of area	ha	000t	£'000‡	£'000‡
Total area		20029			
Total farmed area		20029			
Total arab	0%	0			
Total Gras	100%	20029			
milk production*			0	0	
meat production			2362	**7402**	
Total dairy and livestock**				**7402**	**-95**
Total £000				**7402**	**-95**
				£/ha	**£/ha**
Total £ per ha				**370**	**-5**

Scenario:	Conservation II : Wet Grass (semi extensive)				
	Farmed Areas	Area	Production	Gross Value	Net Value
	% of area	ha	000t	£'000‡	£'000‡
Total area		20029			
Total farmed area		20029			
Total arab	0%	0			
Total Gras	100%	20029			
milk production*			0	0	
meat production			**5294**	**16591**	
Total dairy and livestock**				**16591**	**470**
Total £000				**16591**	**470**
				£/ha	**£/ha**
Total £ per ha				**828**	**23**

Note: ‡agricultural commodity prices based on average of 2008 to 2010, initially expressed in 2010 prices, totals uplifted to 2012 using Defra agricultural prices series

**gross value based on meat and milk sale prices, excluding depreciation of herd

gross value including depr 5658 £k (Conservation I); gross value including depr 12665 £k (Conservation II)

Net Value after fixed costs

Other indicators (Conservation I)	per farmed ha	total area 000
Labour hrs	14.0	281.3
Water hamm	6.9	137.4
Primary Energy used, GJ	3.7	74.2
Global Warming Pot'l, t (100 year) CO2 Equiv	1.7	34.5
Eutrophication Pot'l, kg PO4 Equiv.	10.8	217.1
Acidification Pot'l, kg SO2 Equiv.	21.1	421.7
Pesticides used, dose ha	0.2	3.9
Abiotic depletion, kg antimony Equiv.	2.5	50.3
Nitrates to Water NO3 kg	15.6	312.4

Other indicators (Conservation II)	per farmed ha	total area 000
Labour	32.1	642.6
Water hamm	6.2	124.2
Primary Energy used, GJ	8.3	166.9
Global Warming Pot'l, t (100 year) CO2 Equiv.	3.9	77.3
Eutrophication Pot'l, kg PO4 Equiv.	24.3	486.1
Acidification Pot'l, kg SO2 Equiv.	47.4	949.6
Pesticides used, dose ha	0.4	8.8
Abiotic depletion, kg antimony Equiv.	5.7	113.3
Nitrates to Water NO3 kg	34.8	697.1

Appendix C: Inflation adjustment: 2010 to 2012 prices for agricultural outputs and inputs

The analysis of financial performance of peatland farming carried out in Morris et al, (2010) in 2010 prices, was uplifted to 2012 prices using the price indices below

Adjustment factors used in the uplifting of 2010 prices to 2012 prices

	Inflators
GDP deflator *	1.05
Arable systems	
Gross output	1.24
Variable costs	1.15
Total costs	1.13
Gross Margin	1.08
Net Margin	1.10
Livestock systems	.
Gross Ouput	1.15
Variable costs	1.15
Total costs	1.13
Gross Margin	1.00
Net Margin	1.02

Source: * HMT, 2013, otherwise Defra, 2013

Inflation adjustment from 2010 to 2012 prices for agricultural ouputs and inputs

UK Agricultural ouput and input price series , 2007 - 2012

	2007	2008	2009	2010	2011	2012	2012/2010
Total Outputs	**119**	**144**	**137**	**146**	**166**	**174.1**	**1.19**
Crops	**134**	**155**	**133**	**153**	**152.6**	**190.2**	**1.24**
Cereals	167	207	150	172	246	259	**1.51**
Oil seed rape	144	233	183	204.7	277	281.8	**1.38**
Sugar beet	83	92	98	99	94	100.2	**1.01**
Fresh vegetables	122	117	114	132	120	141.8	**1.07**
Potatoes (main crop)	150	155	124	141	153	174.1	**1.23**
Livestock products	**109**	**136**	**139**	**141.4**	**154**	162.9	**1.15**
L/s for slaughter	105	133	146	146.2	159	168.3	**1.15**
Milk	112	150	128	134.8	148	155.3	**1.15**
							.
Inputs	**114**	**140**	**130**	**135.8**	**151**	**153.7**	**1.13**
Goods currently consumed	**116**	**146**	**133**	**139.3**	**157**	**159.9**	**1.15**
Seeds	104	112	112	110	119	120	**1.09**
Energy	118	158	130	149.7	171	184	**1.23**
Fertilisers	120	273	190	182.4	229	220.3	**1.21**
Plant protection	104	106	109	105.6	105	106.5	**1.01**
Animal feeds	130	167	152	161	195	202.4	**1.26**
Goods and services contributing to				118.9	122.5	123.6	**1.04**
Machinery	106	117	122	124	121.8	1.2	**0.01**

