JBA consulting

Exploring the economics of land use change for increasing resilience to climate change in England

Final Report

07 December 2018

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Committee on Climate Change

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Contract

This report describes work commissioned by Kathryn Brown, on behalf of The Committee on Climate Change, by a letter dated December 2017. The Committee on Climate Change's representatives for the contract was Kathryn Brown and Brendan Freeman. Rachelle Ngai, Angus Pettit, Steve Rose, Phil Bennett-Lloyd, Jeff Lunn, Susie Goodard, Rachel Brisley, and Steve Maslen of JBA Consulting carried out this work.

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Purpose

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Acknowledgements

This project could not have been completed without the local experts in each of the case study areas of Moor House and Upper Teesdale, Norfolk and Suffolk Broads, Petteril, and Somerset and the national experts engaged at the Environment Agency, Defra, Natural England, and RSPB.

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Carbon footprint

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Executive summary

The Adaptation Sub-Committee (ASC) of the Committee on Climate Change (CCC) have commissioned research to investigate how land use change can help adapt to climate change. The research examined how taking a long-term approach to considering the impacts of plausible hazards from climate change and anticipating land use changes to manage these risks could deliver net benefits in terms of natural capital and the ecosystem services it provides.

An 'adaptation pathways' approach was used to build understanding of how the need for planned transformational change can be understood and analysed. The first part of the analysis involved the development of a decision framework, to guide decisions about long-term land use, based on a climate hazard thresholds approach. A climate hazard threshold in this context relates to a given level of a climate hazard that, once reached, will make it cost-prohibitive to maintain the current land use and the ecosystem services it has provided to date. The decision framework comprised of four stages:

- Stage 1. Identify the current land use management strategy and quantify what is produced or provided by the land.
- Stage 2. Determine what level of climate hazard acts as a risk to the current land use.
- Stage 3. Assess the evidence for the plausibility and timing of these hazards occurring.
- Stage 4. Estimating the costs and benefits of alternative decision-making scenarios: (i) a business as usual (BAU) scenario, assuming no land-use change interventions; (ii) an anticipatory scenario, assuming land-use change happens before a climate hazard threshold event occurs; and (iii) a reactionary scenario, assuming land-use change occurs after the climate hazard threshold event.

The decision framework was applied to four local case study locations in rural England to investigate the long-term impact on current land use activities of reaching specific climate hazard thresholds and assessed the effects of pursuing alternative land use strategies. The four case study locations were chosen to represent a varied mix of land uses and comprised:

- Norfolk and Suffolk Broads, East Anglia
- The Petteril Catchment, Cumbria
- Moor House and Upper Teesdale in the North Pennines
- Somerset, including the levels

Benefits assessed within the analysis included those relating to: agricultural production; timber production; carbon sequestration services; recreation; water quality improvements; biodiversity; and aesthetic amenity. Costs assessed as part of the analysis comprised those relating to: ongoing costs of maintaining current land use activities; recovery costs following a climate hazard threshold being reached; costs of land use change.

Findings

The case study analysis found that in scenarios where climate change presents a threat to current land use, the use of adaptation pathways that consider land-use change in advance of the climate hazard event occurring deliver higher net benefits compared to waiting until the hazard has occurred. **The potential gains centre on avoiding**

escalating costs, maximising benefits, and reducing the risk of irreversible change.

Implementing adaptation actions to change land use, in advance of a hazard threshold occurring, limits the increase in costs in all of the case studies presented. For example, in the Norfolk and Suffolk Broads case study, where the majority of land is used for arable and livestock farming, a climate hazard threshold centred on coastal and inland flooding. Costs in relation to agricultural production were shown to be larger due to factors including waterlogged soils exceeding agricultural field capacities, saline incursions into freshwater and farmland habitat, and increased soil runoff and erosion. However, in the anticipatory scenario, costs were shown to reduce through a switch to more flood-resilient land uses such as from arable (cereals crop production) to pastoral (semi-improved grassland) and saltmarsh. Despite an initial short-term rise in costs under this scenario, when compared to the BAU scenario, taking effective land use change actions early reduces total costs by £490 million over the 80-year reference period and reduces the risk of escalating costs over the long-term.

Additionally, in all case studies it was demonstrated that anticipatory adaptive decisions can lead to greater benefits and more sustainable land uses over time. Delaying adaptive actions reduces the land's ability to insulate against the impact from reaching a given climate threshold. For example, in the Petteril case study, the threshold identified was winter/spring waterlogging of fields and/or fluvial flooding of agricultural land. The findings suggest implementing anticipatory adaptation measures deliver higher total benefits in the long term due to the increased level of resilience to climate change achieved through the adaptation actions implemented. When totalled over the 2018 to 2100 reference period, the present value of benefit gains over and above the BAU scenario are £41 million in the anticipatory scenario as opposed to £17 million in the reactionary scenario. The land use changes increased the potential for carbon removal, increased production of timber, and would provide broader benefits such as water quality and biodiversity.

Lastly, findings from the Moor House and Upper Teesdale case study demonstrated how unless addressed in advance, the downside risks from climate change could effectively be irreversible and endanger the supply of essential ecosystem services from the natural environment. Furthermore, the results indicate that the longer unsustainable land use activities are continued, the higher the potential level of degradation to the natural assets that support it. Based on a climate hazard threshold of low winter rainfall followed by spring and summer drought, the findings suggest the complete cessation of damaging activities on peatland habitat at the location, in combination with interventions to restore damaged peat assets, could prevent a loss of the peatland area and support the delivery of ecosystem services over the long-term. When compared to the BAU scenario, the total net present value of carbon sequestration services provided by the land at the case study location was £167 million higher in the anticipatory scenario, and £131 million higher in the reactionary scenario.

Conclusions

The research has explored the economics of land use change to insulate against the potential impacts of reaching climate hazards thresholds in four case study locations in England. The findings indicate that in cases where some land uses are projected to become increasingly unviable into the future because of climate change, land-use change to build resilience before threshold events occur provides greater net benefits than relying on low regret measures to try to maintain the current land use activity.

The systematic approach to decision-making on land-use change demonstrated in this report allows for land-use change to be implemented in a robust and evidence-based way. However, in order to support this, further research is needed into the potential risks from climate change to current land uses. The analysis represents a platform for future work into better understanding the long-term viability of current land use activities.

Contents

List of Figures

List of Tables

Abbreviations

25YEP	25 Year Environment Plan
ALC	Agricultural Land Classification
ASC	Adaptation Sub-Committee
AONB	Area of Outstanding National Beauty
BAU	Business as usual
CAP	Common Agricultural Policy
CCC	Committee on Climate Change
CCRA	Climate Change Risk Assessment
ELS	Entry Level Stewardship
ESS	Ecosystem service
GHG	Greenhouse gas
GNAR	Go North and Ride
HLS	High Level Stewardship
IDB	Internal Drainage Board
LFA	Less Favoured Areas
NAP	National Adaptation Programme
NCA	National Character Area
NCC	Natural Capital Committee
NFU	National Farmers Union
NGO	Non-governmental organisation
NNR	National Nature Reserve
NP	National Park
NR	Nature Reserve
NVZ	Nitrate Vulnerable Zone
RCM	Regional Climate Model
RSPB	Royal Society of the Protection of Birds
SAC	Special Area of Conservation
SMP	Shoreline Management Plan
SPA	Special Protection Area
SSSI	Sites of Specific Scientific Interest
THI	Thermal Heat Index
UKCP09	United Kingdom Climate Change Projections 2009
WFD	Water Framework Directive

Definitions

Climate resilience: The capacity of the landscape to accommodate climate change related impacts, whilst still retaining productive, regulatory, and cultural functions, including those that contribute to mitigating climate change.

Economic feasibility: The analysis of an activities (or scenario's) stream of benefits and costs to determine the long-term effectiveness and whether it is rational to progress with the option.

Land cover: The surface cover or physical material at the surface (i.e. forest, open water).

Land use: The purpose the land serves, or the intention of people to obtain products and/or benefits through the land (i.e. agricultural land, grazing, recreation)

Land management: The process of managing the use and development of the land (i.e. cultivation, use of fertilizers)

Natural capital: The elements of nature that directly or indirectly produce value to people, including ecosystems, species, freshwater, land, minerals, the air and oceans, as well as natural processes and functions. (Definition from the Natural Capital Committee).

Threshold/ turning point: The point at which the current land use can no longer be resilient to climate change (see definition of climate resilience).

1 The project

1.1 Background

The Adaptation Sub-Committee (ASC) of the Committee on Climate Change (CCC) were established under the 2008 Climate Change Act to advise the UK Government and report to Parliament on progress on adaptation to climate change. In July 2016, the ASC published an Evidence Report to inform the second UK Climate Change Risk Assessment (CCRA), with the key findings presented in January 2017. One of the six priority risks identified by the ASC as needing urgent further action in the next five years relates to the provision of natural capital, including terrestrial, coastal, marine and freshwater ecosystems, soils, and biodiversity. Furthermore, the ASC's assessments of the National Adaptation Programme (NAP) have found that while there is much action underway to adapt to climate change, vulnerability to climate change across several indicators in the natural environment is increasing.

1.2 Aim and scope

The Committee on Climate Change have commissioned JBA Consulting to examine how taking a long-term approach to considering the risks from climate change and anticipating land use changes to manage these risks could deliver benefits in terms of both resilience to climate change and the provision of natural capital. Furthermore, it was to calculate, as far as possible, the social costs and benefits associated with land use change scenarios which deliver climate change resilience and natural capital improvements.

To understand how different land use changes in rural England could deliver climate change resilience, the work explored approaches in four case study locations. A case study approach was needed for the work as climate change impacts occur at local scales and the costs and benefits of different choices about land use will vary by location. The case study locations scoped for this research were:

- The Petteril catchment, Cumbria
- Somerset including the Levels
- Moor House and Upper Teesdale, North Pennines
- Norfolk and Suffolk Broads, East Anglia

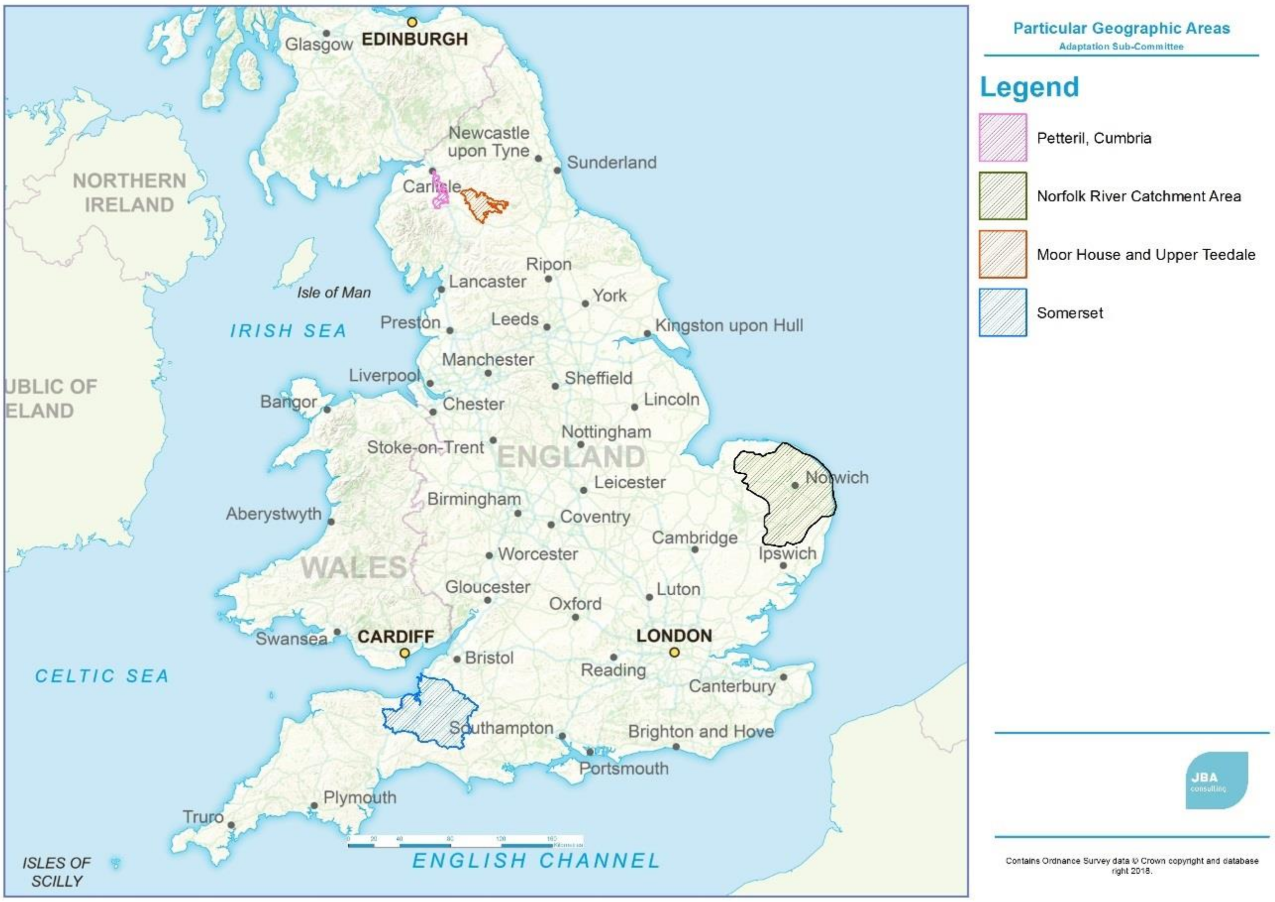

Figure 1-1 – Location of the case studies for this research

These sites were chosen as representative of the varying locations and landscapes within England, often with different national and international designations which may provide several benefits and constraints on the landscape. However, this research does not attempt to fully interact with coastal processes since the ASC has at the same time been funding a separate coastal research project. Additionally, the case studies in this research cannot and should not be extrapolated to the national scale since local data and views were used as much as possible. The case studies are used to illustrate the method for understanding the impacts of climate thresholds on land use.

The Committee on Climate Change is, in parallel to this project, undertaking related research into delivering ambitious emission reductions in the land use sector at a national level. Both projects will be written up into a joint report on the role of land use in tackling and preparing for climate change.

2 Methodology

The aim of this project was to determine and analyse a plausible set of land use change case study scenarios, for particular geographical areas in England, that would likely deliver net benefits for climate change resilience under different future climate scenarios, out to 2100. The scenarios chosen did not need to represent an optimal approach to delivering resilience, as this would involve assessing too many different options compared to the resources available for the work and is a potentially impossible task. Rather, the scenario development aimed to test how different long-term choices on land use can be considered in the context of a changing climate, and whether sensible anticipatory decisions (in advance of a negative impact occurring) can be made that would reduce the overall negative impact.

The approach to determining and assessing these scenarios involved an iterative development of the final methodology. This involved testing different methods to explore and better understand the complexities and nuances surrounding land use, land management, land use change and scenario-making. This section describes the different methods tested, the feedback on these and explains the refinement towards the final method.

2.1 Method A: Initial proposal

The first approach, referred to as the Initial Proposal, aimed to explore whether if and how climate change resilient landscapes can be delivered by 2100 that enhance the overall stock of natural capital in that location. The context for assessing the resilience of the different choices was to consider potential impacts at a 2 and 4°C global temperature rises and the effects of this on land use in the case study locations. The methodology is set out in summary in Figure 2-1 below.

The key element of the approach was to develop an expert group for each case study location to use their collective knowledge of local land use and land management. This group would identify the likely adaptive land use responses based on the climate change projections. They were asked to develop a Business as Usual (BAU) vision (based on continuing with the same land use) and an Adaptive High Resilience vision (to enhance the overall level of resilience of the landscape to climate change compared to the BAU scenario).

Background research was completed, aligning a 2 and 4°C global temperature rises with UK climate change projections (UKCP09). The work aligned 2 and 4°C global temperature rises with projections for UKCP09’s low emissions 50% probability scenario and high emissions 50% probability scenario, respectively.

A description of the BAU and high resilience scenario was developed through the expert groups in each location, desk research and in line with the CCC’s parallel mitigation land use project.

Each of the case study groups were given the UKCP09 results and working assumptions to apply to each individual case study. The local experts then developed the BAU and high resilience visions at a workshop in each case study location.

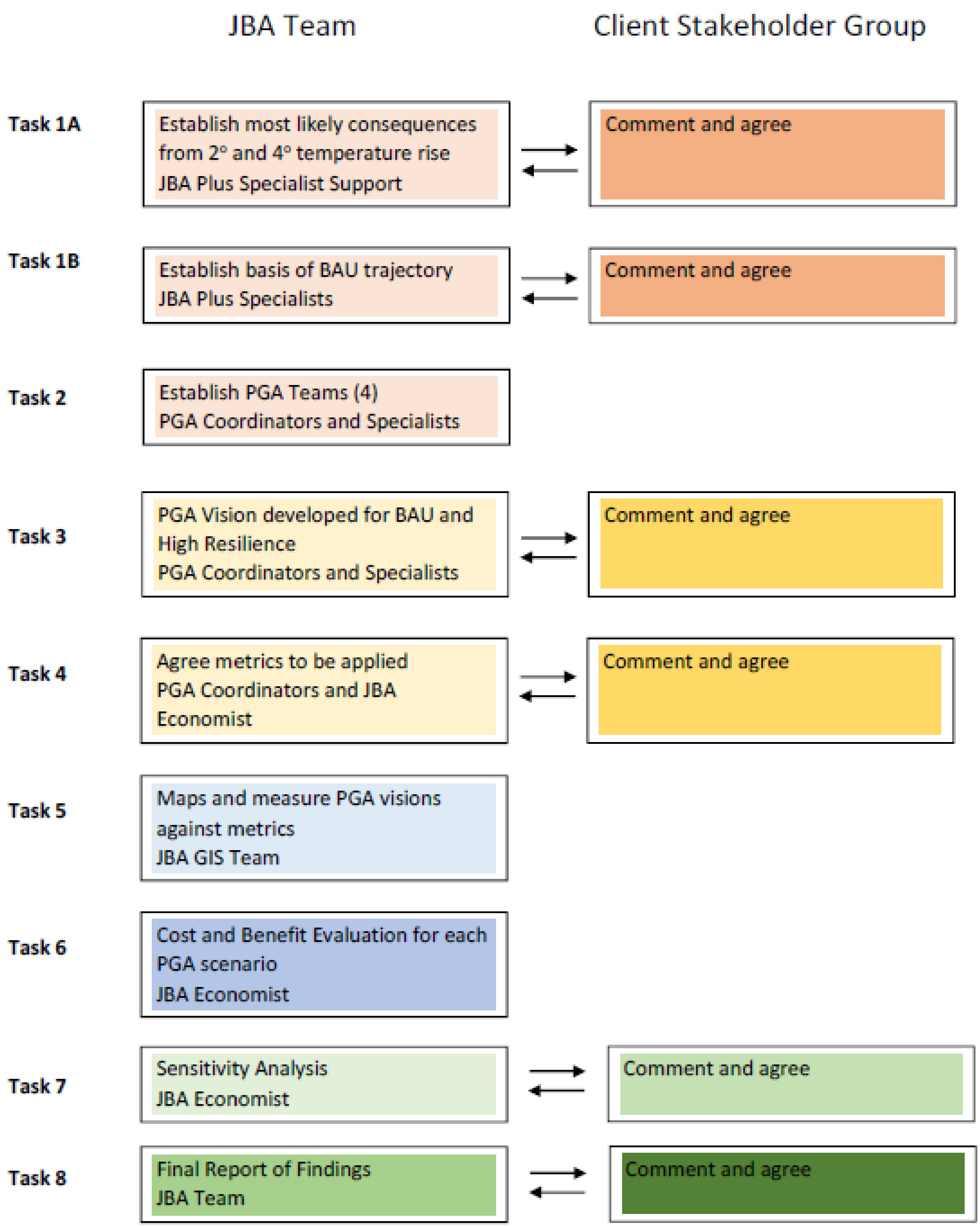

Figure 2-1 – Method A: Initial proposal

Following completion of Task 3 and 4 (developing the BAU and high resilience vision and metrics), the results were reported on and presented to a national client stakeholder group comprising experts from Defra, Natural England, RSPB, Environment Agency, and others.

Following a review of the feedback from both the case study members and the national stakeholder group it was agreed the methodology would be reconsidered and a modified approach would be used to take the research forward. The following summarises the feedback and rationale for this change.

2.1.1 Method A: Stage 3 and 4 Feedback and lessons learned

The discussions at the case study workshops and client stakeholder meeting identified the following main issues to consider in the research

- The need to define more clearly the term 'climate resilience' in the context of land use and the project objectives. The definition of climate resilience is important to be determined for the context of this project because there can be conflicts between different land use functions being resilient (habitat quality versus growing food versus carbon sequestration). A definition for this project reduces uncertainty about the overall aim of determining a 'resilient' land use.
- The use of both 2 and 4°C global temperature change (Low and High emission 50% probability scenario in UKCP09) and the relative distinctions between these 'on the ground' was difficult for local experts to interpret, especially when looking at the 30-year average changes shown in UKCP09. The local experts found it difficult to clearly understand the potential for significant impacts on land use and in any differences between the two temperature increases.
- Extreme events are not well-defined in UKCP09 and it was considered likely that these would most likely precipitate the need for land use change to maintain climate resilience. Related to this the local experts felt they needed the climate data at a more granular scale (field scale), which should include a better and more specific understanding of changes monthly and seasonally and the resulting impacts.
- The approach was heavily dependent on local expertise to develop the visions and scenarios and not completed in a systematic order across the four areas. Therefore, the process would not necessarily be replicable with another group of stakeholders or experts in the area, reducing the confidence in the results.
- As a result of the complexities of understanding the climate projections, there was a clear difference of opinion between local and national experts on the scale of change that would result from climate change. The national experts, as expressed at the client workshop, believed there would need to be a much more radical change in land use than envisioned by the local experts which had been developed in their case study workshops. The national workshop considered the local case study visions were too 'conservative' in their change particularly at the end date of 2100 and for a 4°C global rise. The local case study experts considered land management would evolve in response to the changes in local climate for example through growing different crops, building contingencies to increase water storage on farms.

Following an appraisal of the work and comments, it was agreed the methodology would be developed and should consider at the start of the process the 'vulnerability' of the land use to climate induced change rather than starting with a range of potential changes in climate. This revised approach, Method B, built on the lessons learned above and included:

- A fuller understanding of the impacts of climate change at a local level, differentiating between degrees of T change on average, average change of precipitation, and the related impacts;
- Identifying the importance of seasonal adaptive land management;
- Taking a more risk-based approach, which land managers / owners expressed an interest in;

- For further work, identifying points of transition and change in land use;
- For further work, identifying the drivers of that land use change, and when that may occur.

2.2 Method B: Vulnerability Assessment

The next iteration of the methodology is summarised below in Figure 2-2. It takes a systematic risk assessment approach to determine the vulnerability of different natural capital assets to climate-change related hazards, and consequently it allows for planning of adaptive measures for those assets which are most vulnerable. It is based on the European Commission Directorate - General Climate Action Non-Paper Guidelines for Project Managers: Making vulnerability assessments.

Assessing critical change points in land use

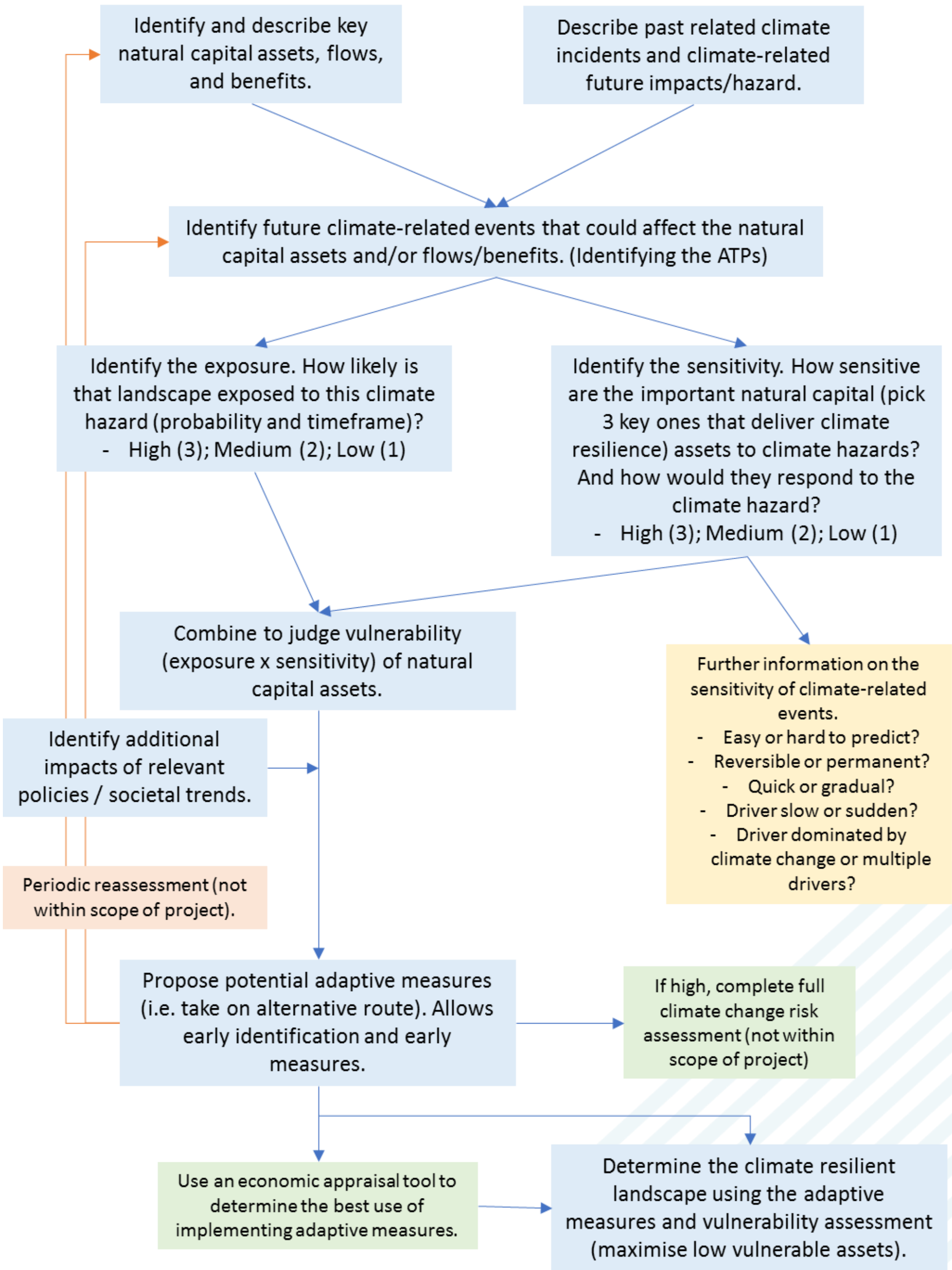

Figure 2-2 – Method B: Vulnerability Assessment

This method attempts to understand the range of adaptations from adaptive land management which addresses the existing land use, to a complete change in land use. It does not solely rely on the climate change projections. It also draws from historical experiences or evidence of the impacts of certain climate hazards.

Appendix B provides screenshots of the process being followed.

The feedback on using this revised Method B approach from the case study leads and other stakeholders in the research pointed to:

- Difficulties in identify the point that land use might need to change;
- The Vulnerability Assessment, specifically the scoring system, was difficult to use, relying on descriptions and an understanding of all the underlying assumptions;
- A complex risk-based process is difficult to complete and communicate to others;
- Its application to both land use and natural capital assets, in accordance with the research brief, led to a very complex picture in each case study.

2.3 Method C: Threshold Analysis

Following on from Method B, the approach was further refined. Specifically, the research question was redefined more simply as: How can land use choices deliver enhanced resilience to climate change? Note that there is no end point for resilience.

The work had now identified the numerous complexities in addressing several research objective variables; 2 and 4°C, Land Use and Natural Capital Assets across 4 distinctly different geographic areas. A simplified research question addressed some of this complexity.

Method C attempts to simplify the risk assessment-based approach previously used and concentrates on understanding the climate change related hazards and thresholds that could have the most significant impacts on the current land use, before assessing the likelihood of these changes happening. It then considers how anticipatory decision-making to change land use before a threshold is reached could be used to ensure the benefits outweigh the costs in the long-term. It also addressed definitions and some of the issues of interpretation expressed as arising with Method A.

This Method C is set out in Figure 2-3 below.

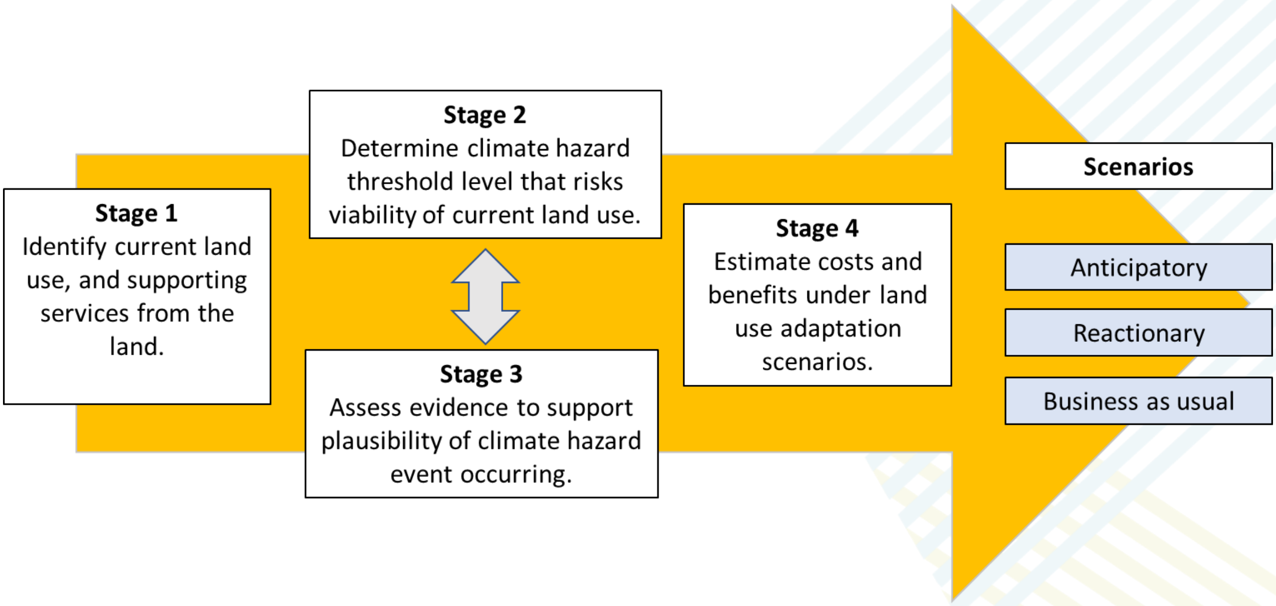

Figure 2-3 – Method C: Building resilience to climate change - Long term adaptation decision-making framework

2.3.1 Definitions

The following definitions were developed to shape the application of the finalised methodology.

Climate resilience is the capacity of the landscape to accommodate climate change related impacts, whilst still retaining productive, regulatory, and cultural functions, including those that contribute to mitigating climate change.

A climate hazard threshold or turning point in this context relates to a given level of a climate hazard that, once reached, will make it cost-prohibitive to maintain the current land use and the ecosystem services it has provided to date. For example, a three-year drought could render the increased costs of water irrigation to potato producers economically unviable, leading to a complete loss of production. Threshold and turning point are used interchangeably in this report.

Thresholds and turning points are not necessarily a single catastrophic climate hazard such as a 1 in 500-year storm event. They can also be a sequence of events, the occurrence of multiple climate hazards such as two 1 in 200-year storm events within two years, or gradual changes in temperature or rainfall that lead to a threshold being reached. In these instances, the threshold is reached when costs or losses related to the current land use outweigh the potential benefits of continuing on the same path into the future, measured in terms of the goods and services provided by the landscape. In these circumstances, the current land use is considered to be no longer resilient to climate change.

2.3.2 Method Description - Stages 1-4

Stage 1 involves determining the current land use and land management for each case study. Alongside the breakdown of land uses, the relevant benefits and costs associated with these is collated. This Stage helps in later Stages to identify which are the most relevant and appropriate climate threats and thresholds to be considered.

The next stages, Stage 2 and 3, are completed together, requiring a mix of local expert knowledge and desk-based research.

Using climate projections and historical and modelled evidence, relevant climate threats are determined for the particular case study. These are not exhaustive but are chosen based on being likely to lead to a loss of resilience for that area.

To understand how the different land uses are vulnerable to the climate hazards identified, local expert knowledge was combined with relevant published research findings.

This work focusses on determining when and to what extent the specific land use such as livestock grazing, or arable cereal land use is resilient to the identified climate change related hazards over time. A land use is considered to be no longer resilient if these hazards will result in a threshold or tipping point being reached such that the costs or losses related to the current land use outweigh the potential benefits of continuing with that land use, up to 2100. It is important to note here that for the purposes of this research in showing how long-term thinking on land use change can be done, these **thresholds just need to be plausible, they are not projections**. Within the scope of this project, the climate threats focused on are those deemed to have the most significant impact.

Stage 4 investigates and analyses adaptive measures in response to these thresholds being reached. Further research into the likelihood of and the impacts of the threshold occurring support the ‘plausible’ application of the method.

Likelihood in the context of the methodology is not statistical probability, but rather further evidence using climate projections, historical records and other indicators that the thresholds could be reached in the present to 2100 timeframe and in either the 2 or 4°C global temperature rise scenario.

Adaptive measures and any justifications for changes in land use to a more resilient land use are identified through research and local expert knowledge.

Stage 4 includes the economic assessment of costs and benefits based on three adaptation scenarios: (i) a business as usual (BAU) scenario, assuming no land-use change interventions; (ii) an anticipatory scenario, assuming land-use

change happens before a climate hazard threshold event occurs; and (iii) a reactionary scenario, assuming land-use change occurs after the climate hazard threshold event. This economic assessment does determine a timeline in which the threshold occurs in order to complete the assessment of costs and benefits for different 'switching times' before or after the threshold.

More detail on these three scenarios is given below:

- A Baseline 'Business as Usual' scenario that includes the impact of the climate hazard(s) with no adaptive interventions, including any adaptive land management or land use actions. No change in land use following the threshold being reached. This scenario is unrealistic in reality since there would likely be adaptive land management actions (i.e. change in tilling methods, change to a more drought resistant crop, and others); however, this research has simplified the scenario and only included an increase in costs relating to, for example, additional fertiliser and pesticide applications to counteract the impacts of climate change on agricultural productivity.

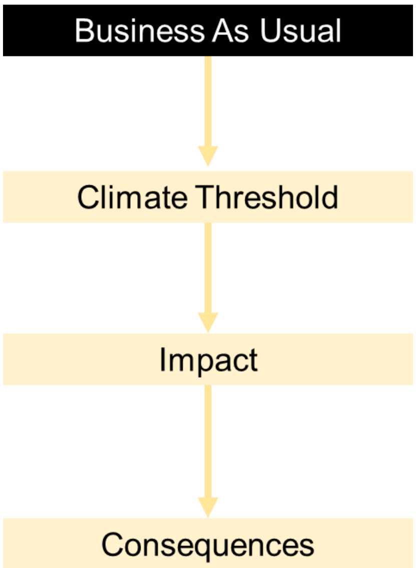

Figure 2-4 – Business as usual

- Anticipatory. This considers that the likelihood of a threshold being reached is such that anticipatory adaptations to land use would lead to change in land use prior to the threshold being reached.

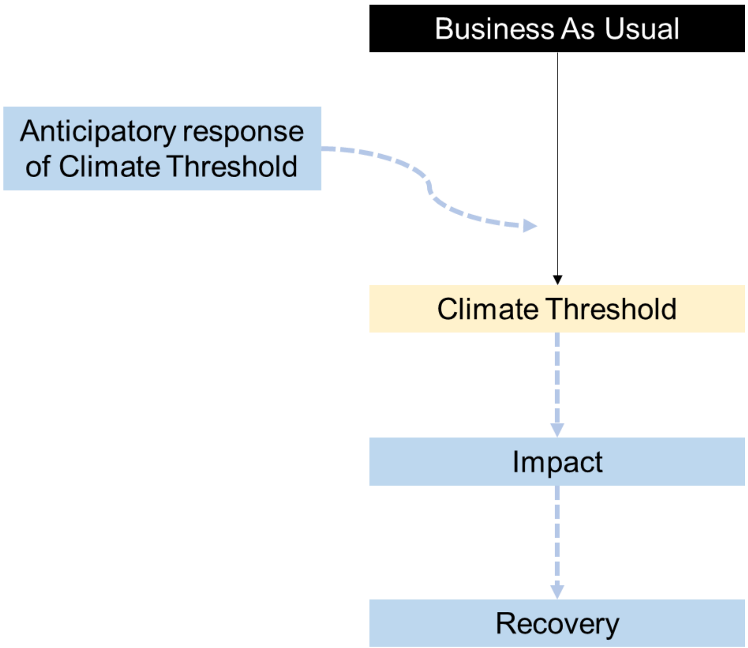

Figure 2-5 – Anticipatory

- Reactionary response. Impact of the climate hazard(s) with reactionary response involves adaptation measures being implemented after threshold is reached. The recovery phase is the impact the reactionary response of the climate threshold has on the land use.

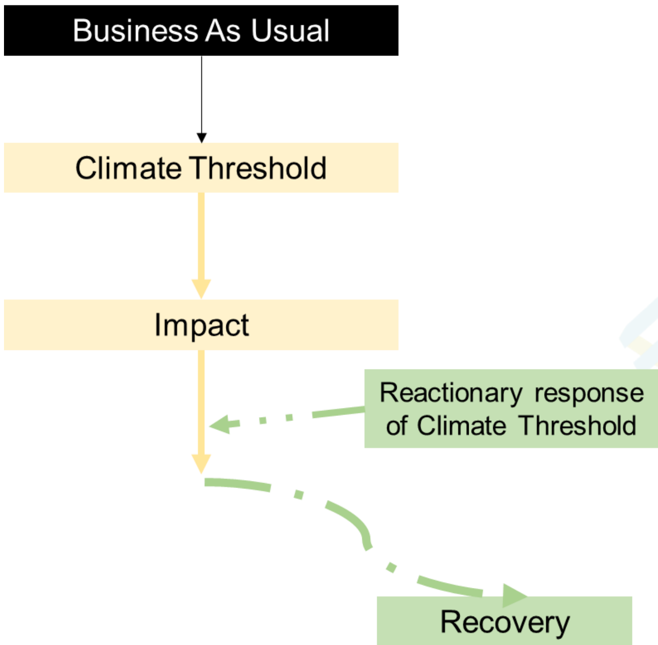

Figure 2-6 – Reactionary Intervention

- The project has also included a fourth Maximum mitigation scenario. This is where the land use is changed to maximise carbon sequestration. This scenario is not included in the Threshold Analysis method but is used to assess how different the scenarios are that look to maximise resilience versus mitigation. This scenario is consistent with the assumptions made for the CCC's mitigation land use project.

The economic assessment includes both qualitative and quantitative factors, and monetized and non-monetized factors. Some sensitivity analysis is included to understand the impact of the different factors included in the valuation in the economic assessment.

The assumptions built into the economic modelling are set out in Appendix C Economic assessment methodology.

3 Structure of the report

The rest of this report will look at testing the Threshold Analysis (Method C) method.

Section 4 will look some of the evidence and literature to support Stage 2 and 3 for each of the case studies. To prevent repetition in the presentation of the findings for each case study, the substantive Stage 2 and 3 results on these topics will presented together. Additionally, general findings of maximising carbon sequestration scenario are presented.

Section 5 will outline the findings for Moor House and Upper Teesdale, introducing the case study, the land use data (Stage 1), identification of plausible climate thresholds using the evidence outlined in Section 4 (Stage 2 and 3), and the impact and possible adaptation of the thresholds, including an economic assessment (Stage 4).

Section 6 will outline the findings for Norfolk and Suffolk Broads, as outlined above.

Section 7 will outline the findings for the Petteril, as outlined above.

Section 8 will outline the findings for Somerset, including the Levels as outlined above.

Section 9 will present the trade-offs and limitations of this study.

Section 10 will present the recommendations.

4 Stage 2 and 3 Reviews

Agricultural land uses are common to all the case studies, and to three of the case studies peat resources underpin the land use.

4.1 Review of Agricultural Land Use and Climate Change Impacts

Because of the interactions and feedbacks that exist between agriculture, the environment and society, any risk assessments (including those that are climate change related) of agriculture are notoriously difficult (Knox et al., 2010).

Outdoor crops grown in the UK are particularly sensitive to changes in climate, both directly from changes in rainfall and temperature and indirectly since any changes in climate will also impact on the agricultural potential of soils by modifying soil water balances. This affects the availability of water to plants and impacts on other land management practices (Knox et al., 2010)

Greater annual variability of climate and frequency of extreme events is likely to be more difficult for farmers to adapt to than gradual changes in climate, though both may lead to the need to change the type of agricultural production in certain areas The impacts of changes in 'average' climate will be more gradual, and growers will adapt autonomously, but the consequences of extreme weather on crop production will be much more unpredictable and damaging (Knox et al., 2010).

In the study completed for Defra, Climate Change and Extreme Weather Events; Establishing a Methodology for Estimating Economic Impacts on Agriculture (ADAS UK Ltd. and University of Leeds, 2013), the researchers considered responses to single and combined weather events which provided a basis for developing a methodology for estimating economic impacts. The study considered flood, drought, high summer temperatures, high winter temperatures and severe winters. The study developed a range of possible future 'plausible' scenarios, identified by stakeholders which represented climate change influenced severe weather events. The study even cites the Cambridge dictionary definition of plausible to be 'likely to be true or able to be believed' and this was used pragmatically in this study for scenario setting. The same approach was adopted in in the finalised methodology for this study.

4.1.1 Drought and heat stress

Arable land

Water stress arising from climate change is increasingly likely to require adaptive measures. This could drive crop production from water stressed areas of east and south east England towards the north and west where growing conditions will be less constrained by soil moisture. On crop yield and quality the two most important impacts are likely to be changes in productivity (yield and quality) and land suitability, which will affect the viability of existing rainfed crops and create opportunities for new crop types (Knox et al., 2010).

Irrigation is thus likely to become more important, both on existing irrigated crops and on other historically rainfed crops such as wheat, in which growth is likely to be affected by increasing levels of water stress and the greater inter-annual variability in climate. Fifty-five per cent of potato and vegetable production is currently in catchments defined by the Environment Agency as being 'over-abstracted' (Hess et al, 2011).

Some crops that are grown in the Broads case study, such as potatoes are much more responsive to irrigation, improving both yield and quality substantially if they receive water at specific times in their growing cycle. It has been evidenced that average yields have risen continuously between 1947 and 2008, but with no support that the relative tolerance to adverse weather conditions such as atmospheric moisture deficit and temperature extremes has improved (Gobin, 2012).

Potatoes in particular are a crop that is particularly vulnerable to climate change due to projections for reduced water availability arising from a trend to drier summers and a reliance on irrigation to address excessive moisture deficits (Brown et al., 2016). The Brown et al. (2016) study (The UK Climate Change Risk Assessment Chapter 3) cited a recent study by Keay et al. (2014) which estimated that the volume of water for irrigation would need to increase seven-fold by the 2050s (UKCP09 high emissions scenario) for present day production of potatoes in England and Wales to continue (Brown et al., 2016). However, long term droughts, or droughts that occur over consecutive seasons may not be mitigated by irrigation, or may at least be restricted, if water storage levels are low (Wreford and Adger, 2010). Major drought episodes tend to occur for months or even years where the soil moisture is low. However, a heatwave lasting for a week or two can also mimic drought conditions.

Warmer temperatures would increase the probability of damage to vulnerable crops (for example wheat and salads) at extreme temperatures. A long growing season in southern England may also lead to increased cultivation of continental crops such as maize, sunflowers, navy beans, soya, lupins and grapevines (Knox *et al*). Mean temperature increases and a lengthening growing season is already affecting crop choice. The dairy industry is important in the Petteril case study. Maize is becoming increasingly important, supporting the dairy herds and newer industry of biofuels and the anaerobic digestor (AD) found locally. However, maize is a late harvest and therefore at a higher risk from wetter autumn conditions, often increasing runoff, and possibly reducing the river's ecosystems to regulate and reduce water quality. Maize cropping can also be associated with soil compaction and erosion, which can lead to water pollution and loss of soil nutrients, especially when planted on steeper slopes (Brown et al., 2016). Maize production is likely to increase due to warmer temperatures in the medium term (to the 2050s) and may start declining in the long-term as temperature further increase (Brown et al., 2016).

As well as likely restrictions on abstraction for agriculture in water stressed locations some coastal areas are also suffering from saline intrusion of groundwater. This is currently affecting parts of the Norfolk Broads case study. The Broadland Agricultural Water Abstractors Group highlighted a growing risk of salination of ground water and open watercourses arising from a combination of factors including tidal cycles/surge, sea level rise, ground-water abstraction and active (pumps, sluices etc) water level management. Sea water incursion and some degree of salination is a historical feature of areas of the Broads. There has been recorded elevated salinity in Hickling, Barton, and Sutton Broads as sea defences are undermined (Brograve) and overtopped (Walcott) (National Farmers Union of England and Wales, 2010). The pump-managed drainage systems of the Upper Thurne around Brograve, where it can be pumping water equivalent to 15-20% seawater concentrations illustrate the impacts of salination. Increasing impacts from sustained elevated salinity reduces the quality and quantity of freshwater and will compromise its use for agriculture, and also may lead to the loss of the Broads' wetland habitats features dependent on fresh water and intolerant to brackish water (Herbert et al., 2015). The impact of saline incursion on the Broads habitat was assessed by the Broads Authority based on the Broads hydrological model and 2006- 07 saline incursion data, and 'probability of success' (a combination of timescale to achieve target and current ecological status, based on water plant population)[1].

National scale studies by Semenov and Shewry (2011) have highlighted the effects of heat stress (above specific thresholds) during flowering on wheat yields in the UK. At a global scale, the study conducted by Lesk et al., 2016 estimated that national cereal production during a drought was significantly reduced by 10.1% on average, while years with extreme heat led to national production deficits by 9.1%. These production deficits were equivalent to roughly six years of production growth; however, no significant lasting effects were noted in the years after the disasters (Lesk et al., 2016). This emphasises that droughts and

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[1] http://www.broads-authority.gov.uk/looking-after/managing-land-and-water/conservation-publications-and-reports/water-conservation-reports/5.-Why-Farming-Matters-to-the-Broads.pdf

extreme heat alone will not cause the long-term reduction in production, but rather the economics and policies driving the crops will.

Pastures

On projected warmer temperatures. Grass growth begins above a minimum temperature (5.5°C) and is stimulated by warmer weather, provided there is sufficient soil moisture. However, as grass yields improve with warmer conditions, they are also vulnerable to reduced soil moisture availability during drought (Brown et al., 2016).

Dairy and beef cattle are important in the Petteril and Somerset case study. The production of dairy and beef cattle is dependent on the quality and quantity of grass. Dairy cows need lots of young nutritious grass and high-quality silage to support milk production, while beef cattle do best on grass that is more mature and lower palatability (Brown et al., 2016). One of the main direct effects of climate on dairy production is heat stress, which can adversely affect milk yield and fat and protein content as well as cause animal welfare issues (Brown et al., 2016). There are further physiological consequences to the dairy cows including reduced dry-matter intake, rate of weight gain, fertility of dairy cattle (both sexes), as well as eventual mortality (Dunn et al., 2014). There is currently a heat stress threshold (known as thermal heat index) for dairy and beef cattle. Overall milk yields are thought to have been largely unaffected by the heatwaves seen in 2003 and 2006, but caused milk production decline by 30% in a single herd in south-west England during the 2006 event (Brown et al., 2016). The study by (Dunn et al., 2014) has looked at the impacts of heat stress in dairy cows in southern Britain. Cattle breeds also vary in their acclimatisation to warmer temperatures, with some beef cattle adapted to sub-tropical climates better able to withstand prolonged periods of mild heat-stress (Dunn et al., 2014).

The study by Dunn et al. (2014) showed that the "RCM (Regional Climate Model) projections of the future change in the number of days exceeding the Thermal Head Index (THI) threshold for the onset of heat stress indicate that for southern parts of the UK, this could increase from on average 1-2 per year to over 20 per year by 2100, with correspondingly more heatwave events". Although this is for the south of England, the Somerset and Petteril case studies will experience similar trends by 2100 requiring adaptive responses.

The costs of adaptation measures and impacts from drought on grassland would include (Elliott, 2014; Living With Environmental Change, 2016):

- Additional shade provisions
- Cooling and ventilation systems if housed indoor, which will lead to other costs:
    - Costs of labour and machinery to relocate livestock
    - Costs of additional labour needed for housing of livestock
    - Additional costs of conserving feed for housed stock plus costs for purchased feed over and above estimated forage losses
    - Additional waste management (slurry disposal), water and vet services associated with housed stock
- Tree / hedgerow planting for livestock shading

- Cost of altering diets
- Reduced milk output
- Costs of increased livestock mortalities due to heat

Impacts of drought or heatwave may not be felt within the year it occurs because farmers may sell more stock, resulting in increased profits (Wreford and Adger, 2010). The livestock sector is more difficult to differentiate the impact of extreme events on because other factors will impact on total production and separating out cause and effect can be difficult. In arable crops, the yield is most dependent on climate.

The costs on the water environment (SMOYER-TOMIC et al., n.d.):

- Increase in water temperatures, decreased dissolved oxygen available for fish respiration, high temperature can increase acute and chronic stress to fish leading to death
- Chronic effects of warmer temperatures can extend throughout the fish life cycle, from egg laying to hatching to maturity; chronic heat stress can limit growth and adversely affect production

4.1.2 Flooding

Currently, flooding and standing water in agricultural fields are considered a problem within northern England, especially in the case of grasslands, winter wheat, and spring barley (Olesen et al., 2011).

As 57% of the best and most versatile agricultural land in England is on flood plains (Morris et al, 2009) there is potential for increased flooding to have significant impacts on UK food production (Knox et al., 2010).

There has been limited literature or research on the impacts of flooding or waterlogging (flooded/ponded/saturated soils) on crops in the UK. Research in the 1970s and 80s identified physiological changes and potential yield impact (Elliott, 2014). Flooding can cause soil oxygen deprivation and nutrient uptake, impacting crop growth and yields. The "soils rapidly lose oxygen as a result of water replacing oxygen in the soil pores and if these anaerobic conditions persist, levels of carbon dioxide, methane and volatile fatty acids increase in the soil" (Elliott, 2014). This causes a change from aerobic respiration to anaerobic fermentation (a much less efficient process) consequently reducing its growth.

Specifically, the impact of flooding on cereal crops includes nodal root protection, chlorosis (yellowing of leaves), premature senescence of leaves, and a decrease in tiller numbers, reducing yield by 10-30% (Elliott, 2014).

The costs for arable land from flooding would include (Elliott, 2014):

- Reduced yield in the year of the flood or planting new crop(s) (if resources, growing time and appropriate conditions permit after flood)
- Additional inputs (fertilisers and sprays) less savings in uncommitted costs
- Additional harvesting costs less savings in uncommitted costs
- Value of output of replacement crop less costs of crop establishment and production costs (fertiliser, chemicals, labour, and machinery)
- Land restoration cultivation and drainage

The field investigations between 2002 and 2011 in the study in South West England by (Palmer and Smith, 2013) determined that late harvested crops, such as maize, had the most damaged soil where 75% of sites were found to be degraded structures generating enhanced surface water runoff. Winter cereals in late autumn also resulted in damaged soil with enhanced surface water runoff in three out of every five cereal fields assessed (Palmer and Smith, 2013).

The Defra report, The Impact of 2014 Winter Floods on Agriculture in England (Elliott, 2014) states that flooding can cause significant damage to grassland. There is a general principle that after 10-14 days of submergence under standing water, ryegrass plants begin to die, and other individual cultivars have diverse responses within and between genotypes. Prolonged flooding will cause a significant proportion of readily available nutrients such as nitrate and sulphate to be lost from the soil through gaseous emissions or leaching, reducing the productivity of the grassland.

According to The Impact of 2014 Winter Floods on Agriculture in England report, the rate of recovery of pastures will increase with these factors:

- Light textured soils to drain water away;
- Pastures with lower covers prior to following due to less silt and mud;
- Sediment deposits of less than 5 cm (However, very fine sediment can cause a surface sealing reducing water infiltration and aeration creating anaerobic conditions in the soil);

With sandy loam soils, pastures will recover better since the water is not retained for as long (Elliott, 2014). Pastures should be maintained according to these factors. Additionally, (Gerard et al., 2007) cited another study that determined the transfer of propagules from species-rich remnants appear to be crucial for the successful restoration of species-rich flood meadows. The pastures should be species-rich to also mitigate against droughts. The diversity of the grassland managed, including mix of flora, number of animals, fertilisation, and the rotation between pasture and cutting, will heavily influence regeneration.

The costs of flooding on grassland would include (Elliott, 2014; Living With Environmental Change, 2016):

- Costs of labour and machinery to relocate livestock
- Costs of additional labour needed for housing of livestock
- Additional costs of conserving feed for housed stock plus costs for purchased feed over and above estimated forage losses
- Additional waste management (slurry disposal), water and vet services associated with housed stock
- Costs of increased livestock mortalities due to flooding
- Net savings in harvesting and storage costs for grass forage

Other damage costs to farm businesses would include (Elliott, 2014):

- Farm structures and contents
- Disruption and replacement of essential farmstead services (e.g. power and water)
- Farm machinery and equipment, including irrigation, hedges, fences/gates, land drainage works, tracks

- Clean up and debris removal and disposal
- Loss of net revenue from services (e.g. contracting, additional borrowing costs)
- Other farm specific costs

On extreme weather events, most evidence from agricultural economics, agronomy, and meteorology suggests that increased frequency and intensity of extreme events from projected climate change (i.e. floods, droughts, etc.) are likely to lead to greater production losses than any increase in mean temperature over the coming decades (Wreford and Adger, 2010). However, any extreme event can carry-over impacts from year to year and if multiple extreme events occur in a row, these impacts could grow exponentially. The UKCCRA2 identified an example where "the adverse weather of 2012 had a knock-on effect in 2013 with the observed shift from autumn-sown to spring-sown cereal crops. There is therefore a concern that yields of some cereal crops could be particularly vulnerable to a run of poor years, as happened in some locations during the 1980s" (Brown et al., 2016). Additionally, maize is significantly affected by extreme heat, with the (Lesk et al., 2016) review showing a 11.7% deficit in productivity and 12.4% in yield reduction[2].

Increased flooding could result in the expansion of the planting of wet woodland (Mitchell et al., 2007).

4.2 Review of peat-based land uses and Climate Change Impacts

Three of the case study areas include significant areas of peatland: Moor House and Upper Teesdale, Somerset, and the Norfolk Broads.

The Upper Teesdale SSSI within the Moor House and Upper Teesdale NNR shows that approximately 86% of the peat is in unfavourable-recovering condition, 2% unfavourable-no change and 12% in favourable condition (Natural England, n.d.)[3]. There is ongoing drainage and vegetation management still taking place to produce grouse and sheep farming.

If in good condition, blanket bog can modify their natural hydro climatological conditions by impeding drainage and producing almost permanently saturated conditions, particularly for the larger, deeper bogs (Brown et al., 2016) and consequently be more resilient to hot and dry conditions. This restoration work to restore the blanket bog to optimal condition includes grip blocking, revegetation, and ceasing vegetation management for grouse shooting. Techniques are now well-established for restoring peat for example the programmes currently being undertaken by Moors for the Future and the Yorkshire Peat Partnership. These include the installation of dams and plugs in drains and ditches, and on bare surfaces, re-vegetation using Sphagnum inoculation and cotton-grass *Eriophorum* planting (though this is more pressing in heavily degraded blanket bogs such as in the Peak District). Prevention of peat management tools, such as vegetation management and burning for grouse management, assist a more diverse vegetation to develop as well as eliminate damage to the peat-forming process.

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[2] Although this is a global review of evidence, the study notes that developed countries were more susceptible to the impacts of drought and extreme heat than developing countries (Lesk et al., 2016).
[3] Data from August 2018.

There is extensive evidence from revegetation trials that links sheep grazing to the prevention of recolonization of bare peat surfaces (Mackay and Tallis, 1996). Ceasing sheep farming on upland peat bogs is a restoration option.

Although Moor House and Upper Teesdale case study does not have a burn management for grouse, many other upland peat areas do. Most moorland vegetation is highly flammable, which is why fire was favoured as an important tool in their management throughout the past (Davies et al., 2016). Wet bogs can also be burnt in the early spring prior to the green-up of vegetation despite standing water at the ground surface (Davies et al., 2016). This 'quick' burn was common in grouse moor management.

Prescribed vegetation burning on peatlands is undertaken predominantly to remove grasses and ageing dwarf shrubs (e.g. *Molinia caerulea* (moor grass) and *Calluna vulgaris* (heather)) that can provide red grouse (*Lagopis lagopus scotica*) populations with refuge from predators and serves as nesting sites. This removal causes the regeneration of young heather shoots deemed suitable for increased red grouse by providing a palatable food source for young birds (Brown et al., 2014).

Controlled burning for land management purposes and uncontrolled wildfires can leave the underlying peat vulnerable to erosion as the protective vegetation layer is temporarily removed. The research completed by (Mackay and Tallis, 1996) identified a combination of unusual factors which led to the summit-type erosion and decline of Sphagnum species in the Forest of Bowland, Lancashire. The "combination of unusual factors included: period of below-average rainfall in the region in the early 1900s, resulting in lowered water tables in the peat; exceptional summer drought in 1921; and a decline in management standards because of a shortage of gamekeepers after the First World War" (Mackay and Tallis, 1996). The Forest of Bowland has a similar landscape to Moor House and Upper Teesdale with upland blanket mire and dwarf-shrub heath which provides an important breeding ground for a number of protected species. Severe fires that destroy large areas of heather moorland and blanket mire more usually arise accidentally during the summer months in years of severe drought ((Mackay and Tallis, 1996)). Catastrophic fires documented across England illustrate that it can destroy the matrix of the peat, turning it to ash and subsequent recolonization of vascular plants is often slow and preceded by the stabilisation of the peat surface with lichen and bryophytes (Mackay and Tallis, 1996). Peat that does not undergo recolonization becomes exposed to large temperature fluctuations and weather elements, further promoting the breaking and fragmentation of the peat surface which can lead to greater peat removal by the weather elements such as higher velocities of wind and increased runoff (Mackay and Tallis, 1996). One documented uncontrolled burn event in 1947 led to the burning of 2,000 ha of moorland, lasting three months until wintery conditions extinguished it was preceded by significant droughts across Britain in the summer months in (Mackay and Tallis, 1996). Most recently during the writing of this report (June/July 2018), there have been multiple wildfires in the uplands of England, including Saddleworth Moor and Winter Hill and over a week, the fires have destroyed approximately 2,000 ha of moorland, though it is too early at the time of writing to assess the full extent of the damage[4].

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[4] https://www.theguardian.com/uk-news/2018/jul/02/firefighters-need-support-to-tackle-lancashire-moorland-blaze-says-andy-burnham

Drought alone can impact the land use dramatically. Between 1921 and 1924, no grouse were shot due to a severe drought in 1921 on Bleasdale Estate (Forest of Bowland) as a result of the decline in Sphagnum spp. and serious erosion of nearby peat (Mackay and Tallis, 1996). For further reference, the main economic generators within the Forest of Bowland is the larger commercial and estate shoots, in which the annual value of grouse shooting can be £720,000[5].

The impact of a wildfire includes the loss of carbon and decline in soil quality depending on the depth of the burn on the peat, with both vegetation and historical accumulations of peat being oxidised. The Davies et al. (2016) study determined that smouldering wildfire had a carbon loss per unit area burnt of 96 ± 15 t ha^{-1}. The remaining surface, once the fire had been extinguished would be subject to wind erosion, with more ash and particulate matter (carbon) dispersed. The Figure below summarises the different impacts of a fire on the peat hydrological system, including difficulty to re-establish Spaghnum outlined above, but also increased overland flow, reduced near-surface macropore flow and hydraulic conductivity and others (Brown et al., 2014).

Additional costs associated with a wild fire also include the costs of fire and rescue services and emergency services and the indirect losses of recreational income.

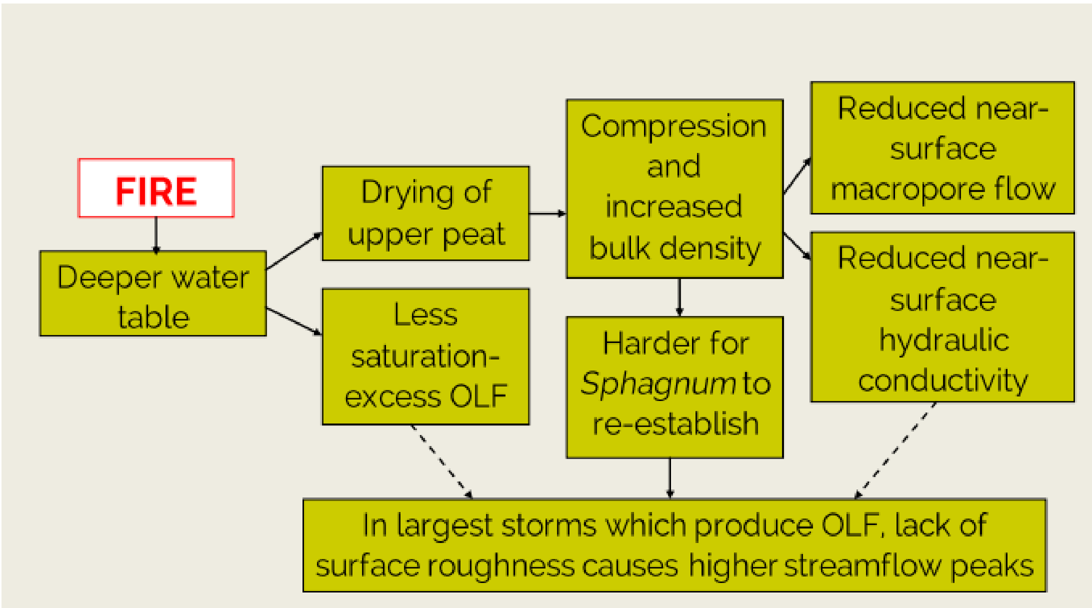

Figure 4-1 – Schematic diagram outlining how the peat hydrological system responds to burning (Brown et al., 2014)

The Somerset Levels and Moors have one of the largest and biologically richest areas of traditionally-managed wet grassland and fen habitats found anywhere in the UK. (Deane, 2016). There is seasonally-wet grassland and associated wetland habitats, such as fens, raised bogs and reedbeds which hold significant cultural value to Somerset and only provide summer grazing.

The large area of peat on the Levels and Moors provide a significant store of carbon, though the long history of drainage and associated land use change,

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[5] https://forestofbowland.com/files/uploads/pdfs/economic_profile_of_the_forest_of_bowland.pdf

together with peat extraction operations, have considerably degraded this valuable natural asset. The store of organic carbon in these peatlands is estimated at approximately 3.7 million tonnes. The current drainage and cultivation by agriculture and extraction for horticulture and gardening contribute to a significant loss of peat, and consequently carbon storage (Deane, 2016).

In the Norfolk Broads case study, The Broads Authority have produced a Carbon Landscapes report on the positive management of peat soils[6]. Crucially, the report identifies that peat soils within the Broads have been estimated to store 25 million tonnes of carbon, equivalent to the annual carbon emissions from a very large coal fired powered station. This carbon remains essentially "locked up" provided the wetland soils remain un-drained and undamaged by cultivation. Measures are identified to minimise carbon loss and promote a neutral or positive carbon balance.