Source Defra. 2013. Agricultural price indices: https://www.gov.uk/government/publications/agricultural-price-indices

Appendix D: Peatland Restoration costs

Peat Restoration establishment and maintenance costs excluding land ownership costs

Capital costs	£/ha
Minor land forming and drainage modifications	300
Fencing /infrastructure	200
Seeding/plantings	75
Total	575
Life years	50
Annuity	0.04
Annual charge	23
Operation and Maintenance	£/ha
Drainage rates	
labour	15
machinery and power	20
buildings and infrastructure	25
general (including utilties)	10
misc expenses	12
Total	82
Task allocation	
grass topping and veg control	25
ditch /pond maintenance	20
fencing and infrastructure	10
drainage rates	15
misc	12
Total	82
Annual capital charge	23
Total annual cost	105

2012 prices.
Capital and operating cost associated with biodiversity enhancements and/or visitor facilities and operation are excluded. Grazing is assumed to be self financing where it applies.

Source: *Pers. comm.* Mr Chris Soans: Estates Manager, Wicken Fen, Cambs

Appendix E: Carbon time series values provided by DECC (2010) and adjusted to 2012 prices

	Traded values			Non-traded values		
	Low	Central	High	Low	Central	High
2013	9	16	20	30	58	88
2014	10	17	22	30	59	89
2015	12	19	25	31	60	91
2016	14	22	28	31	61	92
2017	15	23	29	31	62	93
2018	16	25	32	32	64	95
2019	17	27	34	32	65	96
2020	19	30	36	33	66	97
2021	22	34	44	33	67	99
2022	24	39	52	34	68	101
2023	26	43	59	34	69	102
2024	27	48	68	35	70	104
2025	29	52	75	35	71	106
2026	31	57	83	36	72	108
2027	33	62	91	37	73	110
2028	35	67	98	37	74	111
2029	36	72	107	38	75	113
2030	38	76	114	38	76	114
2031	42	83	125	42	83	125
2032	45	90	135	45	90	135
2033	48	97	145	48	97	145
2034	52	104	157	52	104	157
2035	55	112	167	55	112	167
2036	59	119	177	59	119	177
2037	62	125	189	62	125	189
2038	67	132	199	67	132	199
2039	70	139	209	70	139	209
2040	74	147	220	74	147	220
2041	77	154	231	77	154	231
2042	80	161	241	80	161	241
2043	84	168	252	84	168	252
2044	87	175	262	87	175	262
2045	91	182	273	91	182	273
2046	94	189	284	94	189	284
2047	98	196	294	98	196	294
2048	101	203	304	101	203	304
2049	106	210	316	106	210	316
2050	109	217	326	109	217	326
2051	112	225	338	112	225	338
2052	114	233	350	114	233	350
2053	117	240	364	117	240	364
2054	119	247	376	119	247	376
2055	121	254	388	121	254	388
2056	123	262	401	123	262	401
2057	125	268	413	125	268	413
2058	127	276	424	127	276	424
2059	128	283	436	128	283	436
2060	130	289	448	130	289	448
2061	131	294	458	131	294	458
2062	132	299	467	132	299	467
2063	132	304	476	132	304	476
2064	132	308	485	132	308	485
2065	133	312	492	133	312	492

2066	133	317	500	133	317	500
2067	132	320	506	132	320	506
2068	132	323	512	132	323	512
2069	131	325	518	131	325	518
2070	131	327	524	131	327	524
2071	130	329	528	130	329	528
2072	129	331	533	129	331	533
2073	128	332	537	128	332	537
2074	127	333	540	127	333	540
2075	125	334	543	125	334	543
2076	124	334	545	124	334	545
2077	122	334	547	122	334	547
2078	120	334	548	120	334	548
2079	118	333	548	118	333	548
2080	116	332	548	116	332	548

Appendix F: Switch values for net margin and carbon price for the baseline BAU and semi-intensive grassland scenario

	Switch values*	
	BAU	**Semi-intensive grass**
Baseline net margin**	+ 21% increase per year	+ 141% increase per year
Carbon price***	- 77% per of central estimate	- 97% of central estimate

Notes:
*Here, switch values are the relative rate at which input values need to be increased or decrease to give a NPV of £0
**The switch value for the net margins are calculated for the baseline scenario and are therefore given relative to the existing 1.4% increase in net margin
***The switch value for carbon price assumes the central estimate for carbon values given by DECC