4.3 Review of Extreme Events on Biodiversity

The report by Defra, England Biodiversity Strategy – Towards adaptation to climate change, notes that the only direct effect of increased frequency of extreme events for the Broad habitat (Broad-leaved mixed and yew woodland) and coniferous woodland would be "an increase in wind throw is likely, leading to an increase in gaps in woodland and deadwood" (Mitchell et al., 2007). Summer droughts may cause an increased mortality of drought sensitive species (mostly pertains to the South East) and consequently a change in the nature of the habitat (Mitchell et al., 2007). However, on more favourable geologies (e.g. chalk) and microclimates (e.g. north-facing slopes), drought sensitive species are still expected to persist in the Broad Habitat (Mitchell et al., 2007). In coniferous woodland, drought resistant species such as Douglas Fir and Corsican Pine will likely be planted over a larger area. The impact of increased summer drought can decrease the productivity and carbon sequestration (Mitchell et al., 2007).

4.4 Maximising carbon sequestration

The sister project being undertaken by CEH[7] provides national level figures of predicted carbon sequestration rates of different land-use changes. Whilst many of the different scenarios could be applied to each of the Case Study locations in this study, it is not possible to extrapolate the figures in such a way that they would be able to provide a high-level prediction of the sequestration rates for each land-use change within each case study location.

The principles for applying maximising mitigation to the Case Studies have taken the extracted carbon sequestration rates from the CEH work and used them to determine a land use pattern which would maximise mitigation.

The approaches which can be taken to maximise carbon sequestration in each Case Study area are summarised as

- Increase the woodland and forest land cover. Preferentially plant new woodland on mineral soils rather than high carbon (peaty) soils. Wet woodland[8] has a high capacity for sequestration.
- Convert cultivated lands to managed permanent grasslands.

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[6] http://www.broads-authority.gov.uk/__data/assets/pdf_file/0010/416494/BA_PeatCarbonManagement.pdf

[7] Centre for Ecology and Hydrology, 2018, *Quantifying the impact of future land use scenarios to 2050 and beyond*

[8] Wet woodland is a type of habitat that occurs on poorly drained soil or seasonally wet soils (i.e alder, birch, and willow).

- Convert marginal cropland to native vegetation, grasslands or forestry
- Reduce agricultural grazing intensity on grasslands.
- Reduce the level of mechanical disturbance and cultivation of soils.
- Manage sustainably currently functioning wetlands and peatlands.
- Restore wetland soils and damaged peatlands.
- Minimise controlled burning for managing vegetation

Many of these changes in land use and land management coincide with those prescriptions for early adaptation change. This is illustrated most clearly in the Policy Appraisal Summary Tables in Section 9 Discussion, Policy, Synergy, and Trade-offs.

There are some key learnings from the high level, national figures. Perhaps most importantly the restoration of peat, which demonstrates a reduction in carbon emissions over 50 years, however carbon sequestration may not be achieved for almost 100 years. Similarly, afforestation rates are beneficial for the reduction in carbon emissions, but the extent of the carbon sequestration potential is highly dependent upon the species and age of the woodland.

5 Moor House and Upper Teesdale

5.1 Stage 1: Moor House and Upper Teesdale

The case study area of Moor House and Upper Teesdale comprises a 88 km^2 National Nature Reserve (NNR) in the North Pennines, in a remote Pennine dale forming the upper catchment of the River Tees, and part of a larger 388 km^2 Special Area of Conservation (SAC) and Special Protection Area (SPA) of the same name. The whole area is part of the larger North Pennines Area of Outstanding Natural Beauty (AONB).

The vast majority of the case study area is upland blanket bog, farmed for sheep and grouse, and this falls into the lower slopes and valley bottom with areas of in-bye grassland, scattered broad-leaved woodland and the river floodplain bordered by riparian woodland. Some key special areas for biodiversity are blocks of sugar limestone scattered across the hills which support a rare upland calcicolous flora, including arctic-alpine species and give the area its designations. A more extensive list of the Annex I habitats that are the primary reason for selection of its designations can be found on the Natural England website or JNCC website[9].

The area is notable for supporting species at the northern and at the southern edges of their biogeographical boundaries.

[9] http://jncc.defra.gov.uk/protectedsites/sacselection/sac.asp?EUCode=UK0014774

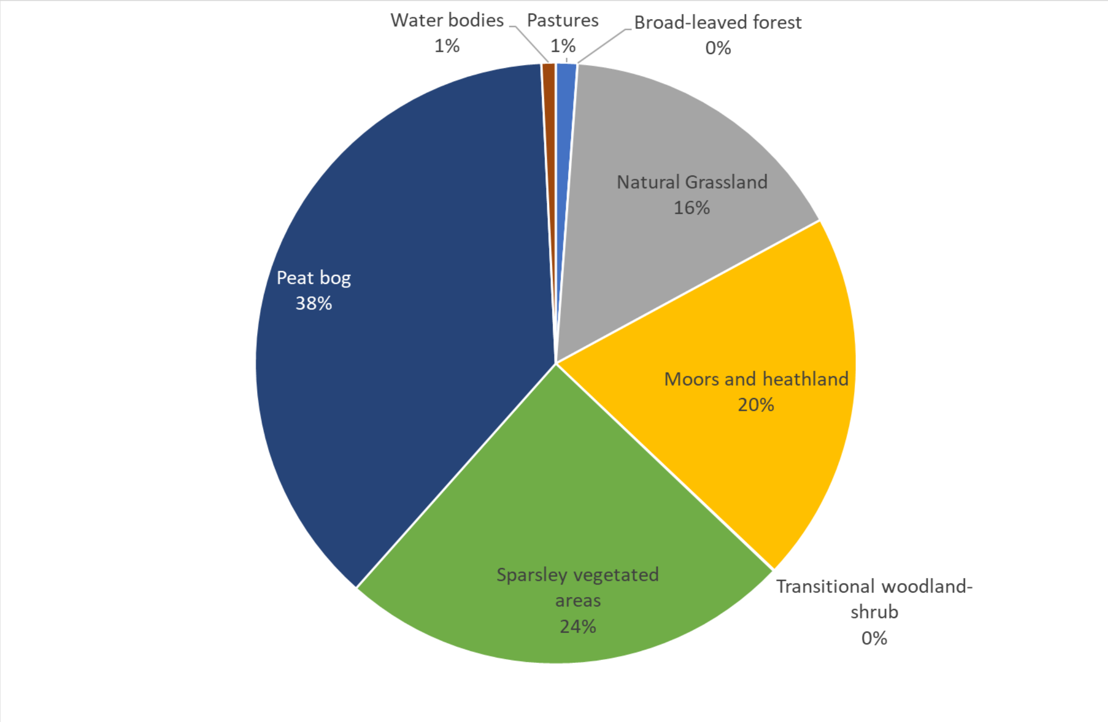

Figure 5-1 – Corine Land Cover 2012 dataset for Moor House and Upper Teesdale

However, the NNR has been mapped in detail using the National Vegetation Classification, providing further information on the vegetation unique to its designations. These unique features mainly include peat bog (38%, as seen in Figure above), and the calcareous grassland.

Manufactured capital is sparse and comprises scattered farmsteads and associated agricultural buildings, some of which are co-used as offices associated with NNR management.

The resident population is sparse and comprises farmers, gamekeepers and their families. The area has a strong local identity but is also a destination for visitors and tourists to visit the High Force waterfall on the River Tees (the highest waterfall in England), and caters for more adventure, walking and nature-based activities.

Table 5-1 – Summary of the main land use, land cover, and land management in Moor House and Upper Teesdale

Land use	Land cover and land management
Peat bog / blanket bog	- Designated for habitat/vegetation - Grazing for sheep - Recreation for grouse shooting - Carbon sequestration
Grassland	- Blocks of sugar limestone supports rare upland calcicolous flora, including arctic-alpine species - Grazing of sheep

5.2 Stage 2 and 3: Moor House and Upper Teesdale

The Moor House and Upper Teesdale catchment is dominated by blanket bog, wet heath, dry heath, and grasslands that is internationally designated for the habitat and vegetation across the landscape, as well as being economically important for grouse shooting. The current peat in Moor House and Upper Teesdale is considered in unfavourable recovering condition according to Natural England's assessments, with managed cutting still taking place for the production of grouse and draining of the bog (Natural England, n.d.). It is considered to be at the lower limit of bioclimatic space[10]. Consequently, this sub-optimal condition of the blanket bog is likely to be affected more severely by climate hazards, such as drought and fire.

The two plausible thresholds identified for this case study are:

- Threshold A:
    - Climate Context –Summer mean temperatures increase by 3.5 to 4°C and summer mean precipitation decreases by 40-50% which are consistent with the UKCP09 high emission scenario for 2080. Low winter rainfall followed by spring and summer drought.
- Threshold B[11]:
    - Low winter rainfall followed by spring and summer drought; Accidental ignition and 2,000 ha of uncontrolled burn, a 'wildfire'.

5.3 Stage 4: Moor House and Upper Teesdale

The narrative introduced in this Section is independent of the economic assessment and should be assessed independently. This narrative introduces other factors that were unable to be represented in the economic assessment.

5.3.1 Threshold A - Increased summer temperatures and drought

Plausible impacts on land use arising from Threshold A

The impact of a severe droughts and heatwaves will be to lower water tables in the peat, resulting in a decline in Sphagnum species and summit-type erosion (Mackay and Tallis, 1996). The Threshold is also likely to depress grouse shooting due to the decline in food and Sphagnum spp. The impact on carbon storage would be significant. A decline in carbon sequestration follows as the condition of the peat worsens and as the peat dries and becomes exposed sequestration could reverse with carbon losses from oxidation and erosion exceeding carbon captured.

Preceding the threshold being reached, the overall climatic conditions of increasing summer temperatures, less rainfall and droughtiness would affect the vegetation over the long-term, potentially producing less grass and more heath. Herbage availability for sheep would reduce especially in summer (although it may become available earlier on the season for a period), meaning reduced stocking levels would be necessary to both maintain sheep quality but also the quality of the moorland habitats. Fewer sheep could make a difference to the viability of individual farming businesses, rendering the farm less attractive if only used for sheep and driving diversification.

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[10] http://www.moorsforthefuture.org.uk/sites/default/files/Presentation_Accessing%20the%20impacts_Joanna%20Clark.pdf

[11] Multiple fires within a season would also be plausible, as evidenced by the two wildfires in the uplands in June/July 2018 that have been persistent after dry periods.

Grouse production in these conditions may also become more difficult as the population dynamics and adaptability of the species would become more pressurised. The species is a northern one where climatic conditions affect its distribution and biology. In a warming scenario, the implication would be for the species to lose its more southerly populations, causing more fragmentation of populations and viability of isolated populations, with the centres of population becoming increasing more northerly. This may affect the density and numbers of breeding grouse, and their production of surplus young for shooting. Additionally, an early onset of spring can impact the young due to decreased availability of food at an earlier period.

There would be increased pressure on the viability of more northerly species to adapt to the warming. For instance, the moorland breeding wading birds rely on wet ground for the production of invertebrates for chick feeding and the scenario would result in drier ground for longer. Wetter habitats would be more pressurised with consequent changes in community composition with unpredictable effects of local extinctions and changes (Buchanan et al., 2006).

See Section 4.1.1 Drought and heat stress for further discussion on the plausible impacts.

Business as Usual Scenario

The BaU scenario involves the continued mix of land use with decrease loss of restored peat areas[12] by the end of the reference period.

With a drought and heatwave, there would be increased difficulties of management, including the greater chances and expectation of fire, especially if the traditional technique of rotational burning was employed. Impacts would be as described in the previous section of reduced carbon storage, greater peat erosion, less grass and more heath, reduction of grouse production, and increased pressure on the viability of more northerly species.

Additionally, there would be no change to recreation/tourism or education as there would still be large areas to be used, and the main attractions such as High Force would unlikely be affected from a recreational point of view.

It is likely the overgrazed peatland would be impacted initially from the threshold and become bare peat or soils, or grassland, due to its vulnerability of increasing temperatures and erosion. Since peatland in unfavourable condition is highly vulnerable, the damage to the peat from the threshold may be irreversible. The economic assessment will represent this change quantitatively.

Anticipatory Scenario

The most effective adaptive response is to restore the blanket bog to optimal condition. Restoration of the blanket bog to an optimal condition would allow for greater resilience to droughts and fire before they occur (Threshold B). Minimising the risk of dry organic soil eroding or being lost in fire events is best approached by restoring the hydrology of the blanket bogs through a programme of re-wetting and restoring a more characteristic surface bog vegetation including establishing peat-forming plant species, notably Sphagnum mosses. The aim of

[12] Although this research assumes no peat restoration, we would like to acknowledge there is a peat restoration occurring within the Moor House NNR. However, we are unable to provide an assessment qualitatively or economically without further research and engagement.

restoration would be to retain as much water as possible, and for the longest time, within the peat body itself, as well as creating the conditions for more peat to form on the surface layer (the ‘acrotelm’).

As previously stated, blanket bog in good condition can modify their natural hydro climatological conditions by impeding drainage and producing almost permanently saturated conditions, particularly for the larger, deeper bogs (Brown et al., 2016). This restoration work to restore the blanket bog to optimal condition would also include grip blocking, revegetation, and ceasing the practices of managed cutting for grouse shooting. By ceasing the drainage and vegetation management for grouse populations, there will be a trade-off between income from shooting days and restoration of peat, which can increase biodiversity, reduce runoff, increase carbon storage, and other benefits.

Techniques are well-established for restoring peat (e.g. the programmes currently carried out by Moors for the Future, or the Yorkshire Peat Partnership) and include the installation of dams and plugs in drains and ditches, and on bare surfaces, re-vegetation using Sphagnum inoculation and cotton-grass *Eriophorum* planting (though this is more pressing in heavily degraded blanket bogs such as in the Peak District). Prevention of fire as a management tool (and using alternative management methods if required) would assist a more diverse vegetation to develop as well as eliminate damage to the peat-forming process.

In addition to revegetating bare peat areas, ceasing sheep farming would assist in adaptation. There is extensive evidence from revegetation trials that links sheep grazing to the prevention of recolonization of bare peat surfaces (Mackay and Tallis, 1996).

Lastly, this landscape may also provide an opportunity to cover translocation of species in a changing climate since species are currently being supported at the northern and southern edge of their biogeographical boundaries.

Reactionary Response Scenario

There will be an decrease in the ecosystem services provided, including a net loss in carbon due to the impact of the threshold and no intervention prior to the threshold taking place.

The impact of the drought and heatwave would be greatly dependent on the conditions after the drought and heatwave. If the climatic conditions returned to being wetter, or more similar to the conditions currently (or pre-threshold), the Sphagnum would re-establish due to the spores and propagules in the surface layers of the peat bog through active peat restoration (Lindsay et al., 2014). Some examples of this can be found across the Dark Peak and South Pennines where the Sphagnum had been completely lost for centuries due to drying out and industrial pollution. However, Sphagnum is now returning rapidly, especially through active intervention of peat restoration programmes, like that outlined above.

Although historical evidence does illustrate peat bogs resilience to drying out and decomposition, the current condition of peat bogs across the UK lack an active living surface which will reduce the resilience of peat bogs to future climate change (Lindsay et al., 2014).

5.3.2 Threshold B - Threshold A plus a fire

Plausible impacts on land Use arising from Threshold B

The threshold identified includes a wildfire, resulting from the drought and heatwaves. Based on the evidence provided in Section 4.2 Review of peat-based land uses and Climate Change Impacts, the threshold identified was 2,000 ha of moorland destroyed by the fire. This assumption would equate to 2.3% of the case study area being directly damaged, and proportionally a higher percentage of the blanket bog habitat in the case study area (3.2%) which is where an accidental fire would be most likely to occur.

The most significant impact of Threshold B occurring is the significant loss of carbon and soil quality depending on the depth of the burn on the peat, with both vegetation and historical accumulations of peat being oxidised. The remaining surface, once the fire had been extinguished would be subject to wind erosion, with more ash and particulate matter (carbon) dispersed. Figure 4-1 above summarises the different impacts of a fire on the peat hydrological system, including difficulty in re-establishing Spaghnum as outlined above, but also increased overland flow, reduced near-surface macropore flow and hydraulic conductivity and others (Brown et al., 2014), possibly increasing flood risk to some receptors.

Additional costs of the fire to be considered include the fire and rescue services, emergency services, increased health services due to irritation and damage to respiratory systems, and carbon costs of these increased services.

Business as usual

Threshold B would cause some pressure on agricultural production (only Less Favoured Areas (LFA) grazing by sheep occurs in this catchment), affecting a handful of sheep farmers. Some adjustment in farming would be required e.g. sale of surplus sheep, or buying in of grazing land elsewhere, which would cause some pressure on the individual sheep-farmers in terms of their businesses both immediate but also long-term as the land would be unusable for decades. The effect on any individual farmers affected could range between inconvenient, temporary hardship and business becoming unviable depending on their tenancy and how significant the 2,000 ha was to them; however, the effect on the viability of the wider farming community in Teesdale would probably not be affected and the community would adjust.

In terms of grouse production, the situation would be similar, with reduced bird numbers over 2,000 ha and reduced surpluses to shoot. It is important to note that there is significant variability in the numbers shot due to the cyclical nature of populations, therefore the extent of the 'experience' of being involved in a shoot may be more financially valuable than the actual bag numbers. However, the fire could cause the closure of certain estates for grouse shooting for extended periods of time and public footpaths for visitors, reducing recreational and aesthetic value.

In terms of biodiversity, there would be a net loss of priority habitat (2.3% or 3.2% as calculated above) which would be significant. There would also be a net loss of priority species e.g. the moorland breeding bird community and other upland species. Depending where the fire occurred, it could be very damaging to the special sugar limestone communities, in which the longer-term effect of this could be significant. Moorland breeding birds occur at low density, so a significant proportion of the local population would be affected which would affect local population dynamics such as recruitment and mortality rates. Recovery times for the burnt moorland are long-term and the areas may never regain their diversity, so this would be a net loss of biodiversity resource.

Some localised deterioration in water quality in feeder streams to the River Tees would occur, with run-off from the burned areas containing particulate matter and dissolved minerals. (impact would have to be monitored).

There would be significant immediate deterioration to air quality through smoke (note the current 2018 example of the moorland fire at Saddleworth Moor, Manchester, which has caused downwind issues of air quality in the city); however, the population is thinly spread and depending on the wind direction, the numbers of people affected would be low (although it may be significant for individuals affected).

Anticipatory Scenario

The anticipatory adaptation scenario would be the same as Threshold A (drought and heatwave).

Reactionary Response Scenario

See Reactionary Response Scenario of Threshold A. However, the fire is likely to increase the risk of the active living surface been destroyed, reducing the capability of the Sphagnum to regenerate.

5.4 Economic assessment

The Threshold chosen to be represented in the economic assessment was threshold A. The narrative introduced in Section 5.3.1 Threshold A - Increased summer temperatures and drought has attempted to be represented in the economic assessment but could not be completed comprehensively. Therefore, the assumptions in the economic assessment should be assessed independently. The scenario in the economic assessment does match exactly the narrative in the Section 5.3.1 Threshold A - Increased summer temperatures and drought.

A summary of the inputs and timing assumptions for all scenario is listed in Table 5-3 overleaf.

It should be noted that the evidence gathered on carbon sequestration or release from peatlands has been broadly based on existing evidence and supports the idea that improved conditions and restoration of degraded peatlands is positive for carbon. However, research from the CEH study suggests that while this is the case for carbon, the rewetting of peatland may have less positive or even negative impacts on other greenhouse gases such as methane and nitrous oxide.

Table 5-2 – Summary the economic assessment for each scenario for Threshold A

	BAU	Assumption	Early intervention	Assumption	Reactionary	Assumption	
Threshold event	2030 over 5 years	Defined by project team	2030 over 5 years	Defined by project team	2030 over 5 years	Defined by project team	
Intervention point	n/a		2022 over 10 years initially, but restoration until 2100	Changes in land use take time to be realised.	2030 over 10 years initially, but restoration until 2100	Changes in land use take time to be realised.	
	BAU		Early intervention		Reactionary		
	Change assumptions	**Costs and benefits**	**Change assumptions**	**Costs and benefits**	**Change assumptions**	**Costs and benefits**	**Limitations**
Threshold impact	Peat deterioration. Reduction in grouse shooting. Fire ignored. Flood impact ignored under this heat stress scenario. Climate hazard threshold impacts assumed to be minimal based on expert opinion of PGA stakeholder group.	Minimum threshold impact under this scenario. Peatland fire impacts assessed as a sensitivitiy test.	Early intervention options mean that threshold impacts are reduced.	As BAU	As BAU	As BAU	Grouse shooting unable to be monetised. No readily available monetary values for this component.
Carbon sequestration	Carbon sequestration rates by land cover based on a range of sources including Natural England (2010).	Carbon unit price taken from BEIS non-traded carbon price.	Restoration of 1/3rds of peatland to undamaged condition by 2022. Restoration of half of peatlands to undamaged condition by 2031 and full restoration by 2100.	As BAU	As BAU up to threshold event. As Early Intervention after threshold event.	As BAU	Unfavourable condition of peatland is based on the cover vegetation, not on the depth of peat soil. Changes in other greenhouse gases not assessed.
Agricultural productivity	No change due to limited agriculture.	4 ha of LFA_Grazing	As BAU	As BAU	As BAU	As BAU	Grouse shooting unable to be monetised. No readily available monetary values for this component.
Other environmental benefits	Benefits assumed to reduce due to climate pressures and overgrazing. 20% reduction in value of 'other benefits' by threshold event, falling to 40% by end of appraisal period.	Includes environmental inputs of the peat and minor woodland benefits. Benefit values based on a range of sources. Linked to land use areas.	As BAU but more undamaged peatland so 10% uplift in benefits assumed, rising to 20% uplift in benefits by end of appraisal period.	As BAU	As BAU up to threshold event. As Early Intervention after threshold event.	As BAU	Unable to value the costs of losing the sugar limestone communities and the reduction in moorland breeding birds. Value the loss of biodiversity specific to the designation of NNR.
Timber sales	Rate of provisioning services from woodland assumed constant throughout reference period.	Timber prices based on Nix, 2016 . Incomes relate to thinning and clear felling activities.	As BAU	As BAU	As BAU	As BAU	Timber sales increase as trees mature built into the analysis by provision of a a 25 year lag.
Recreation	Recreational benefits included but static over the appraisal period.	Values estimated using ORVal (Outdoor Recreation Value).	As BAU	As BAU	As BAU	As BAU	No readily available information on how recreational values will change with changes to the land use or in absolute terms.
Land use change	Current proportion of degraded peatland = 88% (12% restored). Losses due to gradual and ongoing deterioration. 3,000 ha assumed to be lost and converted to heathland by the threshold event.	Peatland deterioration assumed to occur naturally - no managed change or cost of change. Proportion of Peatland degraded based on Natural England 'Designated Sites View' website.	Restoration of 1/3rds of peatland to undamaged condition by 2031 (by the end of the intervention period). Full restoration by 2100.	Peatland restoration assumed to be managed and the costs of this included. Cost estimates based on Environment Agency (2015)	As BAU up to threshold event. As Early Intervention after threshold event.	Peatland restoration assumed to be managed and the costs of this included. Cost estimates based on Environment Agency (2015)	

5.4.1 Summary of land use change

The summary of how the land use changes under each scenario at the end of the appraisal period is shown below. It highlights the significant change in lost or extracted peatland under the BAU scenario.

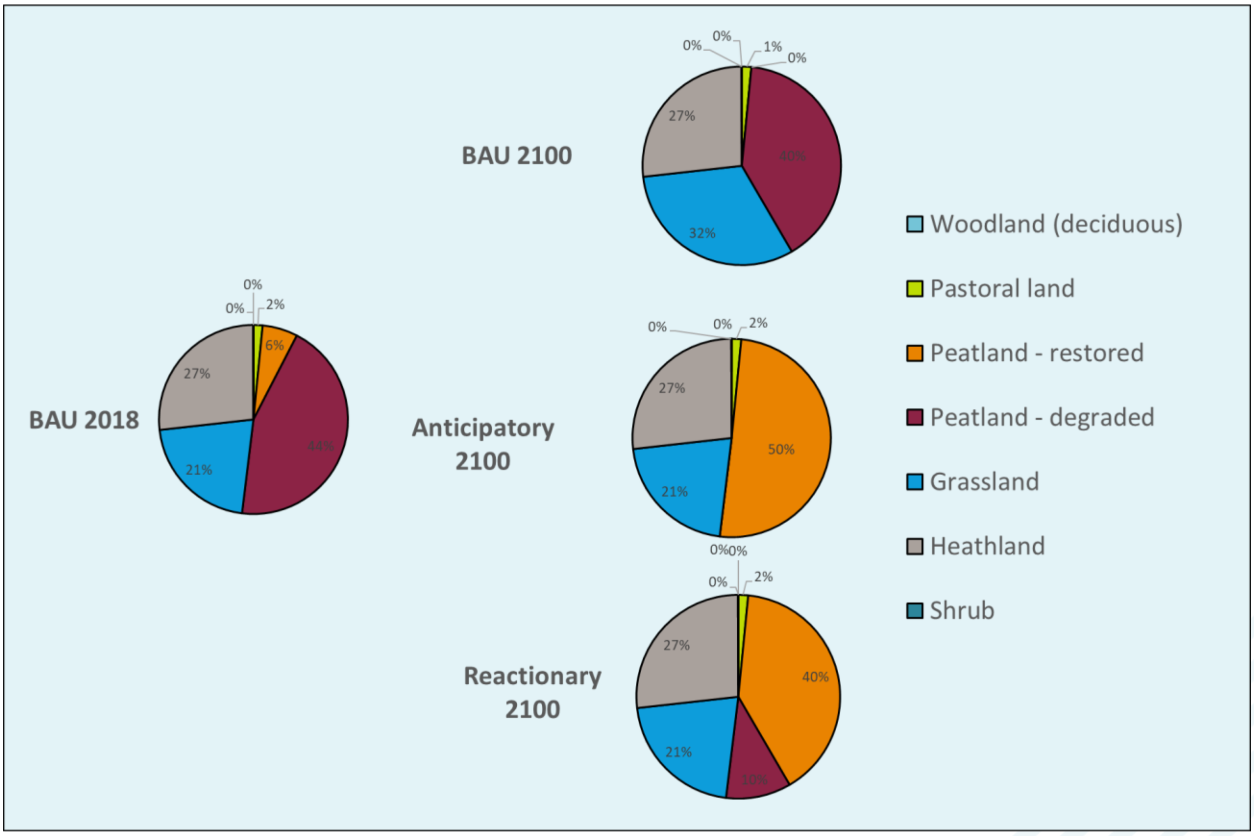

Figure 5-2 – Land use change assumptions for Moor House

5.4.2 Outcome and interpretation of benefit-cost calculations

The summary of the benefit-cost and net change calculations for the Moor House and Upper Teesdale are provided for each scenario in Figures 5-3 to 5-5. These represent cash costs (not Present Values) to allow the differences to be distinguished over the appraisal period. A comparison of the net benefits for each scenario is provided graphically in Figure 5-6.

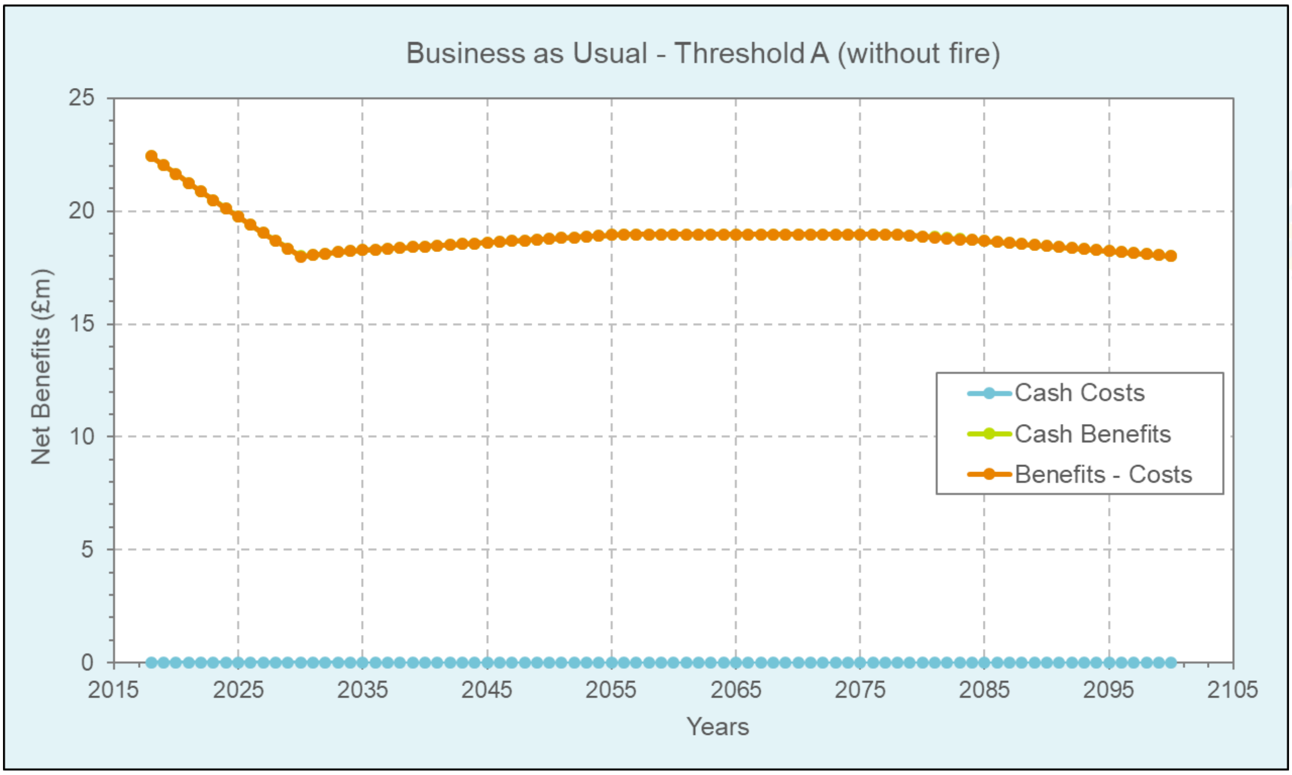

Figure 5-3 – Moor House and Upper Teesdale BAU Scenario

It should be noted that the costs are effectively zero for this scenario. The benefit line is hidden beneath the difference between benefits and costs. Costs are effectively zero because the assumption is that no interventions are being carried out on the moorland and the peatland will degrade as a result. There is a decline in the carbon sequestration and environmental benefits associated with degraded peatland – shown as a reduction in benefits in the chart.

Other costs may include the loss of revenue from grouse shoots – a loss that is applicable but has not been able to be monetised as part of this review due to the lack of any readily available data.

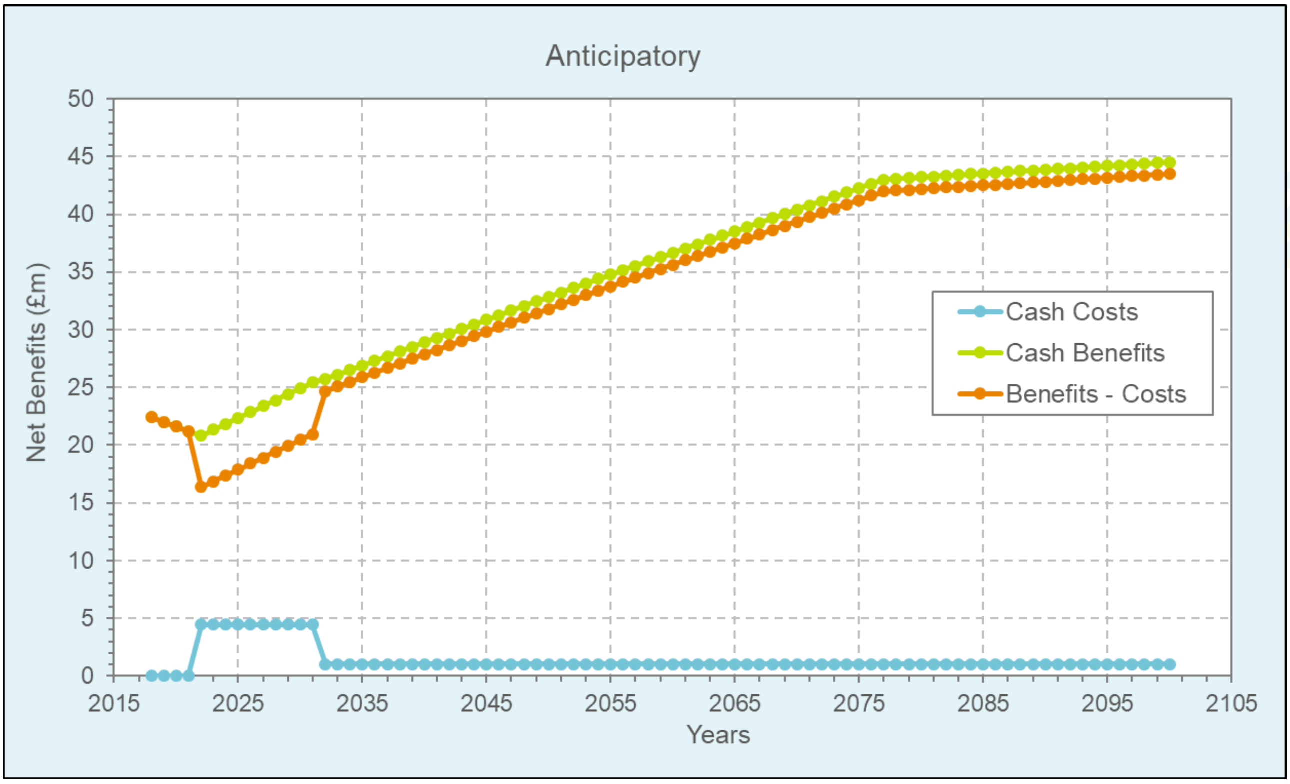

Figure 5-4 – Moor House and Upper Teasdale Anticipatory Scenario

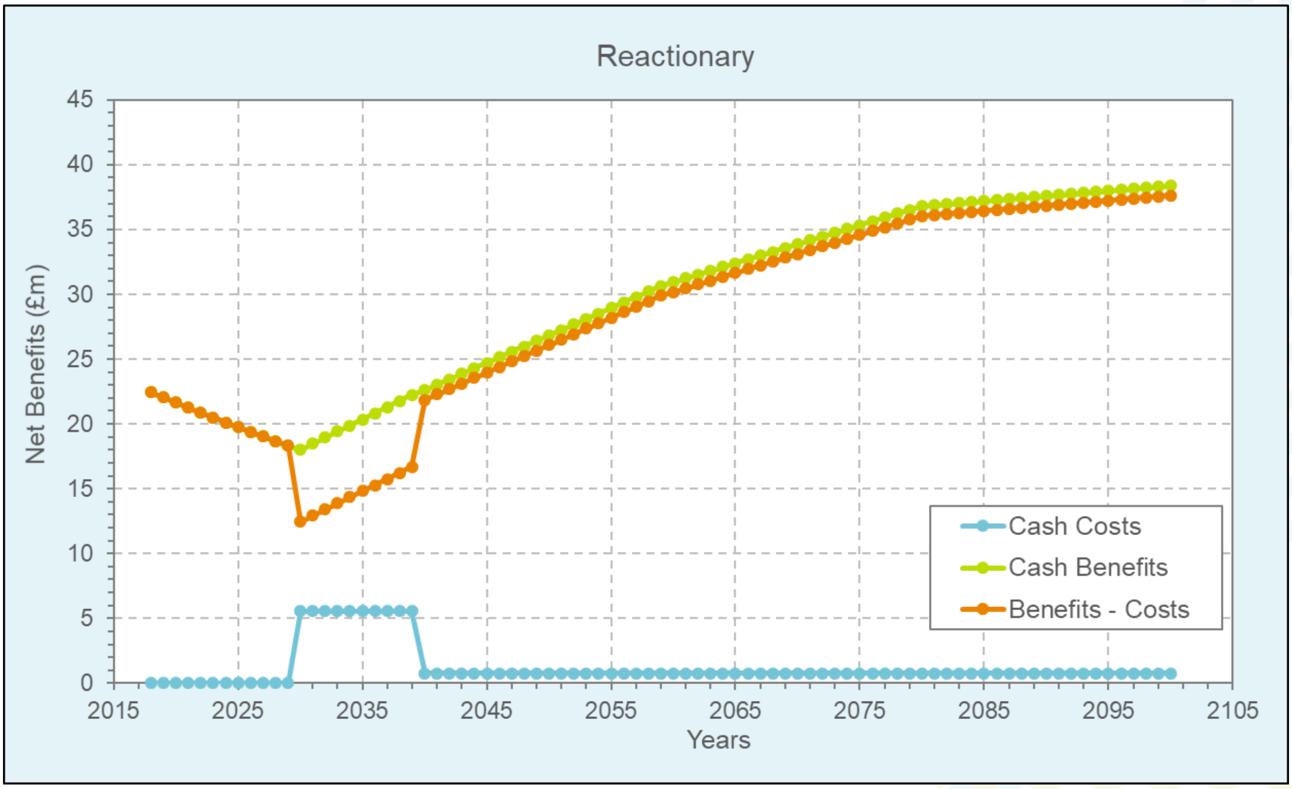

Figure 5-5 – Moor House and Upper Teesdale Reactionary Scenario

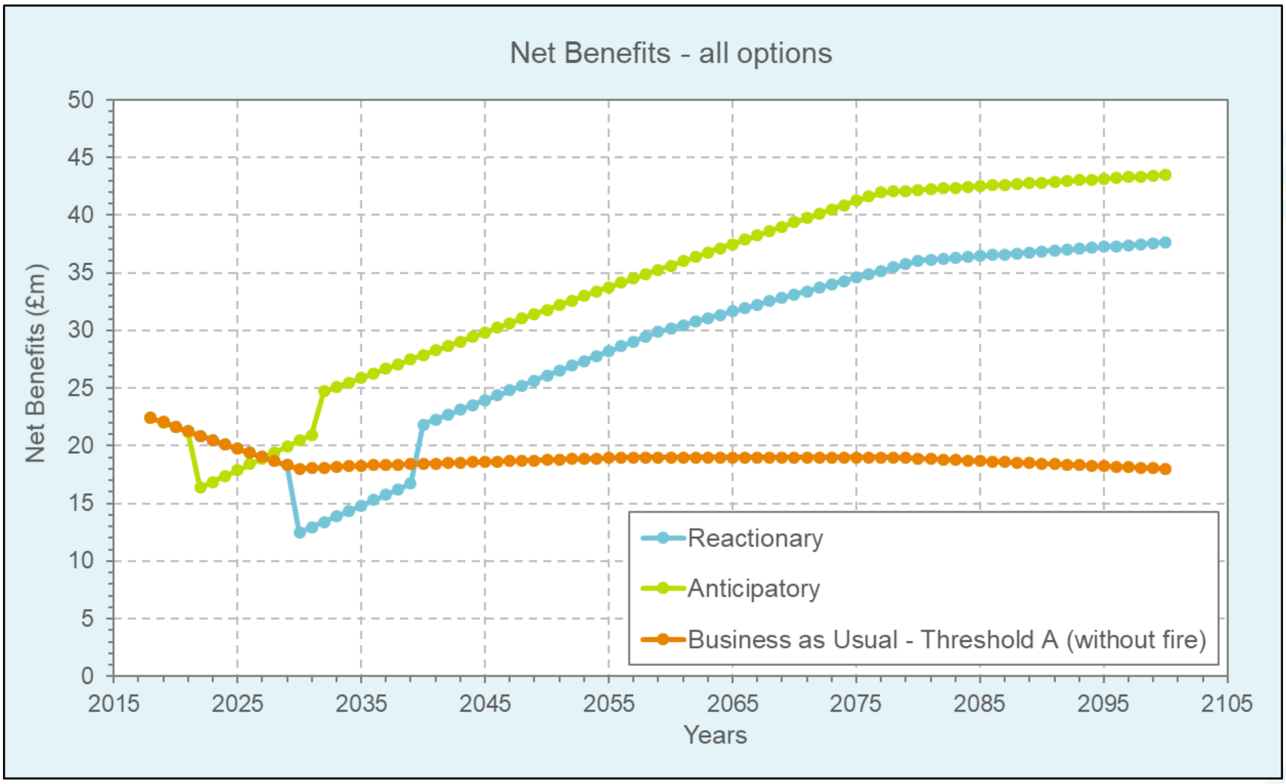

Figure 5-6 – Comparison of benefits minus costs (cash) for each scenario

Total NPV's for each scenario are provided in Table 5-7.

Table 5-3 – Summary of whole life Net Present Values (£m)

Scenario	PV Costs	PV Benefits	Net present value	Relative benefit of option
Business as Usual - Threshold A (without fire)	£0	£550	£550	-
Anticipatory	£50	£850	£800	£240
Reactionary	£40	£710	£670	£120

The results can be summarised as follows:

- This case study is strongly influenced by the carbon sequestration (and release of carbon) and the wider environmental benefits of upland peatland (water purification, water treatment, recreation and tourism, aesthetic value, biodiversity). Other benefits such as the benefits from grouse shooting have been excluded from the analysis due to a lack of readily available value information on this aspect. Secondary wider benefits associated with grassland and heathland are not widely considered to be significant and have been ignored at this stage.

- Moorland management costs are not included in the analysis due to a lack of readily available information on these costs. As a result, the analysis for the BAU suggests that the costs associated with maintaining and managing this this type of habitat and land use are very small, thus the benefits are higher than the costs for the majority of the appraisal period. Overall the whole life NPV equals £550m.
- The anticipatory scenario results in a long term positive impact, primarily on carbon sequestration due to the conversion of poor peatland to favourable condition. It is assumed that the risk of fire is significantly reduced which maintains the benefits. The costs of land use change are also outweighed by the long term environmental benefits. Overall the whole life NPV equals £850m.
- The reactionary scenario suggests that the implementation of improvements to the peatland can offset the losses associated with the BAU scenario but not as efficiently as the anticipatory option. The benefits are greater than the costs for all of the appraisal period following the threshold event. Overall the whole life NPV equals £710m.

Table 5-5 shows that over the life of the appraisal period the benefits of shifting to an anticipatory option are significant. Most of these benefits are as a result of an increase in carbon sequestration and the wider environmental benefits of improved peatland (water quality, recreation and tourism, aesthetic value, biodiversity). These are offset by the potential additional costs incurred of facilitating these changes. This is shown graphically in Figure 5-7.

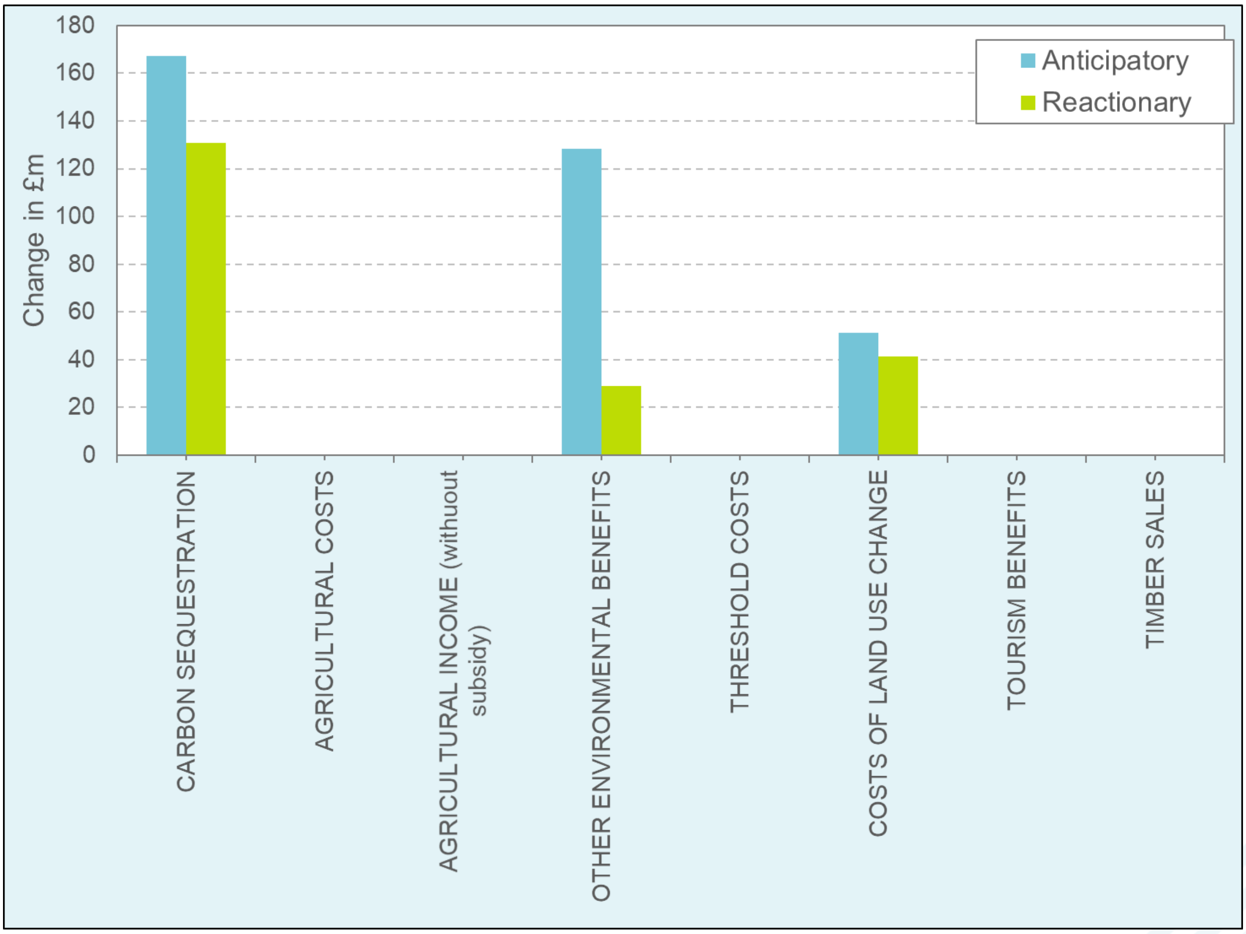

Figure 5-7 – Change in benefits and costs for each scenario

5.4.3 Sensitivities

This case study may be strongly influenced by the assumptions around fire losses ignored from the analysis in the above case due to the high release from moorland under fire. Carbon losses per unit area burnt are estimated to be 96t/ha for a fire event (based on Davies et al. (2016)). The inclusion of these losses significantly impacts the carbon losses and gains assuming the adaptation works reduce the probability of this occurring. This has been tested by implementing the occurrence of a single fire event at the threshold year for both the BAU and reactionary scenario and assuming a 1000ha loss. The results this has on the total NPV's is shown in Table 5-6.

Table 5-4 – Summary of whole life Net Present Values (£m)

Scenario	PV Costs	PV Benefits	Net present value	Benefit of option
Business as Usual - Threshold B (with fire)	£40	£550	£510	-
Anticipatory	£50	£850	£800	£290
Reactionary	£130	£710	£590	£80

5.5 Maximise carbon sequestration

Table 5-7 below, taken from Dawson and Smith's study, outlines measures (small and large scale) that could be taken into account when developing best practice guidelines for the management of the land in Moor House and Upper Teesdale.

Table 5-5 – Land management options that could increase soil C pools

Land use	Land management options
Grasslands	Convert cultivated lands to well managed permanent grasslands, species selection; decrease erosion and degradation; eliminate disturbance e.g. fire protection in established pastures; increase forage production by improved fertilization, irrigation, inter-sowing of grasses and legumes; improve grazing and livestock management with controlled light-to-moderate stocking density; moderately intensify nutrient-poor permanent grasslands; introduce earthworms, improve soil structure; maintain a diverse plant community with a dense rooting system. Avoid fertiliser application during periods of rainfall, near water courses and on heavy and water-logged soils.
Forestry	Forest and Water Guidelines by the Forestry Commission, 'best practice' guidelines; increase forest stock; continuous cover forestry to encourage natural regeneration; conserve soil and water resources; improve site preparation and planting techniques to decrease erosion; streamside management with uncultivated buffer zones to stabilize soil and reduce acidification; design of forest roads and network of drains, culverts and sediment catch pits; reduce disturbances from wind and fire; minimise soil and water impacts and reduce clear felling operations to phased felling techniques; minimise nitrate leaching, enhance base cation retention by early revegetation; use species with high NPP or increase number of actively sequestering younger forests; application of nutrients and micronutrients as fertilizers or biosolids; aesthetic planting of previously native trees and shrubs, enhance biodiversity; maintenance of open bog and moorland habitats; extension of guidelines to include conservation, landscape and recreation; plant trees on mineral soils in preference to highly organic soils.
Peatlands & wetlands	Wetland protection, restoration and revegetation on bare peats; prevention of wind and water erosion; reduce peat extraction and disturbance; preserve biodiversity; rehabilitate acidified surface waters; afforestation only in appropriate areas; controlled burning; aesthetic planting of previously native trees and shrubs; where possible block drains and restore water table.

6 Norfolk and Suffolk Broads

From its origins through medieval peat excavations, the use of wind-pumps for water level management and the commercial and recreational navigation of its waterways, the area of the Norfolk and Suffolk Broads has undergone many changes over the centuries. More recently there have been a wide range of studies, projects and land-use incentives that have influenced the present-day situation and management approaches. In 1967 the then Nature Conservancy Council reported on habitat degradation in the Broads, reinforced by a further study by the Norfolk Wildlife Trust in 1976. In 1978, through a non-statutory joint committee of local authority Members, a management structure was established, with resourcing through the authorities and the Countryside Commission. The “Battle for the Broads” in the 1980s, was prominent in spear-heading a reform of agricultural practices in the area which threatened to deep drain large swathes for arable production. From this the Broads Grazing Marsh scheme was borne, operating as a precursor to the Environmentally Sensitive Area scheme (1986). Protection equivalent to a National Park arrived following the Norfolk and Suffolk Broads Act 1988 and a statutory Broads Authority became formally constituted in 1989, encompassing wider navigation responsibilities. Further legislative changes ensued in 2009, principally to promote greater safety controls on the waterways. It remains subject to a significant number of threats and opportunities associated with climate change adaptation.

Fen habitat constitutes a relatively small proportion of the overall mix of land use types with less than 2,000 hectares remaining as open fen. However, it forms the largest expanse of species rich fen in lowland Britain[13].

6.1 Stage 1: Norfolk and Suffolk Broads

The Broads "National Park" area includes some 25% of the UK's rarest species and is arguably the most biodiverse of all National Parks in the UK[14].

Three potential case study boundaries were considered - (left to right) The Norfolk and Suffolk Broads executive area; The Broads National Character Area; The Broadland Rivers Catchment:

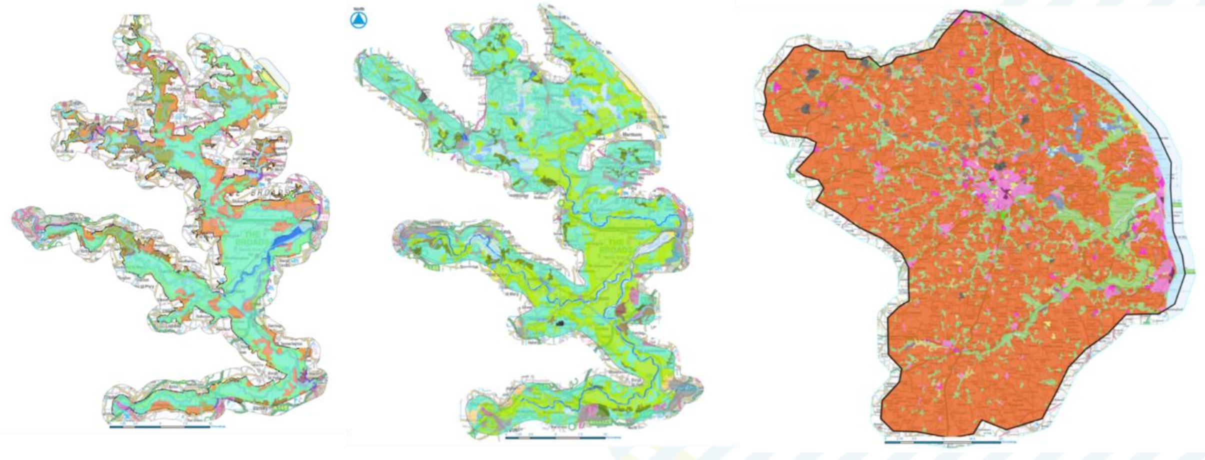

Figure 6-1 – Three potential boundaries for the Norfolk and Suffolk Broads case study (The Norfolk and Suffolk Broads Executive area; The Broads National Character Area; and the Broadland Rivers Catchment – left to right)

The National Character Area incorporates a very high proportion of natural capital resources, protected and internationally important sites. Effective management of the area is however heavily reliant on water resource, level and quality impact

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[13] http://www.broads-authority.gov.uk/__data/assets/pdf_file/0010/424837/Fen_Management_Strategy.pdf
[14] http://www.broads-authority.gov.uk/__data/assets/pdf_file/0020/412922/Broads-Biodiversity_audit_report.pdf

from the wider catchment. The “elephant in the room” is the coast and what may happen along particularly the Eccles – Winterton frontage, with its conditional Hold the Line Shoreline Management Plan policy (but changing to managed realignment if ‘Hold the Line’ is deemed unfeasible in the long-run) and some further tidal impacts relating to potential tidal barrier considerations at Lowestoft and/or Great Yarmouth. This will significantly affect what adaptive approaches might be viable for the Broads. The NCA incorporates the Eccles – Winterton frontage whilst the catchment encompasses all the key coastal policy units.

The case study discussion concluded:

- Catchment scale is key to understanding the impacts affecting the Broads but recognise the complexities and size of the area in terms of the requirements and limitations of this study.
- The National Character Area incorporates the most vulnerable coastline and has a practical scale, although there are limitations and interdependencies with its wider environs.
- The Broads Executive Area is too tightly constrained
- Different metrics may require a different scale of scrutiny (e.g. air quality, salinity, flood, habitat, soil, species etc)
- Relationships with urban areas and infrastructure are needed to explore social and economic dependencies, including factors around scale and distribution of growth.
- Practically, the Broadland Rivers catchment alongside coastal change provides the much of the context for impacts on the priority sites within the NCA

The research continues with the Broadlands River Catchment to capture the beach, dunes, sands land use and the important role in plays in the character of the Broads area. The land use of the Broadlands River Catchment can be seen below. However, it does not include the importance of certain land covers, including inland and salt marshes that provide important biodiversity in the area.

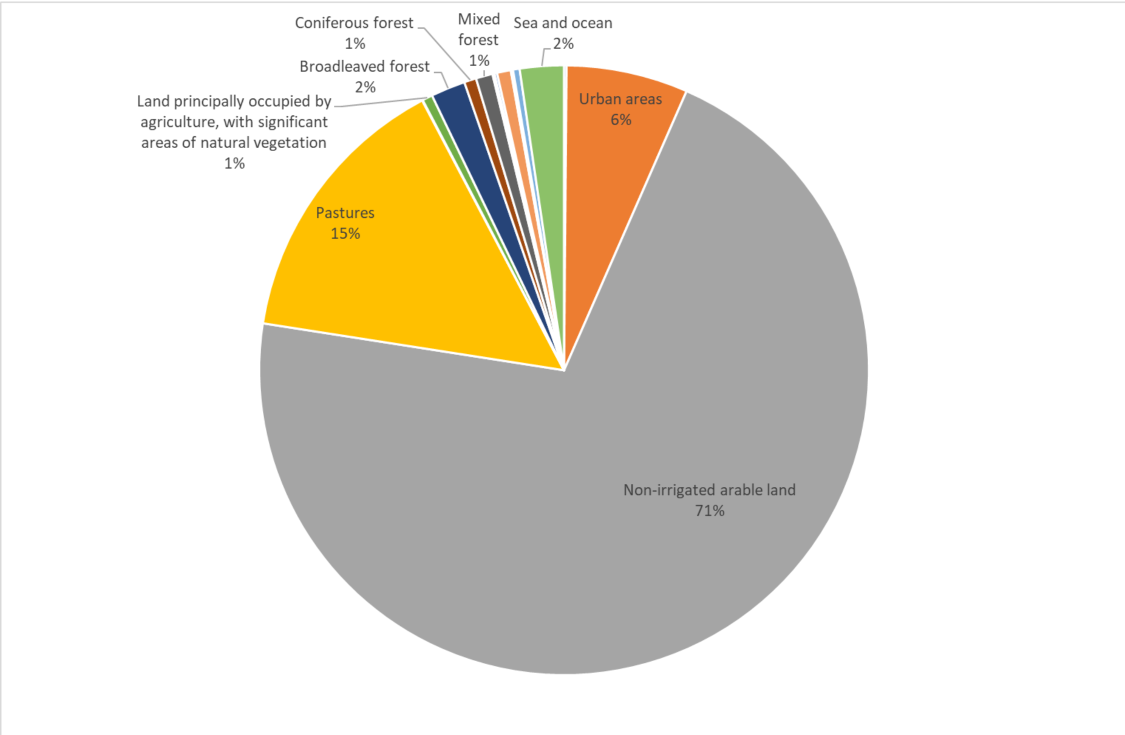

Figure 6-2 – Corine Land Cover (2012) for the Broadlands River Catchment[15]

The category of "non-irrigated" arable land (211) is slightly ambiguous, however the definition describes this as, "Cultivated land parcels under rainfed agricultural use for annually harvested non-permanent crops, normally under a crop rotation system, including fallow lands within such crop rotation. Fields with sporadic sprinkler-irrigation with non-permanent devices to support dominant rainfed cultivation are included."

Arable land and pastures predominate, with arable land dominating the Catchment (70%). There has been extensive research and resources into further understanding the benefits of the land use and its ecosystem services. The Broadland Catchment Partnership has produced opportunity mapping that highlight areas that provide a range of different ecosystem benefits[16]. It highlights the key service of provision of food, energy or materials from agricultural land, but also determines that the extent can vary according to the suitability of the land for providing other ecosystem services including: clean water; flood risk reduction; wildlife habitat; carbon storage; and recreation.

Finally, The Broads Biodiversity and Water Strategy (2013) also incorporates broad descriptions of natural capital features and ecosystem service benefits[17].

Fen habitat constitutes a relatively small proportion of the overall mix of land-use types and is not specifically categorised. There is an estimated 5000 hectares of

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[15] Note that this Figure does not include land covers in which the proportion was 0 or 1%, including salt marshes, intertidal flats, water bodies, sea and ocean, coniferous forest, mixed forest, natural grassland, moors and heathland, transitional woodland, and beaches, dunes, sands.

[16] http://www.broads-authority.gov.uk/mapping/mapping-pages/catchmap

[17] http://www.broads-authority.gov.uk/__data/assets/pdf_file/0003/416487/Broads-Biodiversity-and-Water-Strategy-watermark-removed.pdf

semi-natural wetland habitat remaining in the Broads area, however, less than 2000 hectares remains as open fen. The herbaceous vegetation of Broadland forms the largest expanse of species rich fen in lowland Britain; it is diverse in both plant communities and species. Over one-third of the open fen area supports nationally important plant communities together with a number of nationally rare plant species. Under the Ramsar Convention (1971) the majority (4646 hectares) of wetland habitat in the Broads has been recognised as being of global importance and also as SPA and SAC.

Agri-environment schemes have played a huge part in shaping the current Broads ecology, from the pioneering Grazing Marshes scheme at Halvergate, the Environmentally Sensitive Area payments through a succession of Stewardship schemes to the present day. The schemes account for about two-thirds of the Broads Executive area, with management options ranging from hedgerow and ditch management to creating buffer strips, and the reversion of arable land to grazing marsh. At the time of writing, a proposal has been submitted to Defra for a new pilot (Broads PLUS) agri-environment scheme, developed in partnership with the National Farmers Union, local land managers and local conservation NGOs (Broads Authority 16 March 2018 - item No. 19). This would adopt a catchment-based approach, taking account of longer term trends and build in resilience and adaptive options to address climate change in this vulnerable area.

Table 6-1 – Summary of the land use, land cover, and land management in Broadlands Rivers Catchment

Land use	Land cover and land management
Arable land	- Diverse high value crops that are water sensitive (e.g. potatoes, wheat, sugar beet, maize, etc.) - Main crops include: potatoes, sugar beet, barley, and horticulture[18]
Pastures / semi-improved grassland	- Broadland grazing marshes managed mostly for biodiversity; land supports international significant populations of raptors, aquatic plant and wet woodland communities as well as nationally important populations of breeding waders, waterfowl, and other plant and invertebrate communities - General pasture within wider catchment managed principally for livestock production, dairy hay or silage, with a focus on yield rather than biodiversity - Managed for the landscape/aesthetics - Flood risk through water level management (Internal Drainage Boards have a key role) - Grazing
Freshwater marshes	- Internationally protected habitats / biodiversity - Managed for landscape - Managed for soil conservation - Flood risk management
Broadleaved woodland	- Some managed for aesthetics / recreation, including game shooting (e.g. pheasants, partridges - Some are actively managed for timber - Biodiversity / habitat including for nesting and overwintering birds (e.g. Carr Woodland). Largely unmanaged approx. 3,000ha
Beach, dunes, sand	- Internationally protected habitats (NNR, SSSI, and part of Winterton-Horsey Dunes SAC and Great Yarmouth Denes SAC) in which beach recharge takes place - Bacton Sand Engine scheme will have a major impact on sediment dynamics and medium-term beach levels along this frontage[19]. - Further site-specific coastal flood and erosion risk management - Recreation / aesthetics - Heritage (Waxham Great Barn, Archaeology, etc.)

6.2 Stage 2 and 3: Norfolk and Suffolk Broads

A majority (approximately 71%) of the Broadlands River Catchment is categorised as non-irrigated land, which includes all arable land that does not have a permanent device for irrigation. The main crops grown include potatoes, sugar beet, barley, and other horticulture crops. It has been identified by the Broads Authority and other organisations that this area is highly sensitive to imbalances in water levels, and human intervention is needed to manage the risks of floods and droughts. Additionally, the case study is threatened by coastal flooding and saline intrusion.

From observational data and outputs from 23 global climate models, Battisti and Naylor (2009) determined that temperate countries' seasonal growing temperature is likely to exceed the hottest season on record and therefore the projected seasonal average temperature represents the median of the climate distribution and the norm of the future.. Farmers in the Broads are already taking steps to secure their own supplies of water by filling storage areas during wet winter months, for example by constructing on-farm reservoirs, and using them to irrigate crops during dry summer months.

Finally, the Broads Authority publication on why farming is important states that "if the defences are breached, flooding would mean a loss of productive farmland, the unique landscape and the biodiversity that goes with it"[1].

Plausible thresholds for change identified are:

- Threshold A:
  - Climate context: Drier summers and warmer temperatures
  - Antecedent conditions: 3 years of drought
- Threshold B:
  - Climate context: Increased storminess (higher intensity rainfall events and greater magnitude sea storms)
  - Antecedent conditions: High soil moisture and consecutive storm events (over 1 in 200 storm events); Sea Level Rise; Small scale breaches of sea defences.
  - Note: the Shoreline Management Plan policies in the 3rd epoch are broadly "No Active Intervention", sustaining longshore southwards sediment supply. Eccles – Winterton frontage is however a conditional "Hold The Line" policy, but on the basis of it being technically and economically sustainable – otherwise the policy will revert to "Managed Realignment." which would mean a loss of the coastal defences and replacement with coastal habitat to act as a natural flood management, but with the loss of some land for other uses.

6.3 Stage 4: Norfolk and Suffolk Broads

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[18] http://www.broads-authority.gov.uk/news-and-publications/publications-and-reports/conservation-publications-and-reports/water-conservation-reports/5.-Why-Farming-Matters-to-the-Broads.pdf
[19] https://www.north-norfolk.gov.uk/tasks/coastal-management/bacton-to-walcott-coastal-management/
[1] http://www.broads-authority.gov.uk/news-and-publications/publications-and-reports/conservation-publications-and-reports/water-conservation-reports/5.-Why-Farming-Matters-to-the-Broads.pdf

The narrative introduced in this Section is independent of the economic assessment and should be considered independently. This narrative will introduce other factors that were unable to be represented in the economic assessment.

6.3.1 Threshold A - Warmer drier summers generally with a 3-year drought

Plausible impacts on land use arising from Threshold A

The impacts of warmer drier summers and a drought would cause significant reductions of yields of rain-fed wheat, barley, forage maize, oilseed rape, and sugar beet due to declining water availability, as evidenced above. In extreme conditions and circumstances, complete crop failure is possible. The damage to soils and soil erosion from current practices and drier summers and drought are also likely to contribute to poorer yields. Furthermore, the reduced groundwater recharge and increased competition from other water uses will limit irrigation, causing reductions in crop quantity and quality (Living With Environmental Change, 2016). The overall climatic conditions combine to reduce Agricultural Land Classification (ALC) ranking.

In addition to the reduced income due to lowered yields, there may be increased costs for managing livestock, including increased supplementary feeding or reduced stocking rates and hay or silage cuts become unreliable as the grass becomes less productive.

Other plausible impacts could include:

- Lower ground water increases the likelihood of salination of aquifers which are susceptible to intertidal influences.
- The vulnerability of the Dune system, especially the dune slacks, to the loss of swamp and mire communities' habitats increases.
- Failure to manage water levels adequately in these circumstances would diminish biodiversity and landscape value and lead to localised eutrophication in ditches and watercourses.
- Adverse changes in recreational and aesthetic value are consequence of all the above.

See Section 4.1.1on Drought and heat stress for further discussion on the plausible impacts.

Business as Usual Scenario

The BaU scenario involves the continued mix of land use with no increase or decrease in agricultural areas, including no changes to the types of crops grown or agricultural management practices.

The impact of the threshold may cause changes in land management practices, such as changes to drought-resistant crops, increased on-farm water storage, shading for livestock, and more precise irrigation techniques. However, there would not be any transformational (i.e. land use change) adaptive measures implemented.

Early Adaptation Scenario

Typical land management measures to adapt to drier and hotter summers and drought can be found below. However, these management measures are not considered sufficient in themselves to mitigate the threshold impacts.

Management measures would include water level management plans to sustain biodiversity including managing the risk of eutrophication of ditches and watercourses. Flexible stocking density could take account of some seasonal variations and increased "lay-back" land at the expense of other land-use types (primarily arable). No/low till, paludiculture and drainage / water runoff management measures could reduce risks to arable crops. Crop adaptation, type of crop and early/winter sowing, will support the maintenance of yields in the prevailing drier conditions. Agricultural land-use over the catchment as a whole is likely to be able to exhibit adaptability whilst sustaining its high proportion of arable variants. However, these management measures are not considered sufficient in themselves to mitigate the threshold conditions.

- The following land use changes would increase resilience at the threshold. Increased on farm winter storage of water and the incorporation of water-efficient irrigation systems (ie; drip rather than spray irrigation) can be used to help manage demand on abstraction licences.
- Incorporation of new hedgerow and boundary features to reduce soil erosion on the same principle as the historical Brecks land management arrangements.
- Reversion to alternatives to agricultural production with potential to increase in woodland planting.
- Arable reversion to species-rich grassland across the wider catchment in the Broads and marshes in the estuarine area could increase the resilience of the land to droughts and floods. Current management of the grassland and marshes will help understand the resilience of grasslands.

Currently, traditional grazing and water level management in the Broads has led to the development of species-rich grassland vegetation which still survives in some of the less intensively managed parts of the system, so may be more resilient to impacts of drought. Permanent grasslands often require several years to return to normal after a severe drought. The diversity of the grassland managed, including mix of flora, number of animals, fertilisation, and the rotation between pasture and cutting, will heavily influence regeneration.

Grazing is vital to keep the marshes in a favourable condition because it stops the natural succession and reversion of the marshes to scrubland, whilst delivering biodiversity benefits even on small scales, including habitat for bird species such as lapwing, redshank, pink footed geese, wigeon, and golden plovers. For example, the Valentines Meadow arable reversion of only a 7 ha block of former arable land located on the valley sides has developed a natural flora, with annual cut controls have allowed for a colony of marsh and bee orchids to thrive, breeding skylark have been found to favour the low cut vegetation, and the area has become a hunting ground for brown hares. This land provides some flood control as it produces little water runoff and zero contribution to diffuse pollution (The Broads Authority, 2009).

Reactionary Response Scenario

In this scenario, business as usual would occur until the threshold takes place, in which both low-regret actions and transformative adaptive measures would be implemented as outlined in the Early Adaptation scenario.

6.3.2 Threshold B – Coastal storm events and flooding

Plausible impacts on land use arising from Threshold

The impact of coastal storm events and flooding would cause soils to be at field capacity with localised flooding, increasing soil runoff and erosion, impacting the yields and quality of agricultural land and its outputs. Crops may be waterlogged, causing reductions and yields and waterlogged grasslands may cause impacts on the productivity of the grasslands, impacting the health of the livestock, in some cases leading to increased mortality.

No change for wooded areas outside of coastal impact areas.

Other impacts can include:

- Nutrient loading of water and sediments discharging into the Broads water systems and increase near-shore plumes of nutrient-loaded soils/sediments discharged from watercourses. This pollution can cause impacts on the abiotic and biotic aquatic ecosystem.
- Impacts on breeding success of waders or ground nesting birds reducing biodiversity value.
- Increased tidal flood and erosion risk particularly to coastal/low-lying communities.
- Loss of beach and accelerated erosion impacting flood risk, habitats and amenity recreational value.

See Section 4.1.2 Flooding for further discussion on the plausible impacts.

Business as Usual Scenario

In this scenario, the land use mix would experience a 5% shift from arable land to less favourable area (pastoral land) reflecting a decline in the quality of some land resulting from no adaptation actions being implemented over the reference period

The threshold would mostly impact the agricultural land since the lack of capacity for water level management in storm events would waterlog the land reducing crop yields and productive grassland, as described above. It could also lead to loss of heritage sites and uncontrolled extension of intertidal areas increasing mudflats and saltmarsh.

However, the natural regeneration of storm damaged areas may create enhanced biodiversity opportunities. Furthermore, saline intrusions could negatively impact areas of freshwater biodiversity creating diverse habitat in brackish conditions. These are a few trade-offs identified by stakeholder that can occur but further site-specific research would need to be completed to better understand the benefits and costs.

Anticipatory Scenario

A catchment sensitive farming approach and reconnecting watercourses with the flood plain could help to mitigate against flooding, which in turn would potentially reduce the extent of arable income but derive wider benefits of biodiversity, water quality and others. Actions to support reconnecting watercourses to the floodplain would include river restoration to re-meander watercourses, cease dredging activities, removal of any hard defences or embankments, and other activities.

Management practices would seek to manage overtopping of flood banks and an associated responsive drainage system to minimise short-term impacts. Active management of Carr woodland, including clearance and water regime management (flow and level) could enhance Fen habitat and make it more resilient. There is also potential scope for increasing extent and/or quality of fen habitat or Carr woodland/scrub. The Carr woodland is dominated by alder, sallow, and birch trees, with shrubs such as guelder rose, buckthorn, dog rose, and brambles. It is a damp and shady area with an abundance of ferns, mosses, liverworts, lichen, and fungi. The important communities of alder trees have characteristically wet ground conditions. Protecting, enhancing, or increasing the Fen habitat and Carr woodland could increase the natural capital stock of fen peat soils which are rich in carbon.

Other adaptive land use changes can include:

- Facilitated landward movement of grazing marsh or pasture (impacting on Arable and other land-use types)
- Managed extension of intertidal areas, increasing mudflat and saltmarsh areas
- Loss of beach and increased coastal squeeze.
- Overall species composition shifts but larger areas sustain overall net biodiversity interest. Impacts on breeding success of ground nesting birds mitigated by landward movement of pasture or reconnection with flood plain (reducing arable or other land-use types).

Reactionary Response Scenario

In this scenario, business as usual would occur until the threshold takes place, in which transformative adaptive measures would be implemented as outlined in the Anticipatory scenario.

Late adaptation will largely delay necessary changes although where degradation occurs then constructive adaptation options could be limited (eg; through soil/peat loss, erosion, eutrophication, disease etc). Eutrophication, salination and desiccation of more marginal land-use types will be much more difficult to mitigate. Management of Coastal Squeeze and Shoreline Management Plan (SMP) policies will have a significant impact on coastal and near-shore land-use types.

6.4 Economic assessment

The Threshold chosen to be represented in the economic assessment was threshold B. The narrative introduced in Section 6.3.2 Threshold B – Coastal storm events and flooding has attempted to be represented in the economic assessment but could not be completed comprehensively. Therefore, this economic assessment should be considered separately.

A summary of the inputs and timing assumptions for all scenario is listed in Table 6-3.

Table 6-2 – Summary the economic assessment for each scenario for Threshold B

	BAU	Assumption	Early intervention	Assumption	Reactionary	Assumption	
Threshold event	2050 over 5 years	Defined by project team	2050 over 5 years	Defined by project team	2050 over 5 years	Defined by project team	
Intervention point	n/a		2030 over 5 years	Changes in land use take time to be realised.	2050 over 55 years	Changes in land use take time to be realised.	
	BAU		**Early intervention**		**Reactionary**		
	Change assumptions	**Costs and benefits**	**Change assumptions**	**Costs and benefits**	**Change assumptions**	**Costs and benefits**	**Limitations**
Threshold impact	30% of cereals land area damaged due to flooding. Climate hazard threshold impacts based on expert opinion of PGA stakeholder group.	Productivity losses due to flooding and saltwater inundation estimated by Morris et. al. (2009) as £850/ha/annum.	15% loss of cereals land area. Climate hazard threshold impacts based on expert opinion of PGA stakeholder group.	As BAU	30% of cereals area (ha) lost. Climate hazard threshold impacts based on expert opinion of PGA stakeholder group.	As BAU	Assumed level of impact in terms of % affected under the threshold event.
Carbon sequestration	Change in carbon sequestration rates based on change in area by land cover type. Carbon sequestration rates by land cover based on a range of sources including Christie et.al. (2010).	Carbon unit price taken from BEIS non-traded carbon price.	As BAU but with amendments in landuse proportions taken into account.	As BAU	As BAU up to threshold event. As Early Intervention after threshold event.	As BAU	Unable to model the change in carbon sequestration in the peatland. Reduction in fertiliser use and other greenhouse gases associated with reduction in arable land excluded from analysis.
Agricultural productivity	Costs relate to additional pesticide and fertiliser applications needed to counteract the impacts of climate change on crops.	Costs increase (by 10%) by the threshold event. After the threshold event costs increase by 30% by 2100. Rate based on expert opinion of PGA stakeholder group.	Improved resilience resulting from adaption interventons assumed to decrease level of required pesticide and fertiliser use.	Costs increase (by 5%) by the threshold event. After the threshold event costs increase by 15% by 2100. Rate based on expert opinion of PGA stakeholder group and assumed to be lower than the BAU.	BAU up to threshold flood (10%). Reversion to Early Intervention values (15%) by 2100.	Increases in agricultural costs are assumed to follow the BAU scenario up to the threshold event, but revert to the Early Intervention Scenario after the threshold event as the intervention benefits are realised.	Reduction in greenhouse gases associated with reduction in arable production excluded from analysis.
	Decline in benefits relate to crop failures/drought and flooding under the climate scenario.	Agricultural incomes are expected to reduce (by 10%) gradually by the threshold event. After the threshold event incomes deteriorate by 10-30% by 2100. Rate based on expert opinion of PGA stakeholder group.	Benefits assumed to decrease by a lesser extent than BAU scenario due to adaptation interventions improved resilience of natural environment	Agricultural incomes are expected to reduce (by 5%) gradually by the threshold event. After the threshold event incomes deteriorate by 10% by 2100. Rate based on expert opinion of PGA stakeholder group and anticipated to be lower than the BAU.	BAU up to threshold flood (10%). Reversion to Early Intervention values (15%) by 2100.	Decline in farm incomes follows the BAU scenario up to the threshold event. Beyond this, intervention options minimise any further decline and revert to the values used by the Early Intervention option by 2100.	Cost increases and production losses assumed and tested as part of sensitivity testing. Agricultural subsidies ignored but tested as a sensitivity test.
Other environmental benefits	Woodland and saltmarsh areas considered.Change in ecosystem services supply rate based on the change in area for each.	Benefit values based on a range of sources including Eftec (2016) and Eftec (2010). Linked to land use areas.	As BAU with the addition of the converted 1% of arable land to saltmarsh.	As BAU	As BAU with the addition of the converted 1% of arable land to saltmarsh.		Cannot model water quality reductions in isolation, including saline intrusion from small coastal breaches.
Timber sales	Rate of provisioning services from woodland assumed constant throughout reference period.	Timber prices based on Nix, 2016 . Incomes relate to thinning and clear felling activities.	As BAU	As BAU	As BAU	As BAU	Timber sales increase as trees mature built into the analysis by provision of a a 25 year lag.
Recreation	Recreational benefits included but static over the appraisal period.	Values estimated using ORVal (Outdoor Recreation Value) .	As BAU	As BAU	As BAU	As BAU	The impacts of saline intrusion may influence water quality and landscape that reduce tourism benefits. This aspect is excluded from the assessment.
Land use change	5% decrease in arable land. Loss of arable land converted to LFA pastoral.	Land use change assumed to occur naturally - no managed change or cost of change.	5% decrease in arable land. Loss of arable land converted to semi improved grassland (80%). Loss of arable land converted to saltmarsh habitat (20%).	Managed change in land use, therefore costs of this change assumed. Cost estimates based on Environment Agency (2015)	5% decrease in arable land. Loss of arable land converted to semi improved grassland (60%). Loss of arable land converted to saltmarsh habitat (20%). Loss of arable land converted to LFA grassland (20%) due to delay in action.		No readily available information on how recreational values will change with changes to the land use or in absolute terms.

6.4.1 Summary of land use change within the economic appraisal

The summary of how the land use changes under each scenario at the end of the appraisal period is shown below, although this misses the fact that the anticipatory option provides some of the mitigatory land use changes (e.g. woodland) from an earlier time point).

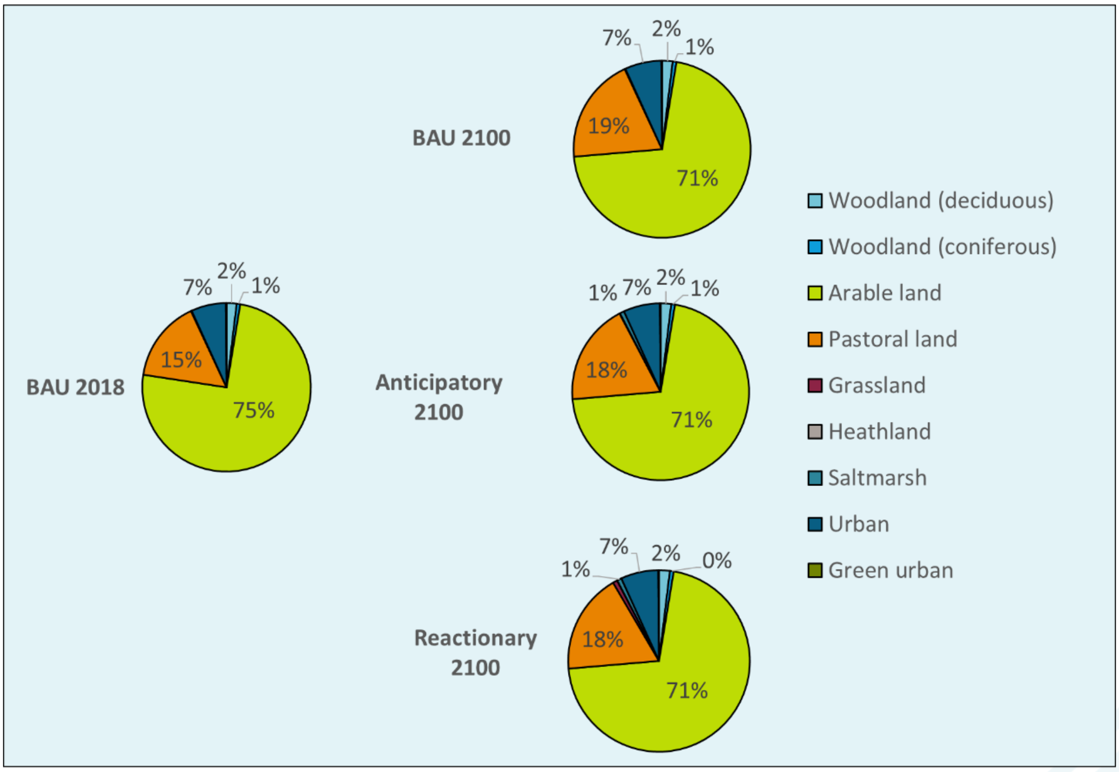

Figure 6-3 – Land use change

6.4.2 Outcome and interpretation of benefit-cost calculations

The summary of the benefit-cost and net present value calculations for the Norfolk and Suffolk Broads case study are provided for each scenario in Figures 6-6 to 6-8. These represent cash costs (not Present Values) to allow the differences to be distinguished over the appraisal period. A comparison of net benefits for each option is provided graphically in Figure 6-9.

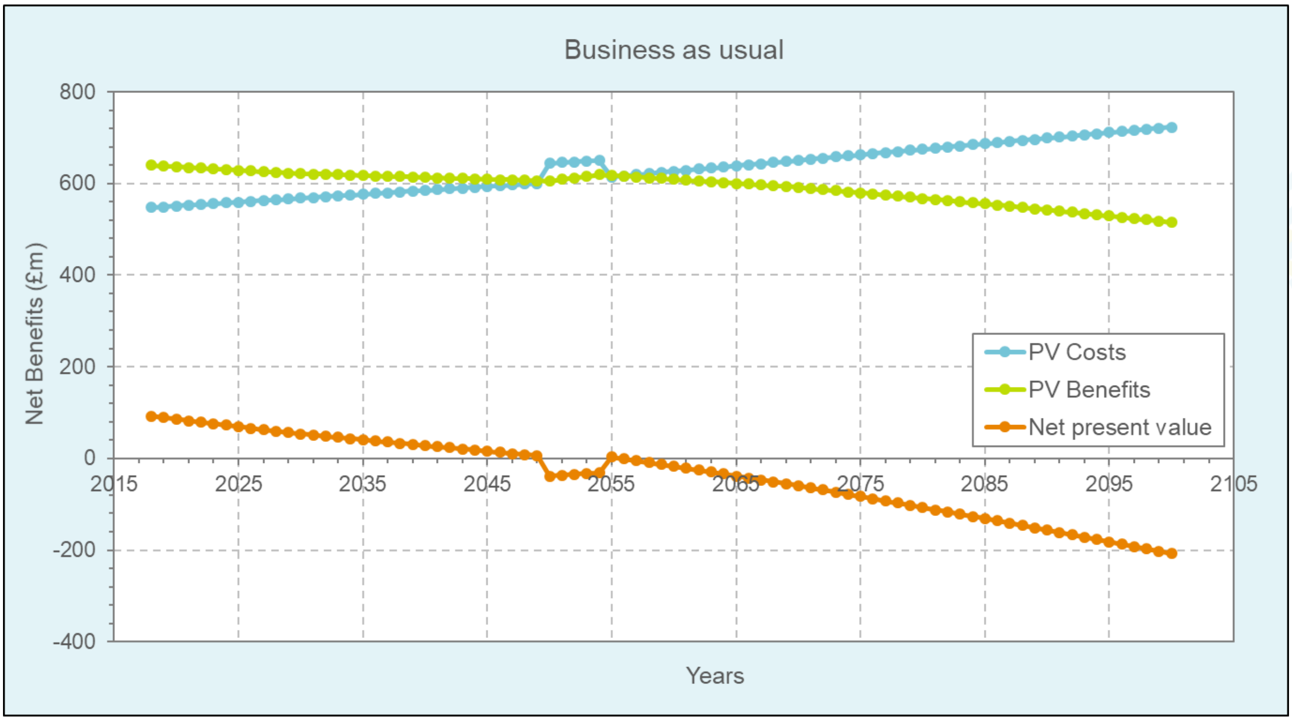

Figure 6-4 – Total costs and benefits for the BAU scenario

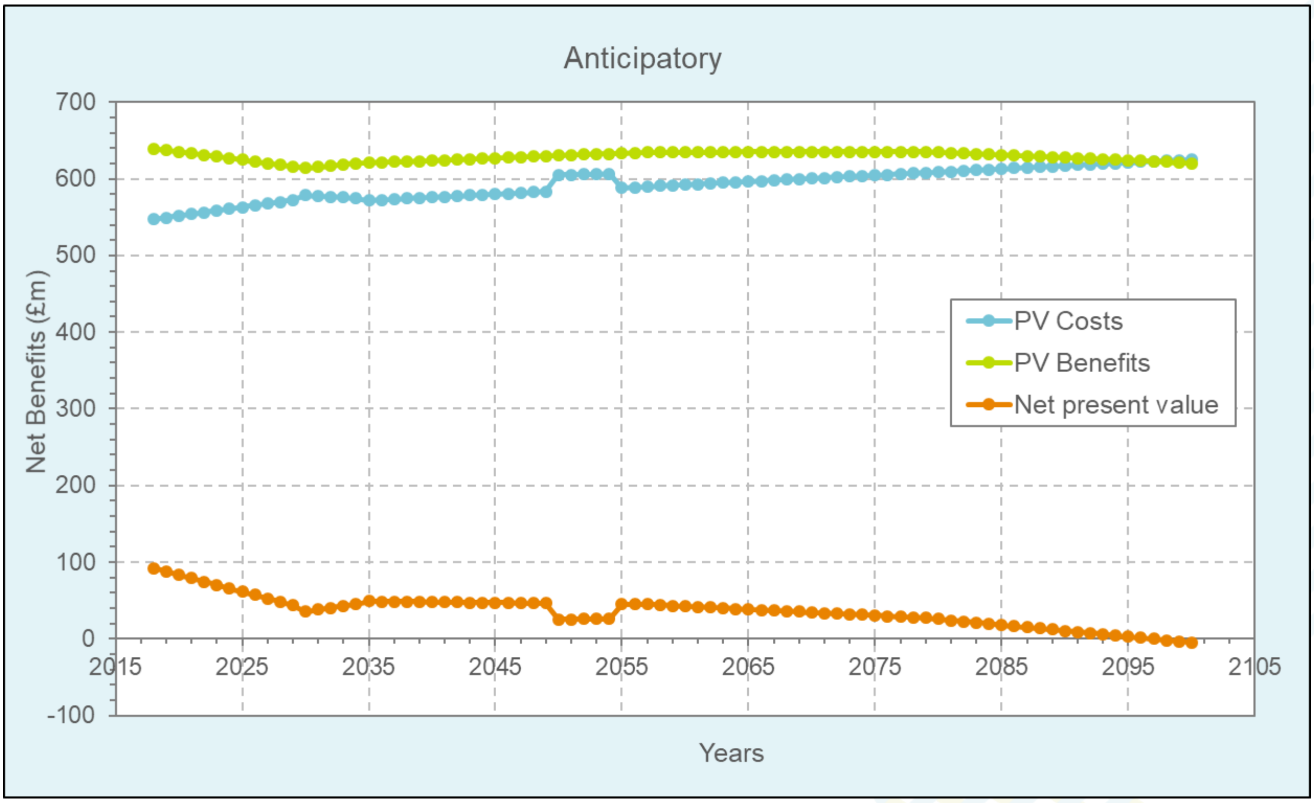

Figure 6-5 – Total costs and benefits for the Anticipatory scenario

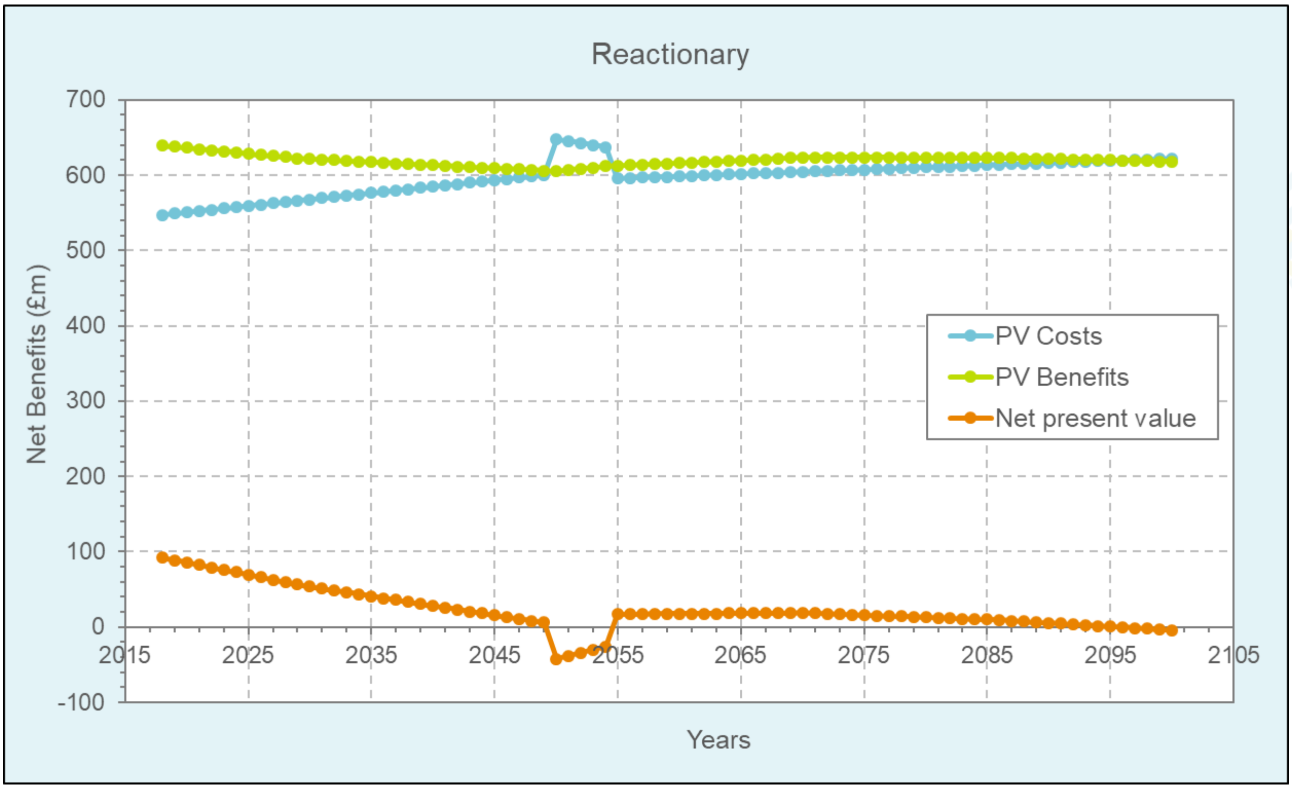

Figure 6-6 – Total costs and benefits for the Reactionary scenario

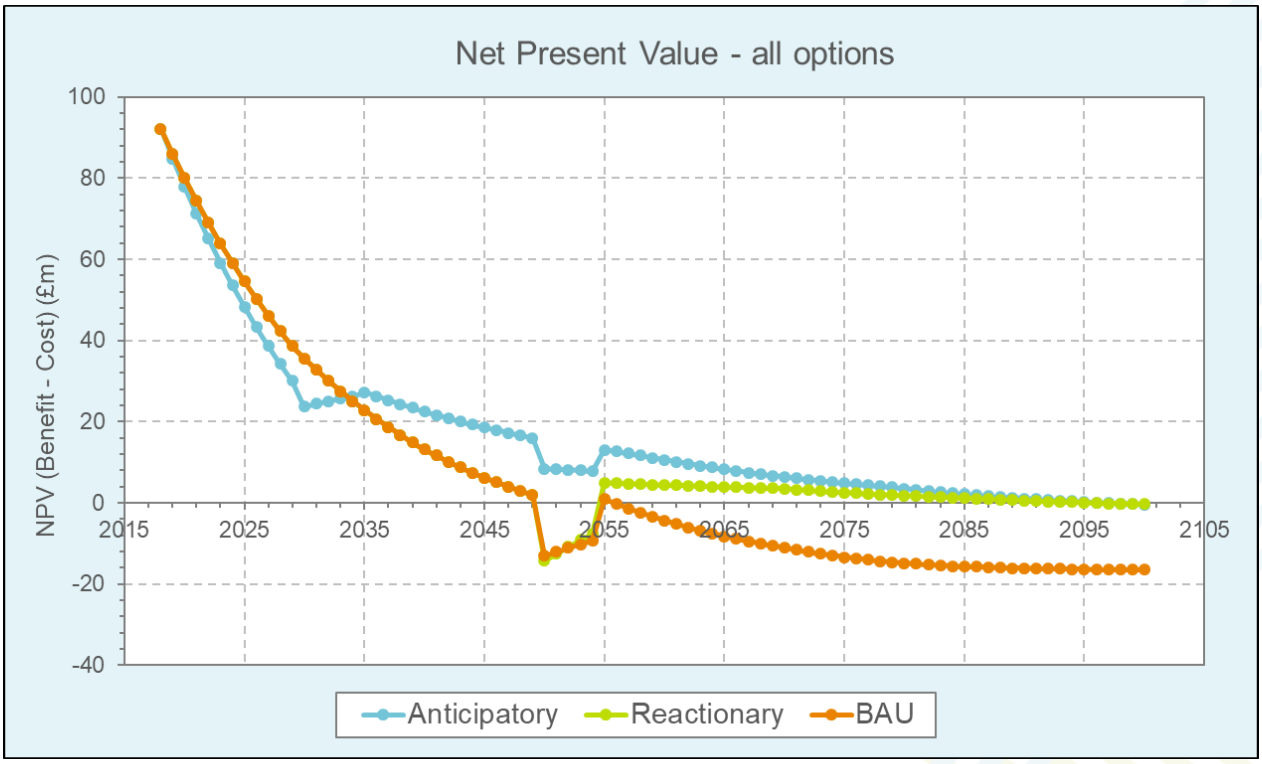

Figure 6-7 – Comparison of net benefits for each scenario

Total NPV's for each scenario are also provided in Table 6-6.

Table 6-3 – Summary of whole life Net Present Values (£m)

Scenario	PV Costs	PV Benefits	Net present value	Benefit of option
Business as Usual	£17,110	£17,580	£470	-
Anticipatory	£16,630	£18,030	£1,410	£940
Reactionary	£16,730	£17,850	£1,120	£650

The results can be summarised as follows:

- This case study is strongly influenced by the agricultural aspects included in the economic calculations. As such the results may be influenced by some of the assumptions used in the analysis. It is recommended that these are fully tested as part of further analysis.
- The BAU suggests that the costs start to outweigh the benefits by the 2050's; enhanced by the additional costs associated with the threshold event. This is partly due to the fact that subsidies are excluded from the agricultural calculations as standard. The inclusion of these will presumably push back the switch when costs exceed benefits, if the subsidies were to favour food over non-food agricultural production. Overall the whole life NPV equals £470m.
- The anticipatory scenario of climate resilient land use and agricultural practices suggests that the natural capital benefits can be enhanced when compared against the BAU case. Overall the whole life NPV equals £1,410m – a significant enhancement over the BAU.
- The reactionary scenario suggests that the implementation of changes to land use can offset the losses associated with the BAU scenario but not as efficient as the anticipatory option. Overall the whole life NPV equals £1,120m.

Table 6-6 shows that over the life of the appraisal period the benefits of shifting to an anticipatory option are significant. Most of these benefits are because of a reduction in agricultural costs and greater agricultural income, with more marginal increases in carbon sequestration and other environmental benefits. This is shown graphically in Figure 6-8.

The changes to agricultural activity assume a cost increase to keep up with the impact of climate change (e.g. higher pesticide use) and farm incomes deteriorate due to reduced or less reliable yields. Under the anticipatory option these changes are reduced (due to better management practices and a change in land use) thus reducing costs and improving incomes when compared to the BAU scenario. The same occurs for the reactionary scenario, but the benefits of this occur later in the appraisal period.

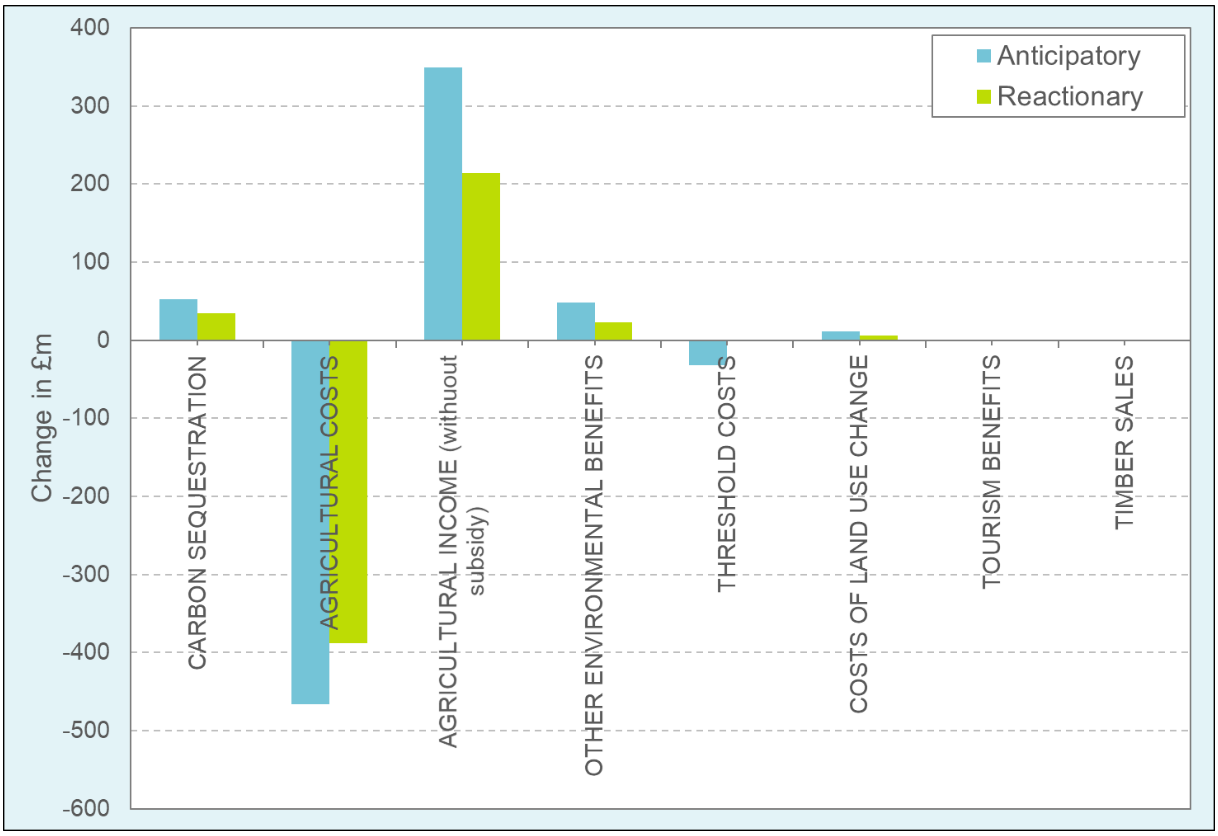

Figure 6-8 – Present value change in natural capital components

6.4.3 Sensitivities

This case study is strongly influenced by the agricultural aspects included in the economic calculations. Some of this will be due to the fact that subsidies have been removed from the analysis and the impact of this has been tested in the following section.

It is also clear that the agricultural costs reduce substantially over the period of analysis (particularly with the anticipatory option). This is caused partly by the assumptions regarding the changes in agricultural costs (and reduction in income) under climate conditions. These assumptions are tested further below Section 6.5.5.

6.4.4 Results with agricultural subsidies

A sensitivity test was undertaken with the inclusion of subsidies for the agricultural income aspect. The comparison between annual costs and benefits is repeated and provided in Figure 6-10. This shows that there is an uplift in the overall benefits which enhances the total NPV for all scenarios assessed; the inclusion of agricultural subsidies does not however change the overall pattern of results.

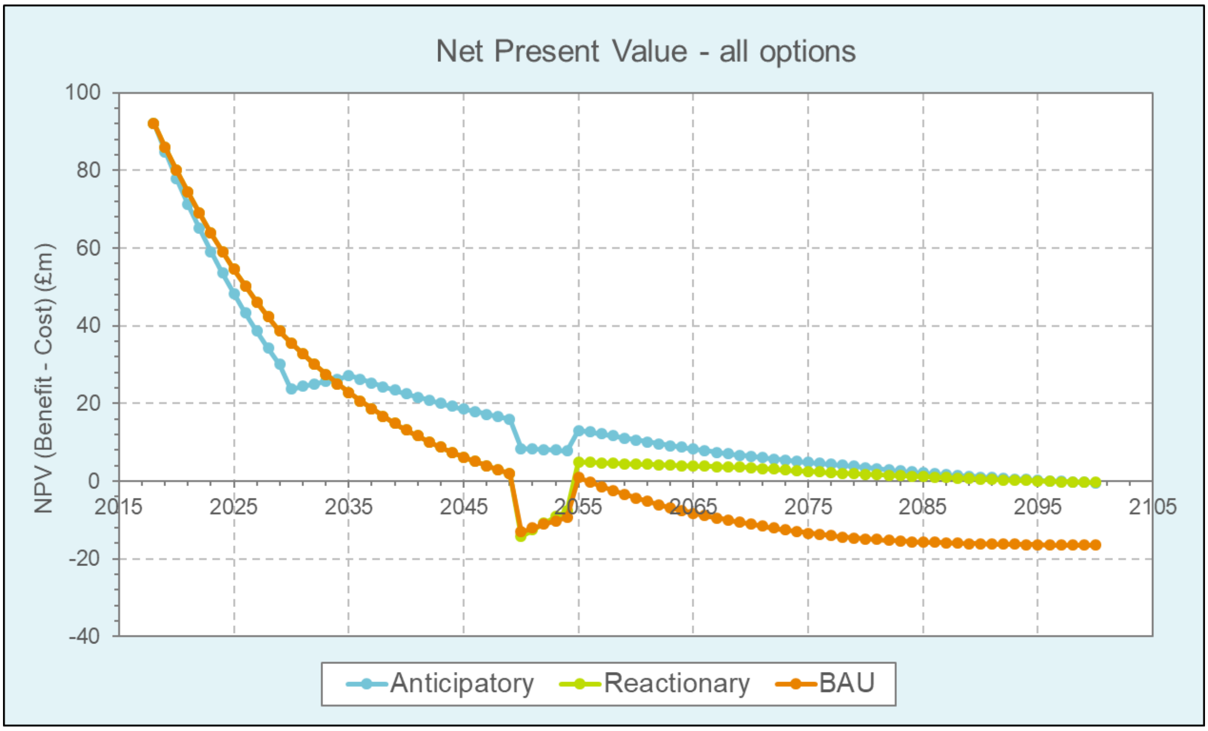

Figure 6-9 – Comparison of net benefits (cash) for each scenario

6.4.5 Sensitivity test on agricultural cost/income 'levers'

It is anticipated that both the costs of maintaining agricultural land types and the income received from these will increase and decrease respectively with climate change. Whilst it has been possible to estimate this impact for some land types under the business as usual scenario, a set of 'levers' have been used in the tool to force these impacts and to change them for each scenario. These are relatively blunt tools in the absence of more detailed information or more detailed methodologies (outside the scope of this assessment). They have therefore been subject to a sensitivity test to quantify the impact on the overall analysis.

The increase in costs and reduction in income for this test is half of what was assumed under the current scenarios. The results of a test on a lower impact of agricultural costs and income are shown in terms of the long term NPV in Figure 6-11. This suggests that under this test, the overall Business as Usual case is more robust with higher benefits and lower costs. Overall the pattern between scenarios is similar although the anticipatory option and reactionary scenarios have much higher long term NPV's.

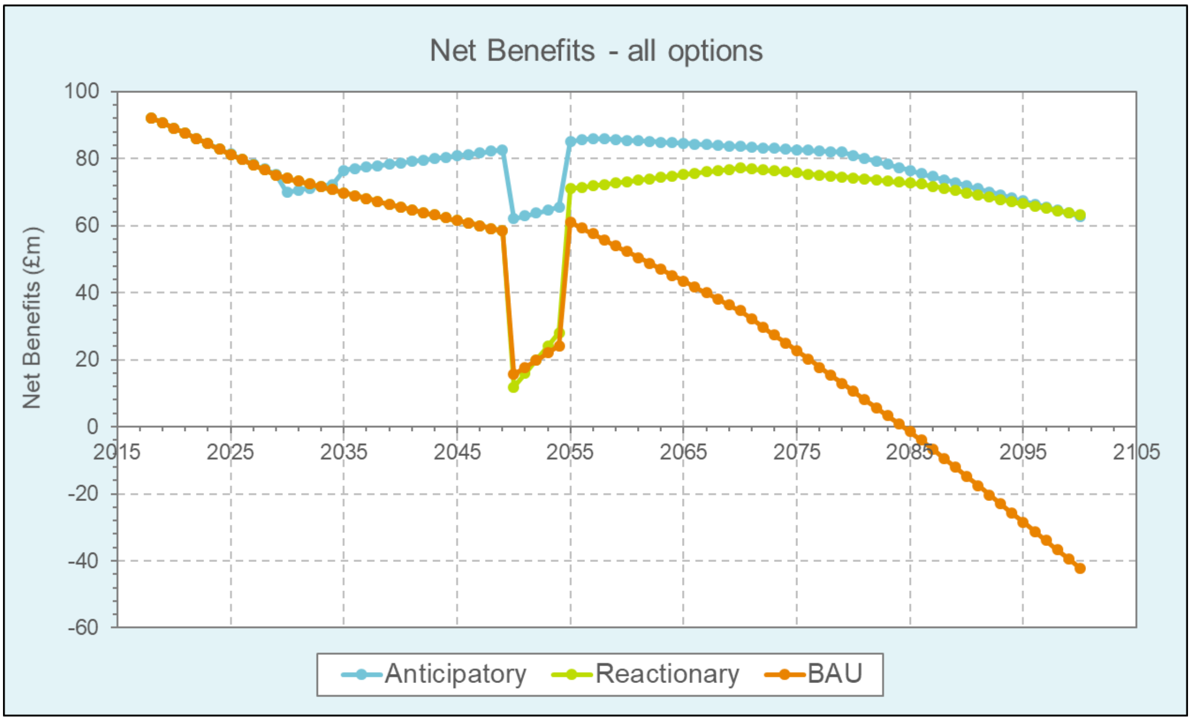

Figure 6-10 – Net benefits - comparison between scenarios

6.5 Maximising carbon sequestration

To maximise carbon sequestration, you would maximise the amount of wet woodland which has the highest carbon storage. However, this requires a high water table. Therefore, wherever high groundwater levels can be maintained, you would continue this management so the accumulation of organic matter can exceed peat breakdown, leading to peat growth (Broads Authority, n.d.).

Table 6-4 Carbon storage in biotic environments (The Broads Authority, 2010, p.39)

Biotic environment (Habitats)	Stored CO2e (tCO2e)	As % of Total	C Density (t CO2e ha-1)
Woodland/Dense Scrub	936,234	88.9%	224
Marsh/Fen	17,384	1.6%	7
Arable/Cultivated Land	43,416	4.1%	5
Grassland/Pasture	56,660	5.4%	4

The Broads Authority's Greenhouse Gas strategy identifies woodland and afforestation as having the highest potential for carbon sequestration on account of the high percentage of CO2e already stored in woodland and dense scrub (see table 6-6) and the cost-effective nature of woodland planting. That said, however, it is important that afforestation does not compromise the waterlogged peat soils or peat-rich fens and should take place on shallow organic or mineral soils to avoid the need for any drainage associated with land preparation.

Carbon storage in earthy peat soils accounts for approximately 65% of the total carbon 39 million t CO2e stored in soils in the Broads, highlighting the importance of conserving such soils, which cover approximately 9,000 ha across the Broads National Park area (The Broads Authority, 2010). Dawson & Smith (2007), propose a range of best practice land management methods to preserve existing carbon stores in soils and sequester further carbon (see Table 5-5). In their GHG Reduction Strategy, the Broads Authority acknowledges that it would be preferential to focus efforts on preserving and enhancing the fen peat soils, which are rich in carbon, rather than typical agricultural soils, which are limited in their potential on account of the risk of food production being displaced. Drainage of large areas of peat in the Broads has resulted in significant carbon losses, therefore the Broads Authority in 2010 identified four practices that could be implemented immediately:

- "enhancing the protection and ultimate restoration of wetland soils by reducing the level of drainage and by blocking a suitable proportion of drainage ditches;
- reducing the level of mechanical disturbance, cultivation and extraction;
- controlled/reduced burning, re-vegetating bare surfaces and taking actions to promote re-colonisation, so as to prevent wind and water erosion; and
- rehabilitating acidified surface waters;" (The Broads Authority, 2010)

Although these practices can preserve existing carbon stores in soils and sequester further carbon, greater amount of fen peat soils will have higher water tables and consequently may cause a reduction in flood storage and also more methane emissions in the short-term (Bonn et al., 2014).

7 Petteril, Cumbria

The River Petteril is a tributary of the River Eden in Cumbria. It is part of the Eden catchment, with a total catchment area of approximately 2,400 km^2. The source of the River Petteril is near Penruddock and Motherby, and Greystoke, flowing north through Blencow, Calthwaite, and Southwaite, running parallel to the M6 motorway towards Carlisle, where it joins the River Eden. The Petteril catchment covers an area of 160 km^2 (16,075 ha).

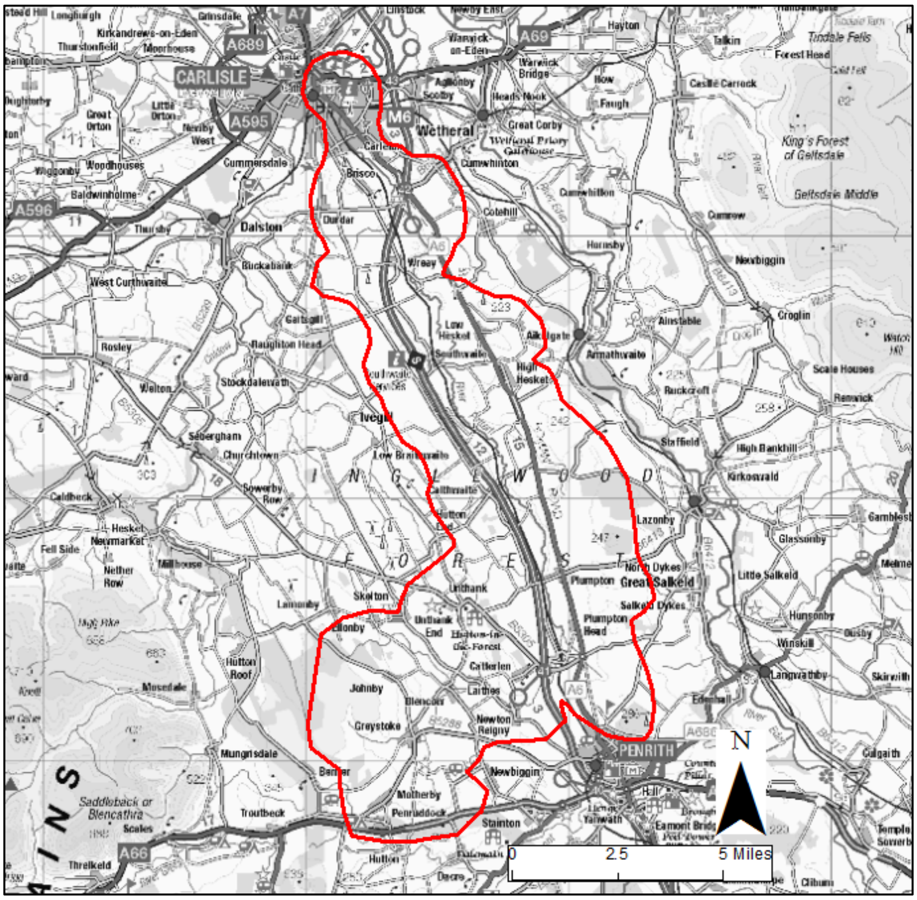

Figure 7-1 – Petteril catchment

The Petteril catchment neighbours the Lake District National Park, Yorkshire Dales National Park, and North Pennines Area of Outstanding National Beauty (AONB). It is not designated itself. It is characterised by its mix of arable and livestock farming. The majority of the River Petteril has a 'Moderate' Water Framework Directive (WFD) status. Upstream, nearer to Greystoke is 'Good' and it is 'Poor' for a section along Blackrack Beck. There is high to very high risk of diffuse pollution, high levels of riparian damage and little bankside cover due to intensive grazing. There is also runoff from the M6 motorway and urban expansion of Carlisle.

7.1 Petteril: Stage 1

The most recent open data available for land use in the Petteril is the CORINE 2012 dataset. The CORINE 2012 maps show that approximately 90% of the land in the Petteril catchment is used for farming, arable, livestock, or grassland. 64% of the farmland is used for livestock. The majority of farming in the catchment is dairy and beef.

The CORINE 2012 dataset uses European designations and is at a broad scale; it, however, does not account for small coppices and areas of woodland in pastoral land, which makes up a sizeable area when added together in the whole catchment.

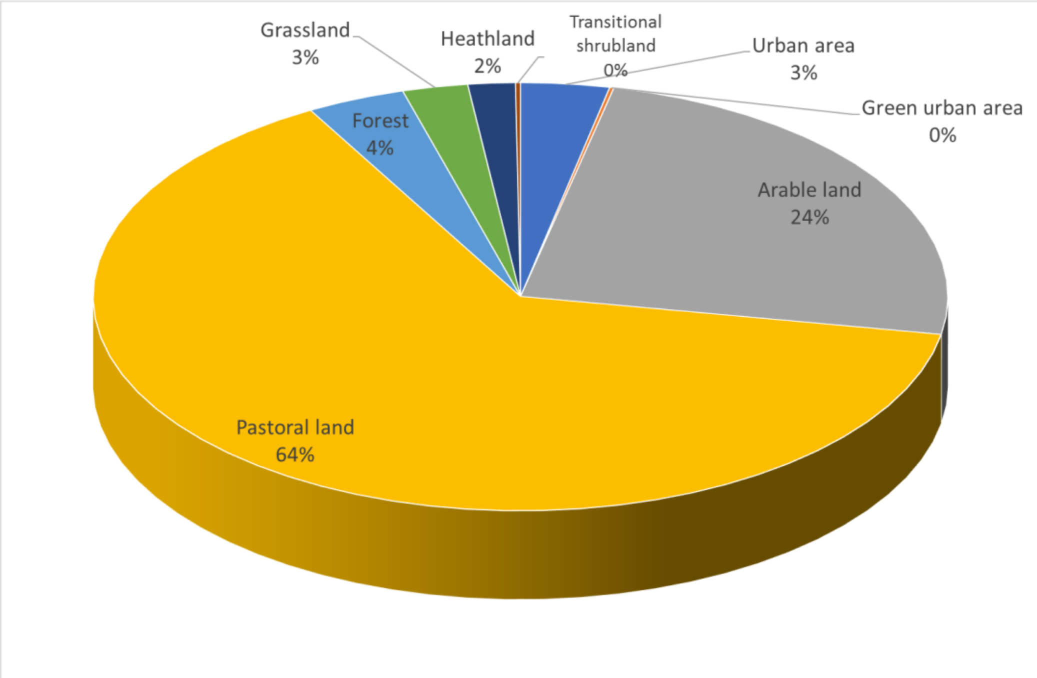

Figure 7-2 – Percentage land use cover in the Petteril (Corine 2012)

In the opinion of the local stakeholders, the most valuable aspect for the primary farming land use is the area's soils. The soils allow the area to be productive in grazing, crop production, and livestock. The soils are generally sandy loam soil, but also are vulnerable to climate change since sandy soils have a lower retention of water. The soils on Lazonby Fell and Wan Fell are very sandy.

The value of the recreation is low since there is little public access into the countryside making leisure activities such as horse riding or recreational walks limited. The neighbouring Lake District National Park, Yorkshire Dales National Park, and the North Pennines AONB cater and manage for recreational uses. One recent addition and successful recreational activity was the opening of a Go North and Ride (GNAR) Mountain Bike Park in May 2016 in woodland in the catchment.

With historically limited public access across fields, it is considered there would be landowner and farmer resistance to changing the access arrangements.

The aesthetics and landscape value is high although not as high as the surrounding designated areas. The designations of the neighbouring two National Parks and the North Pennines AONB support the Petteril's landscape value and its character supports their value. A wind farm application was rejected in the area due to its impact on the neighbouring AONB, in that it would obstruct views of the North Pennines.

According to the Wild Trout Trust report, electrofishing surveys showed there are poor juvenile trout numbers and no juvenile salmon.

Approximately 50% of the Petteril is a designated Nitrate Vulnerable Zone (NVZ), as seen in the screenshot below.

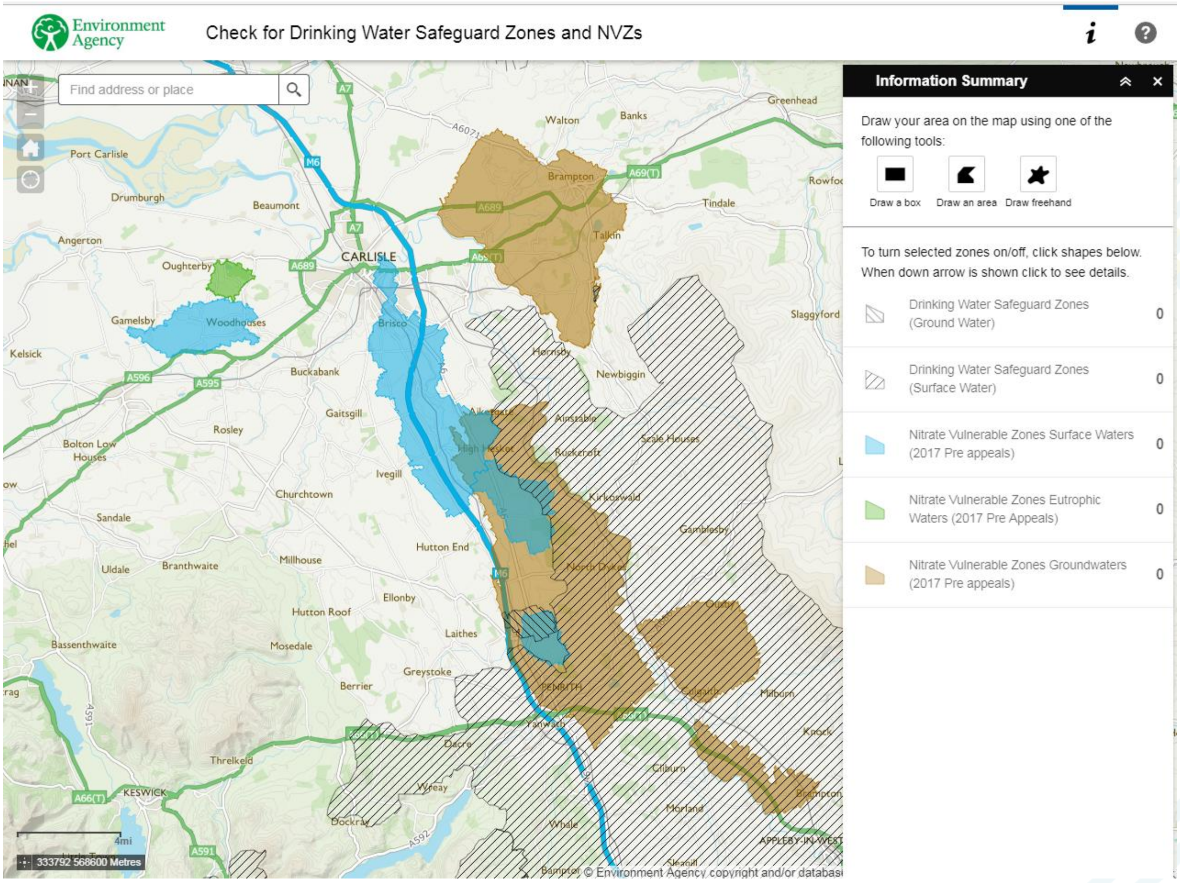

Figure 7-3 – Screenshot from Environment Agency's Drinking Water Safeguard Zones and NVZs

The Eden Catchment Flood Management Plan details that the flood risk to people and property is low within the Petteril catchment with approximately 50 properties at risk in a 1% APE from the main rivers. It also suggests that large-strategic scale storage to reduce flood risk in Carlisle is not considered viable in the Petteril; however, land management to reduce surface runoff may have some positive benefits on reducing flood risks.

Below is a summary of the land use and land management of the Petteril catchment.

Table 7-1 – Summary of land use, land cover, and land management in the Petteril catchment

Land use	Land cover and land management
Arable	- Cereals, maize for dairy cows and biofuels - General cropping - Catchment Sensitive Farming
Productive grassland	- Mostly dairy farming - Sheep - Cattle
Woodland	- Deciduous - Coniferous - Recreation
Watercourses and water bodies	- Biodiversity - Water quality - Recreation / aesthetics

7.2 Stage 2 and 3: Petteril

The following thresholds have been identified through the climate change projections and the research reviewed in Section 4.1 Review of Agricultural Land Use and Climate Change Impacts above. Both flooding and a combination of drought and a heatwave are plausible climate events which have occurred in the past and are plausible in the future. With a predominantly agricultural landscape (pastoral and arable), these climate thresholds could have a major impact on the agricultural landscape, reducing productivity and resulting in a change in land use.

The plausible thresholds identified are:

- Threshold A:
    - Climate context: Warmer and drier summer seasons
    - Antecedent conditions: 3 years of drought[20]
    - Summer heatwave
- Threshold B:
    - Climate context: Warmer and wetter winter seasons
    - Antecedent conditions: Three seasons in five years of winter/spring waterlogging of fields and/or fluvial flooding that causes the crops and grassland to be submerged for more than 14 days

7.3 Stage 4: Petteril

The narrative introduced in this Section is independent of the economic assessment and should be assessed independently. This narrative will introduce other factors that were unable to be represented in the economic assessment.

7.3.1 Threshold A: Warmer and drier summers plus repeated summer droughts

[20] Plausible droughts in the UKCCRA2 High++ Scenarios.

Plausible impacts on land use arising from Threshold

The impact of drought on both arable and grassland management would be to increase costs and to reduce yields. Failed germinations and post emergent crop failures will lead to losses and cost increases. Furthermore, dry exposed soils will be prone to erosion when the drought breaks leading to long term loss in soil fertility.

As previously cited, increased frequency and intensity of extreme events such as droughts and flooding, would lead to greater production losses than any increase in mean temperature over the coming decades (Wreford and Adger, 2010). Furthermore, extreme events such as Threshold A which carries the impacts from year to year could cause an extreme negative impact.

See Section 4.1.1 Drought and heat stress for further discussion on the plausible impacts.

Business as Usual Scenario

The BaU Scenario involves the continued mix of arable and stock farming with no increase in the area of woodland.

With no interventions, maize production is likely to increase due to warmer temperatures (Brown et al., 2016) in the Petteril. The data from the ALC classification projections (Keay et al., 2014) show that the agricultural land will become more productive when solely taking into account temperature change. Increased maize production would need to avoid more sensitives sites (e.g. steep slopes) since in these locations there is likely to be negative impacts from soil erosion (Brown et al., 2016). Overall the ALC classification (ALCLIMIT2) shows a decline of classification (ALC Grade 2 to Grade 5) within all low, medium, and high emission scenarios. The limiting ALC criteria is droughtiness (ALC_MORECS) with the greatest change occurring between 2030 and 2050 with continuing decline to 2100.

In this scenario, we assume that the threshold will occur, resulting in the impacts outlined above. However, this BaU scenario assumes the land use would remain similar, with potential low regret adaptation measures implemented. The costs associated with warmer temperatures and drought include additional shade provision for livestock, cooling and ventilation systems if livestock are housed indoor, costs of labour and machinery to relocate livestock, cost of feed and storage and the costs of waste management. Any livestock mortality due to heat stress will also reduce long-term farm profitability.

Anticipatory Scenario

To adapt to this climate threshold, management practices would need to take up advances in availability and use of drought resistant varieties of cereals, grasses and maize. Investment in additional on-farm water capture and management assets (e.g. on-farm water storage and irrigation systems) would be likely.

Adaptive land use would involve a gradual move towards new crops such as sunflowers, grain maize, soya, and horticulture (fruit and vines). However, there could plausibly be a reduction in the area of farmed land with a move towards agro-forestry and woodland to secure long term stable incomes, both of these being more tolerant of drought and heat-stress. Riparian woodland would also provide more shade for the water environment to reduce the increase in water temperatures and minimising the impact on the ecology. Any change in land use from agricultural land should be taken from the lowest quality in order to maximise the benefits of the new land use and minimise the costs of conversion or loss of income.

In this scenario, we assume the threshold will occur after the change in management practices and land use reducing the impact of the threshold.

Reactionary Response Scenario

In this scenario, business as usual would occur until the threshold takes place, in which transformative adaptive measures would be implemented as outlined in the Anticipatory scenario.

Introducing adaptive land use measures of increasing agro-forestry and woodland of more drought-tolerant species from the lowest quality agricultural land proceeding the threshold can cause profit losses. Since the Petteril is a largely agricultural catchment, drought and extreme heat will cause the livestock to be vulnerable and certain crops to wither in the heat, even if profits due to increasing maize will lessen the costs to the livestock. There will also be a reduction in the available land in the short-term able to convert the arable fields or grasslands to agro-forestry and woodland due to the increased soil erosion that may require remediation before the conversion of land use.

7.3.2 Threshold B: Flooding

Plausible impacts on land use arising from Threshold

The impact for arable land include would include reduced yield in the year of the flood, increased costs associated with replacement crops, restoration costs, and additional costs for fertilizers and sprays (Elliott, 2014).

The impacts of flooding on grassland would include increased costs of labour and machinery to relocate livestock, costs of additional labour needed for housing of livestock, additional costs of conserving feed for housed stock plus costs for purchased feed over and above estimated forage losses and any direct losses from increased livestock mortalities (Elliott, 2014).

Other damage costs would include damages to the farm assets, loss of soil fertility through waterlogging, and trafficking on wet soils (Elliott, 2014).

See Section 4.1.2 Flooding for further discussion on the plausible impacts.

For the purposes of the Stage 4 economic appraisal, it is considered there would be a one-off loss in production from the farmland, varying between 10 and 30% dependant on land use. Woodland would not be adversely affected with the impact of the threshold event.

Business as Usual Scenario

Business as usual would involve the continued mix of arable and stock farming with no change in land use.

Similar to BaU for Threshold A, maize production is likely to increase regardless of climate hazards due, according to local stakeholders, due to its greater productivity in the increasing temperatures. However, as a result of threshold B occurring, there would be increased costs associated with housing livestock during storm events, the costs of labour and machinery to relocate livestock, the costs of feed and storage, and the costs of waste management would all be new farm business costs. Additionally, there would be further costs associated with the loss of crop, waterlogging of the soils reducing crop productivity which may reduce long term farm profitability.

Early Adaptation Scenario

To adapt to climate Threshold B, land use change could minimise the impact on overall agricultural productivity. A switch away from arable to a mix of productive grassland for forage and to wet grasslands in the high flood risk locations would limit the cost of impacts. An increase in agroforestry (i.e. combining agriculture and trees, such as fruit trees within cereal production) involving a move from arable and pasture could maintain the long-term productivity of the land. The lowest quality agricultural land would be converted in order to minimise the costs to farmers.

In this scenario, we assume the threshold will occur after the change in land use reducing the impact of the threshold.

Reactionary Response Scenario

This scenario will assume the business as usual scenario until the threshold occurs (i.e. increase in maize production, but no change in area of arable and pastures). After the threshold occurs, the transformative adaptation measures (i.e. move from arable to mix productive grassland and increase in agroforestry) would be implemented from the lowest quality agricultural land. However, the area allocated for the transformative adaptation measures would be reduced due to the impact of the threshold in the short-term.

7.4 Economic assessment

The Threshold chosen to be represented in the economic assessment was threshold B. The narrative introduced in Section 7.3.2 Threshold B: Flooding has attempted to be represented in the economic assessment but could not be completed comprehensively. Therefore, this economic assessment should only be considered independently.

A summary of the inputs and timing assumptions for all scenario is listed in Table 7-3.

It should be noted that there may be additional emissions reductions when shifting from agriculture to forestry which are omitted from this broad scale analysis. For example, there may be significant reductions in methane and nitrous oxide as a result of less fertiliser use when moving from agricultural land types to forestry.

Table 7-2 – Summary the economic assessment for each scenario for Threshold B

	BAU	Assumption	Early intervention	Assumption	Reactionary	Assumption	
Threshold event	2050 over 5 years	Defined by project team	2050 over 5 years	Defined by project team	2050 over 5 years	Defined by project team	
Intervention point	n/a		2025 over 5 years	Changes in land use take time to be realised.	2050 over 5 years	Changes in land use take time to be realised.	
	BAU		Early intervention		Reactionary		
	Change assumptions	**Costs and benefits**	**Change assumptions**	**Costs and benefits**	**Change assumptions**	**Costs and benefits**	**Limitations**
Threshold impact	Agricultural land areas damaged due to flooding (30% cereals/dairy/horticulture, 15% cropping/mixed, 10% grazing). Climate hazard threshold impacts based on expert opinion of PGA stakeholder group.	Productivity losses due to flooding estimated by Morris et. al. (2009). Variable damage values by agricultural types.	Agricultural land areas damaged due to flooding (5% for all agricultural types). Climate hazard threshold impacts based on expert opinion of PGA stakeholder group.	As BAU	As BAU	As BAU	Assumed level of impact in terms of % affected under the threshold event.
Carbon sequestration	Change in carbon sequestration rates based on change in area by land cover type. Carbon sequestration rates by land cover based on a range of sources including Christie et.al. (2010).	Carbon unit price taken from BEIS non-traded carbon price.	As BAU but with amendments in landuse proportions taken into account.	As BAU	As BAU up to threshold event. As Early Intervention after threshold event.	As BAU	The split between coniferous and deciduous woodland for the Petteril is not known. Simplified assumptions used that do not consider the variable impact of woodland carbon sequestration with age.
Agricultural productivity	Costs relate to additional pesticide and fertiliser applications needed to counteract the impacts of climate change on crops. This is assumed to enhance after the threshold event due to increased climate impacts and post event recovery.	Costs increase (by 10%) by the threshold event. After the threshold event costs increase by 30% by 2100. Rates of change for agricultural costs and benefits based on expert opinion. Incomes and costs supplied by Farm Business Survey.	Improved resilience resulting from adaption interventons assumed to decrease level of required pesticide and fertiliser use.	Costs increase (by 5%) by the threshold event. After the threshold event costs increase by 15% by 2100. Rate based on expert opinion of PGA stakeholder group and assumed to be lower than the BAU.	BAU up to threshold flood (10%). Reversion to Early Intervention values (15%) by 2100.	As BAU / Early Intervention.	Cost increases and production losses assumed and tested as part of sensitivity testing.
	Decline in benefits relate to crop failures/drought and flooding under the climate scenario. Impacts reduce yields and productivity for some years with a permanent change in biodiversity. This is enhanced after the threshold event.	Agricultural incomes are expected to reduce (by 10%) gradually by the threshold event. After the threshold event incomes deteriorate by 30% by 2100. Rate based on expert opinion of PGA stakeholder group.	Benefits assumed to decrease by a lesser extent than BAU scenario due to adaptation interventions improved resilience of natural environment	Agricultural incomes are expected to reduce (by 5%) gradually by the threshold event. After the threshold event incomes deteriorate recover by 2100. Rate based on expert opinion of PGA stakeholder group and anticipated to be lower than the BAU.	BAU up to threshold flood (10%). Reversion towards Early Intervention values (5%) by 2100.	As BAU / Early Intervention.	Cost increases and production losses assumed and tested as part of sensitivity testing. Agricultural subsidies ignored but tested as a sensitivity test.
Other environmental benefits	Woodland benefits considered. Environmental benefits included but static over the appraisal period.	Benefit values based on a range of sources including Eftec (2016) and Eftec (2010). Linked to woodland areas.	Woodland benefits rise inline with increased woodland. Coniferous woodland benefits assumed to be minimal, Broadleaved woodland and wet woodland assumed to have higher natural capital valuations.	As BAU	As BAU up to threshold event. As Early Intervention after threshold event.	As BAU	Assumptions made on the split between woodlands with 'standard' woodland benefits and those classed as 'priority woodland' with higher monetary benefits.
Timber sales	Area of woodland not anticipated to change over appraisal period. Rate of provisioning services from woodland assumed constant throughout reference period.	Timber prices based on Nix, 2016. Incomes relate to thinning and clear felling activities.	Area of woodland increases by intervention period, therefore timber sales increase in value.	As BAU	As BAU	As BAU	Timber sales increase as trees mature built into the analysis by provision of a a 25 year lag.
Recreation	Recreational benefits included but static over the appraisal period.	Values estimated using ORVal (Outdoor Recreation Value) .	As BAU	As BAU	As BAU	As BAU	No readily available information on how recreational values will change with changes to the land use or in absolute terms.
Land use change	No change in area of proportion of land use.	N/A	Assume 10% conversion of arable to agroforestry. Another 10% conversion of arable to pasture (5% to wet woodland and 5% to grassland).	Managed change in land use, therefore costs of this change assumed. Cost estimates based on Environment Agency (2015)	As BAU up to threshold event. As Early Intervention after threshold event.	Managed change in land use, therefore costs of this change assumed. Cost estimates based on Environment Agency (2015)	Grassland conversion assumed to be wet grassland - species that can tolerate wetter conditions.

7.4.1 Summary of land use change

The summary of how the land use changes under each scenario at the end of the appraisal period is shown below, although this misses the fact that the anticipatory option provides some of the mitigatory land use changes (e.g. woodland) from an earlier time point).

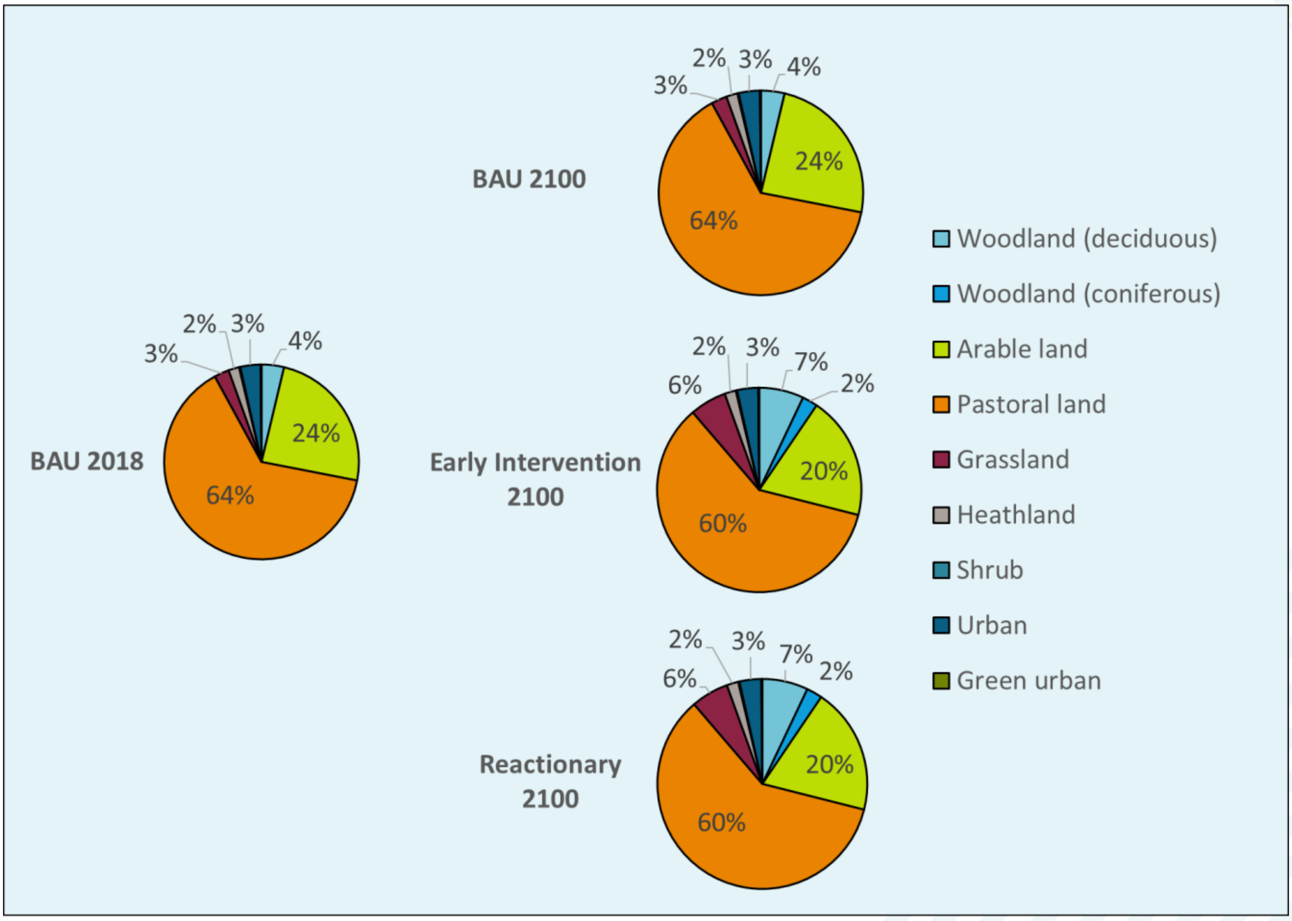

Figure 7-4 – Land use change for Petteril PGA

7.4.2 Outcome and interpretation of benefit-cost calculations

The summary of the benefit-cost and net present value calculations for the Petteril are provided for each scenario in Figures 7-4 to 7-6. These represent cash costs (not Present Values) to allow the differences to be distinguished over the appraisal period. A comparison of the net benefits for each scenario is provided graphically in Figure 7-7.

It should be noted that the graphs exclude subsidies, meaning land use activities are not economically viable beyond 2035 in the BAU and reactionary scenarios.

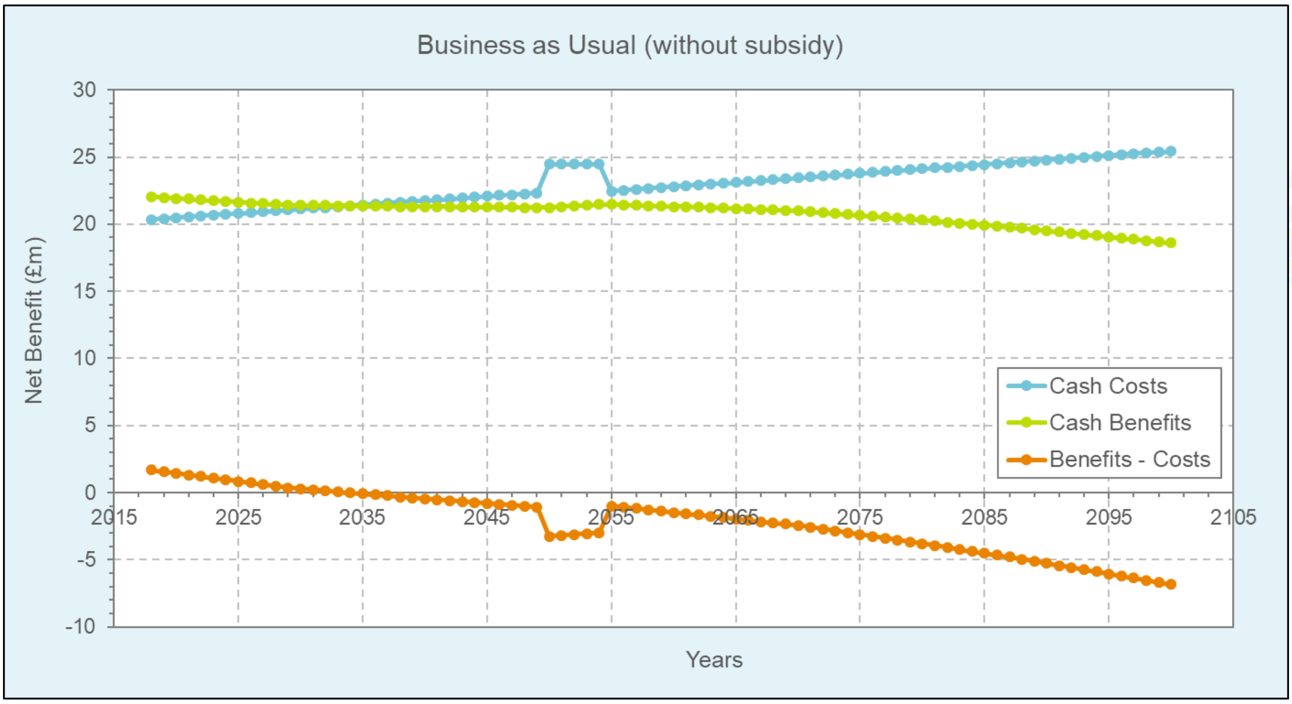

Figure 7-5 – Total costs and benefits for the Business as Usual scenario

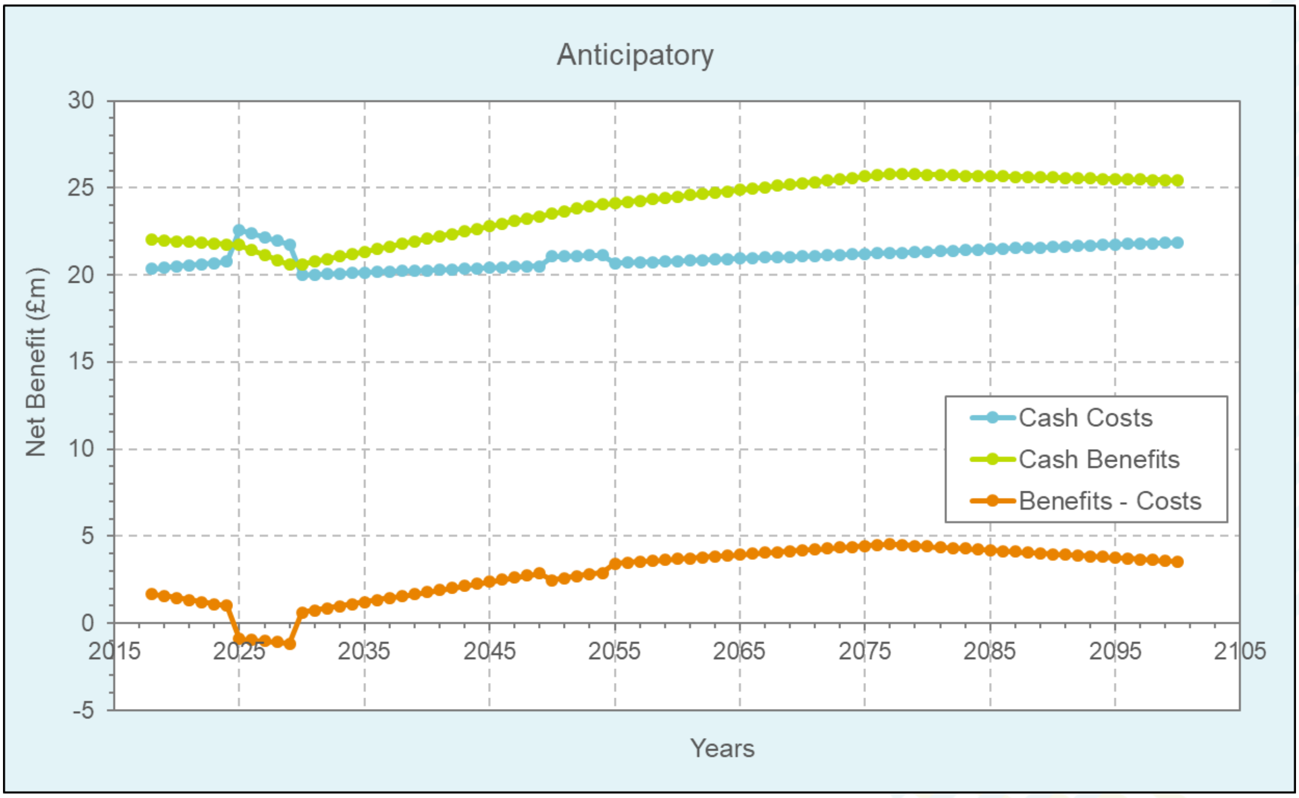

Figure 7-6 – Total costs and benefits for the Anticipatory scenario

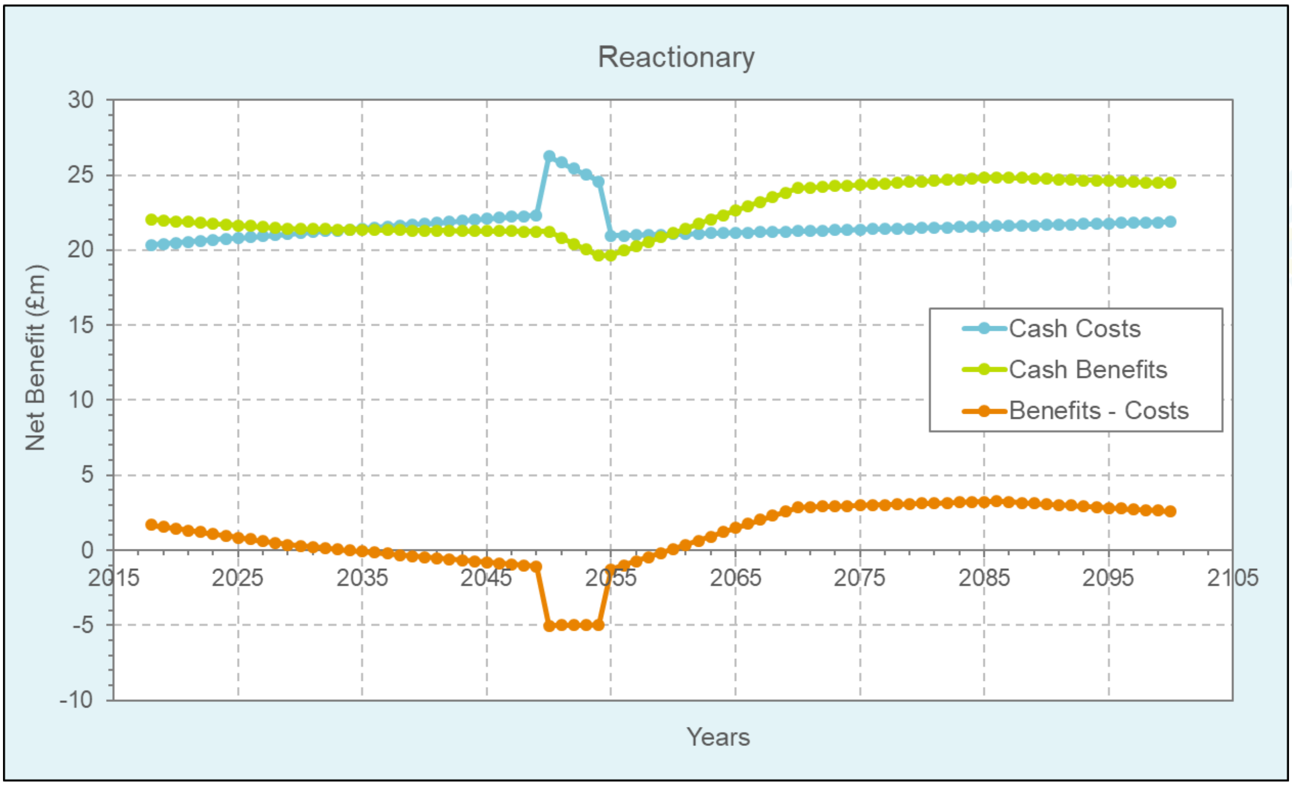

Figure 7-7 – Total costs and benefits for the Reactionary scenario

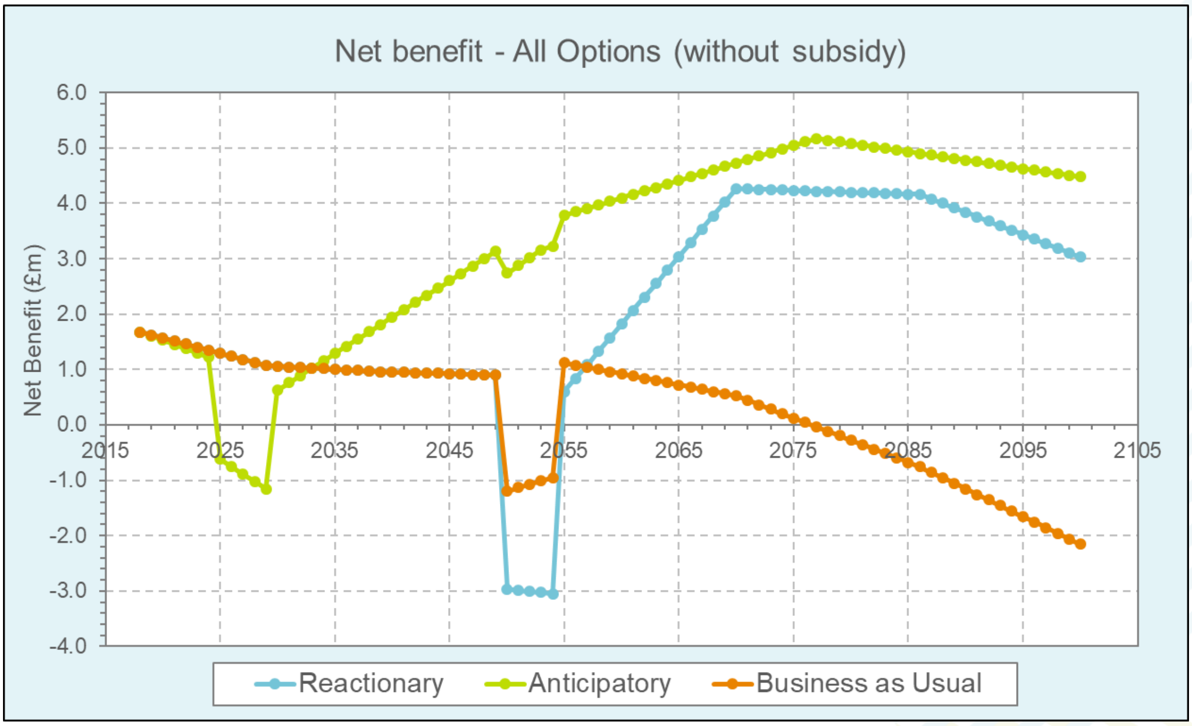

Figure 7-8 – Net benefits for each scenario

Total NPV's for each scenario are also in Table 7-6.

Table 7-3 – Summary of whole life Net Present Values (£m)

Scenario	PV Costs	PV Benefits	Net present value	Benefit of option
Business as Usual	£630	£610	-£20	-
Anticipatory	£600	£650	£50	£70
Reactionary	£620	£630	£10	£30

The results can be summarised as follows:

- The BAU suggests that the costs outweigh the benefits almost from the start of the appraisal period. This is partly to do with subsidies being excluded from the agricultural calculations as standard. The inclusion of these will push back the switch when costs exceed benefits. The implication of this is that the land use may not appear to be cost effective, however there may also be other aspects of natural capital that have not been considered or included that would reverse this assumption. The key implication however is that under the BAU scenario costs continue to increase and benefits reduce, leading to a negative NPV throughout the majority of the appraisal period. Overall the whole life NPV equals £-20m.
- The anticipatory of climate resilient land use and agricultural practices suggests that the natural capital benefits can be enhanced when compared against the BAU case. The benefits exceed the costs throughout the appraisal period except during the intervention period. Overall the whole life NPV equals £50m – a significant enhancement over the BAU.
- The reactionary scenario suggests that the implementation of changes to land use and agricultural practices can offset the losses associated with the BAU scenario but not as efficiently as the anticipatory option. Overall the whole life NPV equals £10m, suggesting that the overall whole life costs are greater than the benefits.

Table 7-6 shows that over the life of the appraisal period the benefits of shifting to an anticipatory option are high. Most of these benefits are as a result of a reduction in agricultural costs, carbon sequestration improvements and greater agricultural income, with more marginal reductions in the threshold costs and timber sales. This is shown graphically in Figure 7-9.

The gain in the wider environmental benefits (e.g. water quality, recreation and tourism, aesthetic value, biodiversity) is limited, partly as the grassland that is a major beneficiary in the Petteril is not included as a land use with significant wider benefits.

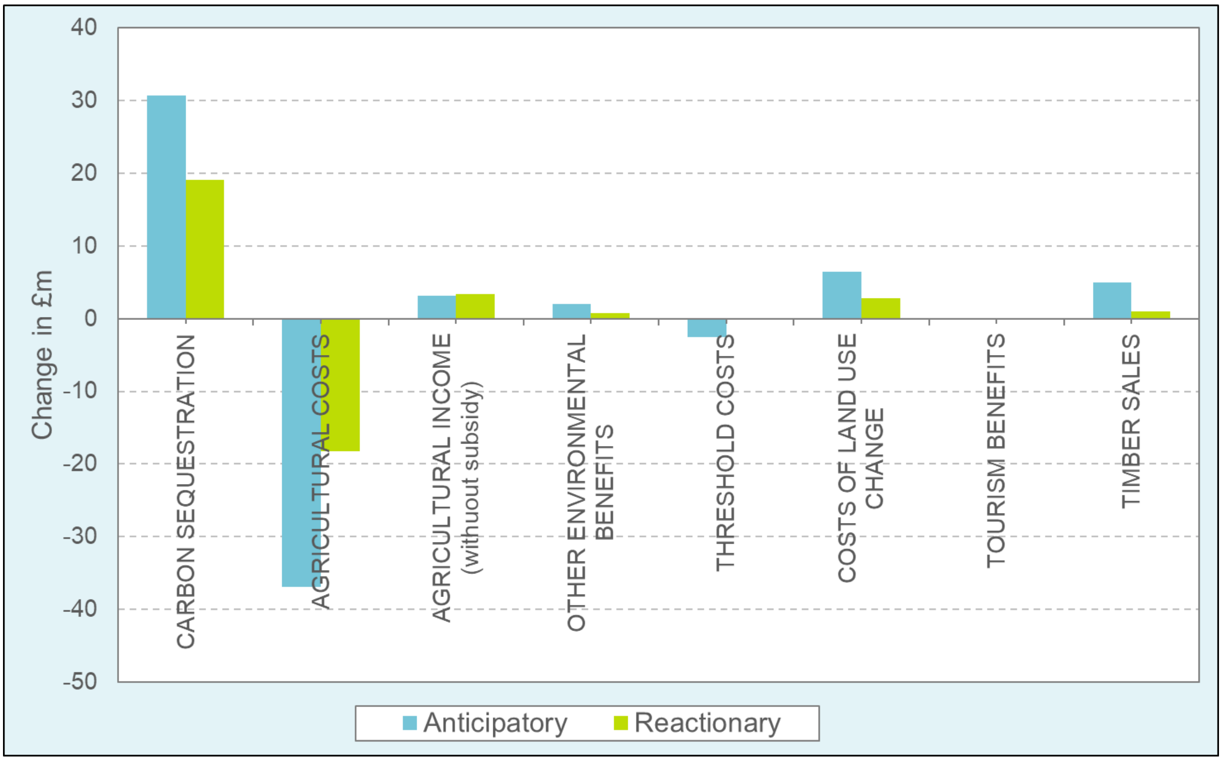

Figure 7-9 – Whole life change in total value for each natural capital component

7.4.3 Sensitivities

This case study is strongly influenced by the agricultural aspects included in the economic calculations. In particular is the low yield on agricultural land which results in an early crossing of costs and benefits in the analysis. Some of this will be due to the fact that subsidies have been removed from the analysis and the impact of this has been tested in the following section.

It is also clear that the agricultural costs reduce substantially over the period of analysis (particularly with the anticipatory option. The reason for this is to do with shift in lower cost agricultural land types (a shift away from cereals), and the assumption that with this in place, the uplift in costs associated with maintaining agricultural land types with climate change is lower than the assumed uplift under the BAU case. However, this uplift in costs (and reduction in income) is a key assumption, and one that should be tested. Further analysis on this is provided in Section 7.4.5.

7.4.4 Results with agricultural subsidies

A sensitivity test was undertaken with the inclusion of subsidies for the agricultural income aspect. The NPV comparison chart has been repeated and is provided in Figure 7-8. This shows that there is an uplift in the overall benefits which enhances the total NPV for all scenarios assessed; the inclusion of agricultural subsidies does not however change the overall pattern of results.

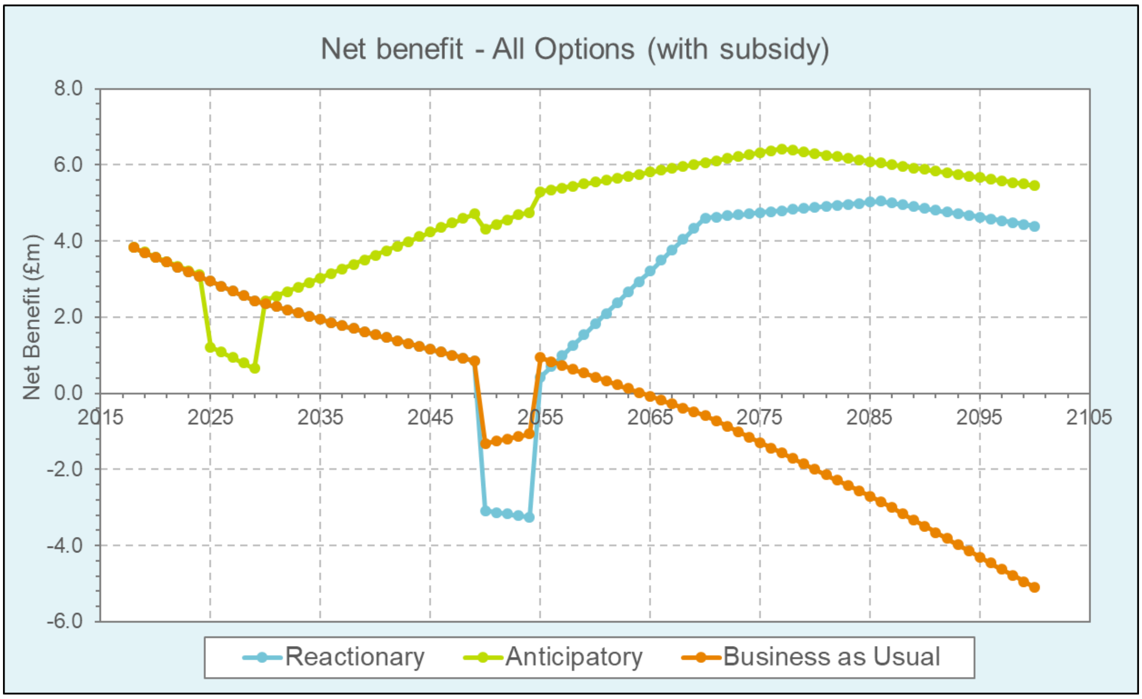

Figure 7-10 – Net present value comparison between scenarios

7.4.5 Sensitivity test on agricultural cost/income 'levers'

It is anticipated that both the costs of maintaining agricultural land types and the income received from these will increase and decrease respectively with climate change. Whilst it has been possible to estimate this impact for some land types under the business as usual scenario, a set of 'levers' have been used in the tool to force these impacts and to change them for each scenario. These are relatively blunt tools in the absence of more detailed information or more detailed methodologies (outside the scope of this assessment). The two key assumptions within the calculations are that agricultural costs increase (such as increased fertiliser and pesticide use to counteract the impacts of climate change) and farm incomes reduce (due to reduced crop yields for example). The key assumptions used are provided in Table 7-3). Due to the high level assumptions employed, they have therefore been subject to a sensitivity test to quantify the impact on the overall analysis.

The increase in costs and reduction in income for this test is half of what was assumed under the current scenarios. The results of a test on a lower impact of agricultural costs and income are shown in terms of the long term NPV in Figure 7-10. This suggests that under this test, the overall benefit/costs are more marginal for the Business as Usual case, particularly in the mid-point of the appraisal. Overall the pattern between scenarios is similar although the anticipatory option and reactionary scenarios have much higher long term NPV's.

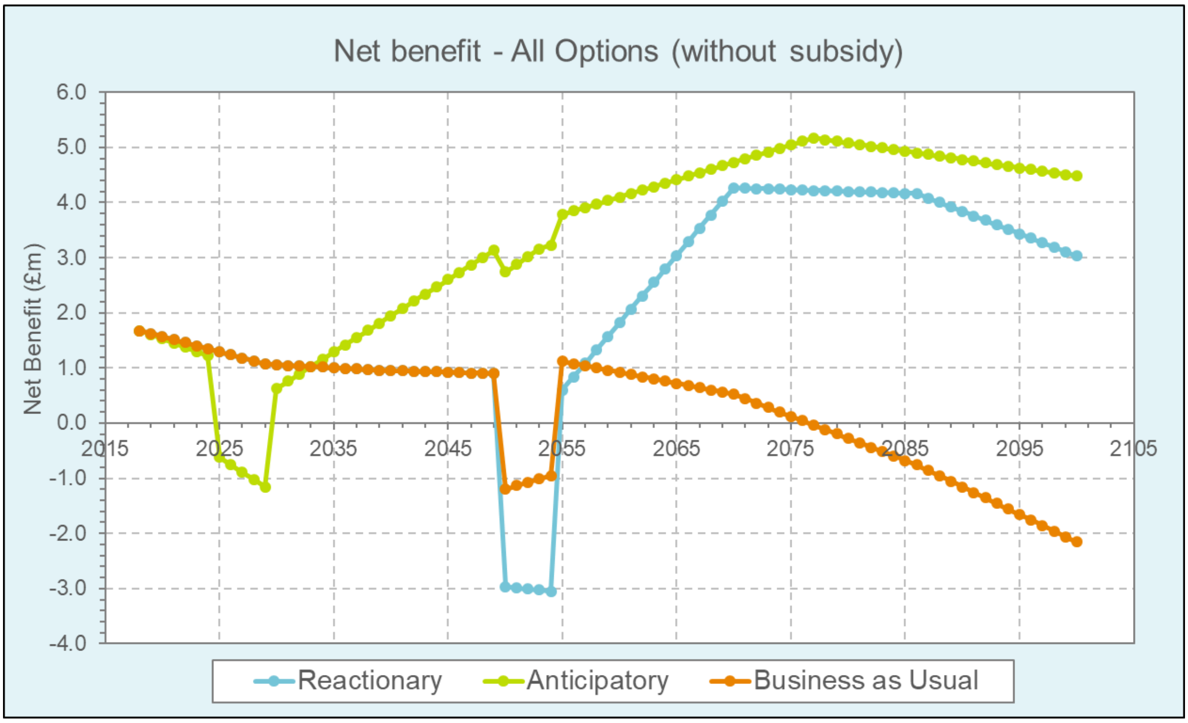

Figure 7-11 – Net present value comparison between scenarios

7.5 Maximising carbon sequestration

Grazing intensity is a significant determinant of carbon losses in the vegetation from pastures, with intensive farming responsible for up to 60% of net primary productivity (NPP). Large volumes of soil organic carbon are also lost through clearing and cultivation (Dawson and Smith, 2007). Dawson and Smith (2007) highlight the importance of land use and its management as a means of reversing and limiting further carbon losses. In the context of the Petteril catchment, Dawson and Smith's advice regarding croplands, grasslands and forestry is particularly pertinent (see Table 5-5). They also highlight the greater sequestration potential of forestry on relatively young, disturbed or degraded soils in comparison to mature forests, whose accumulation of terrestrial C slows over decades to centuries. There is an opportunity, therefore, to convert the lowest quality agricultural land back to forest, causing a step change in C storage. Best practice land management practices will contribute in optimising the C storage potential already present (Dawson and Smith, 2007).

Table 7-4 – Summary of land change options to increase carbon storage in the Petteril

Land use	Land change options to increase C storage
Croplands	Convert marginal cropland to native vegetation, grasslands or forestry; improve crop production and erosion control; improve management of set-aside and field margins; improve farming on eroded soils, erosion control buffer strips, riparian filters; improved residue management; eliminate bare fallow; organic amendments, increased

	efficiency of animal manure, sewage sludge and composting; inter-sowing and increased duration of grass-leys; improved crop rotations; use perennial crops; use deeper rooting crops; use bioenergy crops; improve water and nutrient (fertilizer) management; increase number of agroforestry systems; do not use highly organic soils for cropping; use of N fixing crops, legumes and nutrient management plans.
Grasslands	Convert cultivated lands to well managed permanent grasslands, species selection; decrease erosion and degradation; eliminate disturbance e.g. fire protection in established pastures; increase forage production by improved fertilization, irrigation, inter-sowing of grasses and legumes; improve grazing and livestock management with controlled light-to-moderate stocking density; moderately intensify nutrient-poor permanent grasslands; introduce earthworms, improve soil structure; maintain a diverse plant community with a dense rooting system; use of N fixing crops, legumes and nutrient management plans.
Forestry	Forest and Water Guidelines by the Forestry Commission, 'best practice' guidelines; increase forest stock; continuous cover forestry to encourage natural regeneration; conserve soil and water resources; improve site preparation and planting techniques to decrease erosion; streamside management with uncultivated buffer zones to stabilize soil and reduce acidification; design of forest roads and network of drains, culverts and sediment catch pits; reduce disturbances from wind and fire; minimise soil and water impacts and reduce clear felling operations to phased felling techniques; minimise nitrate leaching, enhance base cation retention by early revegetation; use species with high NPP or increase number of actively sequestering younger forests; application of nutrients and micronutrients as fertilizers or biosolids; aesthetic planting of previously native trees and shrubs, enhance biodiversity; maintenance of open bog and moorland habitats; extension of guidelines to include conservation, landscape and recreation; plant trees on mineral soils in preference to highly organic soils.

8 Somerset

The Somerset case study is about 2,500 square kilometres in size covering the catchments of the Parrett, Axe and Brue. The case study has a population in excess of 500,000 with nearly half living in the four largest towns of Weston-super-Mare, Taunton, Yeovil and Bridgwater.

Natural England Priority Habitats cover nearly a quarter of the case study, 60% of which is coastal and floodplain grazing marsh. Just over 5% of the case study is designated as Sites of Special Scientific Interest. The peat soils of the Levels and Moors covering 20,000ha are a significant store of organic carbon (estimated at 3.7 million tonnes).

Somerset is subject to considerable flood risk from sea-level rise and from both rainfall (surface water), river (fluvial) and groundwater flooding. The area contains a range of complex water and flood management systems, which ultimately discharge excess water into the Bristol Channel. The functions or ecosystem services (e.g. food production, biodiversity, flood management, carbon storage, heritage, etc.) provided by Somerset's landscape are intrinsically linked to the complex way in which water is managed both in times of excess and deficit.

The way in which the area responds and adapts to climate change, and the emphasis that is placed upon climate change adaptation in relation to other pressures will ultimately determine the appearance, function and sustainability of Somerset's landscape into the future.

8.1 Somerset: Stage 1

According to the Corine Land Cover dataset 2012, about 40% of the case study is under some form of arable farming (mostly cereals, maize, oilseed rape and field beans), about 50% is improved grassland (sheep and cattle) and about 5% is woodland (mostly broadleaved).

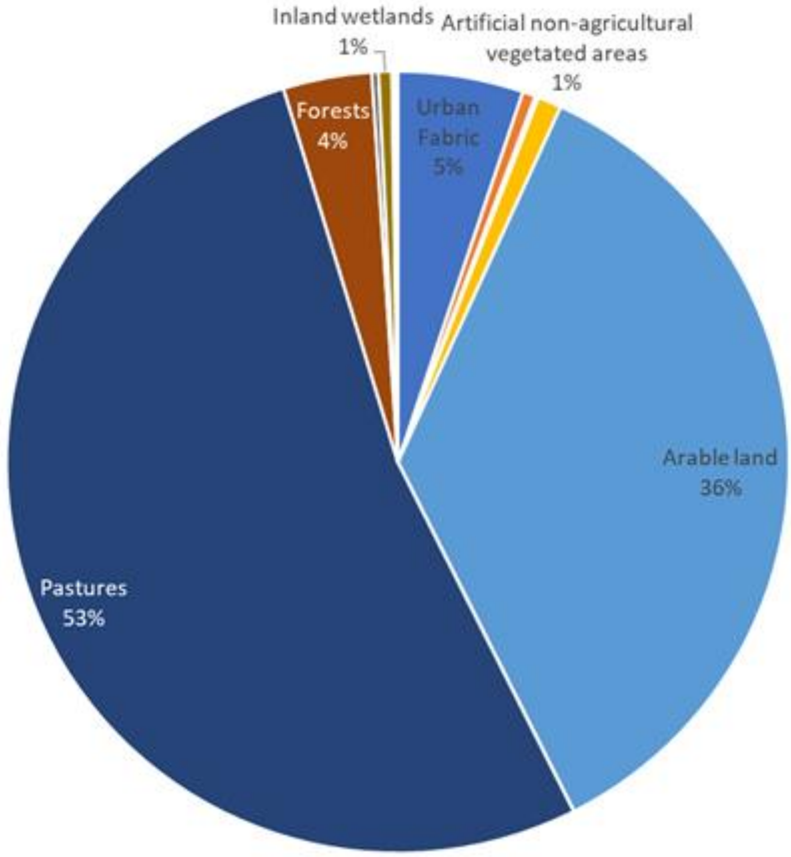

Figure 8-1 – Land Use Cover of Somerset (Corine 2012)

Agricultural land use covers 90% of the catchment, so food production is a major ecosystem service. However, significant parts of the agricultural area, together with the woodlands and heaths provide considerable biodiversity services (species and habitats). The large area of peat on the Levels and Moors provide a significant store of carbon, though the long history of drainage and associated land use change, together with peat extraction operations, have considerably degraded this valuable natural asset. The natural drainage network across the whole case study has been modified and extended over many centuries in order to meet numerous objectives, such as land use and land management change to deliver food to the population, gradually becoming more complex through multiple water level management and water flow control assets. Both Entry Level Stewardship and High Level Stewardship options from the Countryside Stewardship Scheme are prominent within the catchment and often determine how the land is managed. Consequently, there is a great opportunity post Brexit and the Common Agricultural Policy (CAP), and using the 25 Year Environment Plan, to develop schemes which maximise the ecosystem service benefits, such as flood and soil regulation and minimise climate hazards.

Entry Level Stewardship options	No. of agreements	Higher Level Stewardship options	No. of agreements
EK2: Permanent grassland (low inputs)	3,576	HR1: Grazing supplement for cattle	281
EK3: Permanent grassland (v. low inputs)	1,547	HR6: Supplement for small fields	251
EC2: Protecting in-field trees (grassland)	664	HK15: Grassland maintenance for target features	216
EE3: 6m buffer strips on cultivated land	570	HK10: Maintenance of wet grassland for wintering waders and wildfowl	205
EE1: 2m buffer strips on cultivated land	527	HK6: Maintenance of species-rich, semi-natural grassland	138
UX2: Grassland and arable	489	HK7: Restoration of species-rich, semi-natural grassland	132
EK5: Mixed stocking	484	HK19: Raised water levels supplement	113
ED5: Management of archaeological features on grassland	418	HR2: Grazing supplement for native breeds at risk	88
EB2: Hedgerow management for landscape (on one side of a hedge)	408	HK9: Maintenance of wet grassland for breeding waders	86
EE2: 4m buffer strips on cultivated land	398	HC7: Maintenance of woodland	84

Figure 8-2 – The most common options (ranked in declining order) included in Environmental Stewardship agreements in Somerset (Deane, 2016)

The highest building and business densities are present in about 15 main towns across the case study. However, there are many small rural villages together with numerous individual farmsteads, distributed across the whole area.

The case study has a population in excess of 500,000 with nearly half living in the four largest towns of Weston-super-Mare, Taunton, Yeovil and Bridgwater. The primary sectors of employment across the case study are wholesale/retail trade, human health and social work activities, manufacturing and construction. Lower levels of employment are in the accommodation sectors and food service, information and communication and agriculture, forestry and fishing.

The landscapes and land use of the Catchment are varied, from the flat wetlands of the Levels and Moors, the rolling mixed farming to the east and south, and rising to upland heathland and woodland on the Mendip, Quantock and Blackdown Hills. The case study contains 7 separate National Character Areas (Somerset Levels & Moors, Mid Somerset Hills, Vale of Taunton and Quantock Fringes, Quantock Hills, Mendip Hills, Yeovil Scarplands, Blackdowns). The NCA sub-divisions are based on a combination of landscape, biodiversity, geodiversity and economic activity. The sub-divisions follow natural lines in the landscape rather than administrative boundaries, thereby making them a good decision-making framework for the natural environment.

Land use	Land cover and land management
Arable	- Mostly cereals and forage maize - Agri-environment schemes
Productive grassland	- Mostly dairy farming - Beef - Sheep - Silage - Agri-environment schemes
Woodland	- Mostly broadleaved cover - Some priority habitat – deciduous woodland - Landscape / heritage / recreation
Watercourses and water bodies	- SSSI, NR for habitat / biodiversity - Flood control - Water level management - Recreation / aesthetics

Table 8-1 – Summary of the majority of land use, land cover, and land use management in Somerset

8.2 Stage 2 and 3: Somerset

Somerset is vulnerable to climate change, particularly the Levels due to its proximity to the sea, the volume of water the rivers are required to carry at times of high rainfall, and the valuable agricultural land. The Summer 2012 and Winter 2013-14 floods demonstrated this vulnerability (Deane, 2016).

The arable land in Somerset is approximately 40% of the catchment, providing important farmed goods and services both locally and nationally. The main crops include cereals, forage maize, oilseed rape, and field beans. The UKCCRA2 expresses some concern that yields of some cereal crops could be particularly vulnerable to a run of poor years, as happened in some locations in the 1980s.

Somerset Levels and Moors have one of the largest and biologically richest areas of traditionally-managed wet grassland and fen habitats found anywhere in the UK. Elsewhere in the catchment, there is more dispersed but varied distribution of habitats (Deane, 2016). There is seasonally-wet grassland and associated wetland habitats, such as fens, raised bogs and reedbeds which are very important to the character of Somerset and only provide summer grazing.

- Plausible thresholds identified:
- Threshold A:
    - Climate context: Warmer and drier summer seasons

- Antecedent conditions: 3 years of drought[21]
- Heatwave

- Threshold B:
  - Climate context: Sea level rise, warmer and wetter winter seasons
  - Antecedent conditions: Three seasons in five years of waterlogging of fields and floods that causes the crops and grassland to be submerged for more than 14 days from a tidal surge in the Bristol channel or a period of unusually intense rainfall in the upper catchment[22]

8.3 Stage 4: Somerset

The narrative introduced in this Section is independent of the economic assessment and should be assessed independently. This narrative will introduce other factors that were unable to be represented in the economic assessment.

8.3.1 Threshold A – Warmer and drier summers, 3-year drought

Plausible impacts on land use arising from Threshold

Warmer and drier summer seasons, followed by a drought would cause the agricultural productivity to be at great risk, since it is a majority of the service provided in the catchment (covering over 80% of the catchment).

From the evidence presented above, the impacts would include:

- Reduction in yield of cereal crops, forage maize (reduction of productivity by 12.4% (Lesk et al., 2016)), oilseed rape, and field beans
- Increase runoff and potential flood risk due to drier soils (if crusted or suffering from hydrophobicity)
- Reduction in dairy production, impacting milk yield and fat protein content
- Animal welfare, with potential impacts on weight gain, fertility
- Reduction in yields of grasslands

These impacts would have associated costs discussed below.

See Section 4.1.1 on Drought and heat stress for further discussion on the plausible impacts.

Business as Usual Scenario

In this business as usual scenario, it assumes no significant advances in availability and use of drought-resistant varieties of cereals, grasses, and maize. Maize production is actually likely to increase due to warmer temperature (Brown et al., 2016). It is assumed no additional on-farm water capture and management assets (e.g. on-farm water storage and irrigation systems) will be provided.

The current trends suggest that there would be an increase in off-floodplain grassland areas, at the expense of growing cereals. Additionally, the warmer

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[21] Plausible droughts in the UKCCRA2 High++ Scenarios.

[22] Determined as a combination of extreme weather events that pose the greatest risk of overwhelming flood defences and causing a catastrophic flooding in the future, concluded from the flood risk modelling scenarios (Deane, 2016).

climate could also increase horticulture (fruit, vines), also at the expense of growing cereals.

As a result of the climate threshold A occurring, increased costs would be associated with additional shade provision, cooling and ventilation systems if livestock (esp. cattle) housed indoor where the costs of labour and machinery to relocate livestock, the costs of feed and storage and the costs of waste management would all be new farm business costs. The cost of new natural shade, hedges and woodland would be new costs. Additionally, any livestock mortality due to heat stress will reduce long-term farm profitability. These adaptive measures are low-regret and would not include any transformative adaptive measures.

Early Adaptation Scenario

To adapt to threshold A, farm management would take up advances in the availability and use of drought resistant varieties of cereals, grasses and maize. Investment in additional on-farm water capture and management assets (e.g. on-farm water storage and irrigation systems) would help manage the water shortages.

Additional water level control measures (e.g. sluices, wind/solar pumps) installed on the Levels and Moors would hold as much water as possible within the peat bodies to retain higher water levels and conserve the peat mass.

Plausible adaptation could include a gradual increase of 15% in cereals, general cropping (including newer crops to the area such as sunflowers, grain maize, soya) and horticulture (fruit and vines). These new crops of sunflowers, grain maize, soya, and horticulture are well-suited to warmer climates.

Reactionary Response Scenario

In this scenario, business as usual would occur until the threshold takes place, in which both low-regret actions and transformative adaptive measures would be implemented as outlined in the Early Adaptation scenario.

8.3.2 Threshold B – Warmer wetter winters, 3 seasons of waterlogging

Plausible impacts on land use arising from Threshold

With warmer and wetter winter seasons and three seasons in five years of waterlogging of fields and crops or periods of unusually intense rainfall in the upper catchment, the impact would be a fall in agricultural productivity. From the evidence gathered, the impacts would include:

- Greater runoff from increased maize production[23], particularly if soils are compacted during untimely harvesting operations
- Reduction of yields of cereal crops (10-30% (Elliott, 2014)), other crops and grasslands directly affected by the floods
- Reduction of available nutrients such as nitrate and sulphate, lost from the soil through gaseous emissions or leaching, reducing productivity of the grassland

[23] Maize is a late harvested crop and often show more signs of soil degradation due to trafficking during harvest operations, etc., when soils are wet causing greater runoff (SCF0405 Maize AD report by Defra).

See Section 4.1.2 Flooding for further discussion on the plausible impacts.

Business as Usual Scenario

In a business as usual scenario, it is assumed there would be continued availability of some form of agri-environment scheme payments that continue to target priority habitats and peatland conservation. It is assumed there are no significant advances in availability and use of flood/wet resistant varieties of cereals, grasses and maize.

Minimum land use change would occur including:

- 10% increase in low intensity low input extensively managed lowland wet grassland area on the Levels and Moors, at the expense of improved grassland would take place. This would actively assist in ongoing peatland conservation and restoration.
- 10% increase in improved grassland area (in non-floodplain middle catchment areas), would take place at the expense of cereals.

Early Adaptation Scenario

Adaptation assumes continued availability of agri-environment scheme payments (or a payment for ecosystem services scheme) that targets priority habitats and peatland conservation and helps deliver other benefits to the environment and society. Furthermore, there are advances in availability and use of more flood/wet resistant varieties of cereals, grasses and maize.

It assumes a gradual 20% increase in low intensity low input extensively managed lowland wet grassland area on the Levels and Moors, at the expense of higher intensive high input improved grassland to increase resilience to flooding. This change in land use would also actively assist in peatland conservation and restoration. This would become similar to the currently seasonally-wet grassland and associated wetland habitats, such as fens, raised bogs and reedbeds within the catchment. It could conceivably even include certain forms of paludiculture.

It assumes a gradual 5% increase in improved grassland area, at the expense of the cereals (non-floodplain middle catchment areas). Arable reversion to more species-rich grassland in the middle of the catchment can also increase resilience to droughts and floods. Permanent grasslands often require several years to return to normal after a severe and prolonged flood. The diversity of the grassland managed, including mix of flora, number of animals, fertilisation, and the rotation between pasture and cutting, will heavily influence regeneration.

Assume 10% gradual increase over a 20 to 30-year period of mature woodland (mostly deciduous) and hedgerows, especially in middle and upper catchment areas at expense of improved grassland. This will also help to provide natural flood management and carbon sequestration benefits. If the change of land use to woodland became a Broad habitat (in non-peat areas), the wet woodland would be more resilient to flooding and no direct effects could be determined on coniferous woodland (Mitchell et al., 2007). It would also provide summer shade for stock in projected higher temperatures. Woodland is more resilient to Threshold B and therefore can be considered as an option to change in land use in the middle and upland areas of the catchment.

Reactionary Response Scenario

In this scenario, business as usual would occur until the threshold takes place, in which both low-regret actions and transformative adaptive measures would be implemented as outlined in the Early Adaptation scenario.

8.4 Economic assessment

The Threshold chosen to be represented in the economic assessment was threshold B. The narrative introduced in Section 8.3.2 Threshold B (Flooding) has attempted to be represented in the economic assessment but could not be completed comprehensively. Therefore, this economic assessment should only be assessed independently.

A summary of the inputs and timing assumptions for all scenario is listed in Table 8-3.

It should be noted that there may be additional emissions reductions when shifting from agriculture to forestry which are omitted from this broad scale analysis. For example, there may be significant reductions in methane and nitrous oxide as a result of less fertiliser use when moving from agricultural land types to forestry.

Table 8-2 – Summary the economic assessment for each scenario for Threshold B

	BAU	Assumption	Early intervention	Assumption	Reactionary	Assumption	
Threshold event	2050 over 5 years	Defined by project team	2050 over 5 years	Defined by project team	2050 over 5 years	Defined by project team	
Intervention point	n/a		2030 over 25 years	Changes in land use take time to be realised.	2055 over 25 years	Changes in land use take time to be realised.	
	BAU		Early intervention		Reactionary		
	Change assumptions	**Costs and benefits**	**Change assumptions**	**Costs and benefits**	**Change assumptions**	**Costs and benefits**	**Limitations**
Threshold impact	Agricultural land areas damaged due to flooding (20% cereals and general cropping and 10% for dairy, horticulture and grazing). Climate hazard threshold impacts based on expert opinion of PGA stakeholder group.	Productivity losses due to flooding estimated by Morris et. al. (2009). Variable damage values by agricultural types.	Agricultural land areas damaged due to flooding (5% for all agricultural types). Climate hazard threshold impacts based on expert opinion of PGA stakeholder group.	As BAU	As BAU	As BAU	Assumed level of impact in terms of % affected under the threshold event.
Carbon sequestration	Change in carbon sequestration rates based on change in area by land cover type. Carbon sequestration rates by land cover based on a range of sources including Christie et.al. (2010).	Carbon unit price taken from BEIS non-traded carbon price.	As BAU but with amendments in landuse proportions taken into account.	As BAU	As BAU up to threshold event. As Early Intervention after threshold event.	As BAU	There may be additional emissions reductions when shifting from agriculture to forestry which are omitted from this analysis. For example, there may be significant reductions in methane and nitrous oxide as a result of less fertiliser use when moving from agricultural land types to forestry.
Agricultural productivity	Costs relate to additional pesticide and fertiliser applications (or a change to drought resistant crop varieties) needed to counteract the impacts of climate change on crops. This is assumed to enhance after the threshold event due to increased climate impacts and post event recovery.	Costs increase (by 10%) by the threshold event. After the threshold event costs increase by 30% by 2100. Rates of change for agricultural costs and benefits based on expert opinion. Incomes and costs supplied by Farm Business Survey.	Improved resilience resulting from adaption interventons assumed to decrease level of required pesticide and fertiliser use.	Costs increase (by 5%) by the threshold event. After the threshold event costs increase by 15% by 2100. Rate based on expert opinion of PGA stakeholder group and assumed to be lower than the BAU.	BAU up to threshold flood (10%). Reversion to Early Intervention values (15%) by 2100.	As BAU / Early Intervention.	Cost increases and production losses assumed and tested as part of sensitivity testing. Advances in drought resistant varieties may increase costs. Increased runoff and flooding could deliver pollution to the Levels and Moors which could negatively affect grassland and wetland habitat.
	Decline in benefits relate to crop failures/drought and flooding under the climate scenario. Impacts reduce yields and productivity for some years with a permanent change in biodiversity. This is enhanced after the threshold event.	Agricultural incomes are expected to reduce (by 10%) gradually by the threshold event and throughout the appraisal period. Agricultural incomes for horticulture expected to rise (5% assumed). Rates based on expert opinion of PGA stakeholder group.	Benefits assumed to decrease by a lesser extent than BAU scenario due to adaptation interventions improved resilience of natural environment	Agricultural incomes are expected to reduce (by 5%) gradually by the threshold event and throughout the appraisal period. Agricultural incomes for horticulture expected to rise (5% assumed). Rates based on expert opinion of PGA stakeholder group.	BAU up to threshold flood (10%). Reversion towards Early Intervention values (5%) by 2100.	As BAU / Early Intervention.	Cost increases and production losses assumed and tested as part of sensitivity testing. Agricultural subsidies ignored but tested as a sensitivity test.
Other environmental benefits	Woodland benefits considered. Environmental benefits included but static over the appraisal period as woodland area not anticipated to change significantly.	Includes environmental inputs of the peat and minor woodland benefits. Benefit values based on a range of sources including Eftec (2016) and Eftec (2010). Linked to land use areas.	Woodland and peatland benefits considered. Environmental benefits raised due to increase in woodland and peatland during the intervention period. New woodland assumed to be priority site with higher benefits.	As BAU	As BAU up to threshold event. As Early Intervention after threshold event.	As BAU	Assumptions made on the split between woodlands with 'standard' woodland benefits and those classed as 'priority woodland' with higher monetary benefits.
Timber sales	Area of woodland not anticipated to change over appraisal period. Rate of provisioning services from woodland assumed constant throughout reference period.	Timber prices based on Nix, 2016. Incomes relate to thinning and clear felling activities.	Area of woodland increases by intervention period, therefore timber sales increase in value.	As BAU	As BAU	As BAU	Timber sales increase as trees mature built into the analysis by provision of a a 25 year lag.
Recreation	Recreational benefits included but static over the appraisal period.	Values estimated using ORVal (Outdoor Recreation Value) .	As BAU	As BAU	As BAU	As BAU	No readily available information on how recreational values will change with changes to the land use or in absolute terms.
Land use change	10% reduction in arable land and conversion of this to pastoral land.	Land use change assumed to occur naturally - no managed change or cost of change.	20% reduction in pastoral grassland converted to lower intensity grassland (3/4) and peatland (1/4). 10% increase in woodland (converted from arable land)	Managed change in land use, therefore costs of this change assumed. Cost estimates based on Environment Agency (2015)	As BAU up to threshold event. As Early Intervention after threshold event.	Managed change in land use, therefore costs of this change assumed. Cost estimates based on Environment Agency (2015)	

8.4.1 Summary of land use change within the economic appraisal

The summary of how the land use changes under each scenario at the end of the appraisal period is shown below.

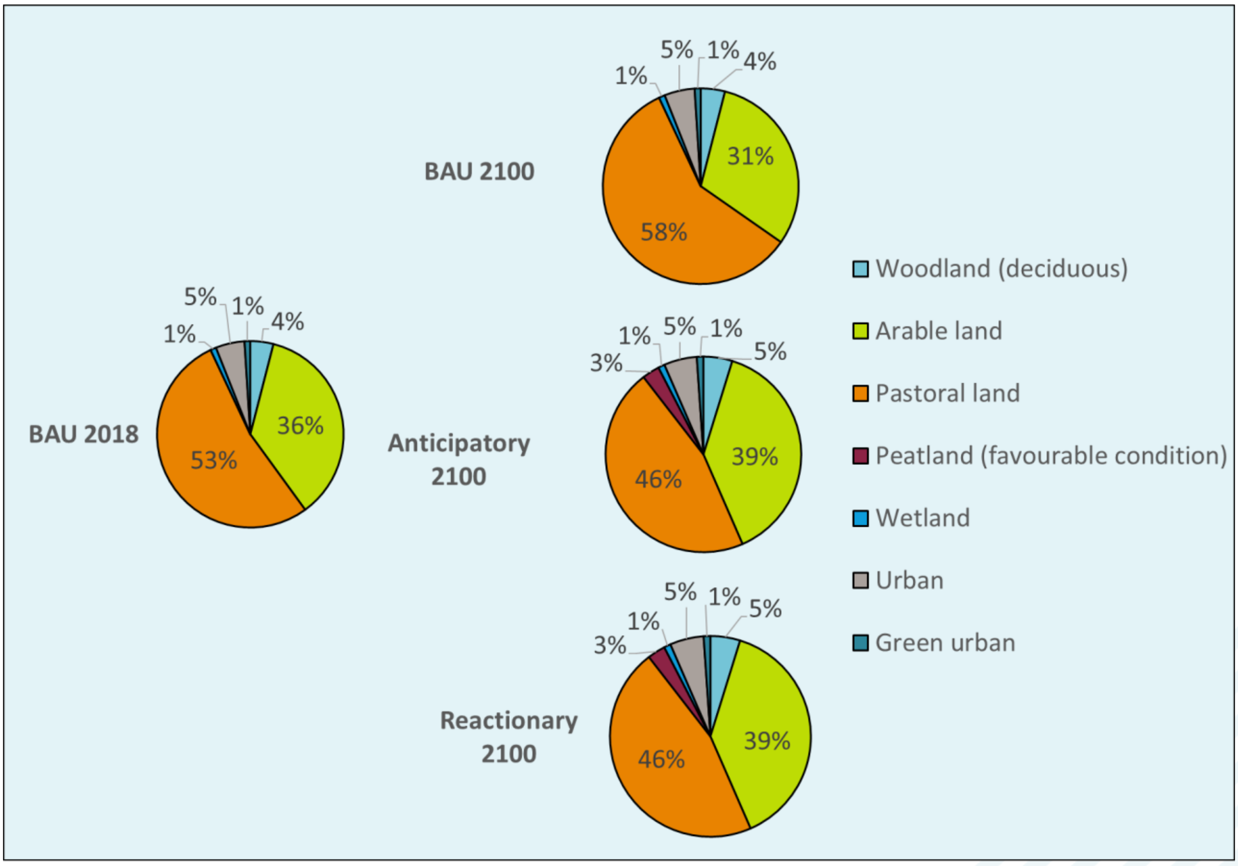


Figure 8-3 – Land use change

8.4.2 Outcome and interpretation of benefit-cost calculations

The summary of the benefit-cost and net present value calculations for the Somerset case study are provided for each scenario in Figures 8-4 to 8-6. These represent cash costs (not Present Values) to allow the differences to be distinguished over the appraisal period. A comparison of net benefits for each option is provided graphically in Figure 8-7.

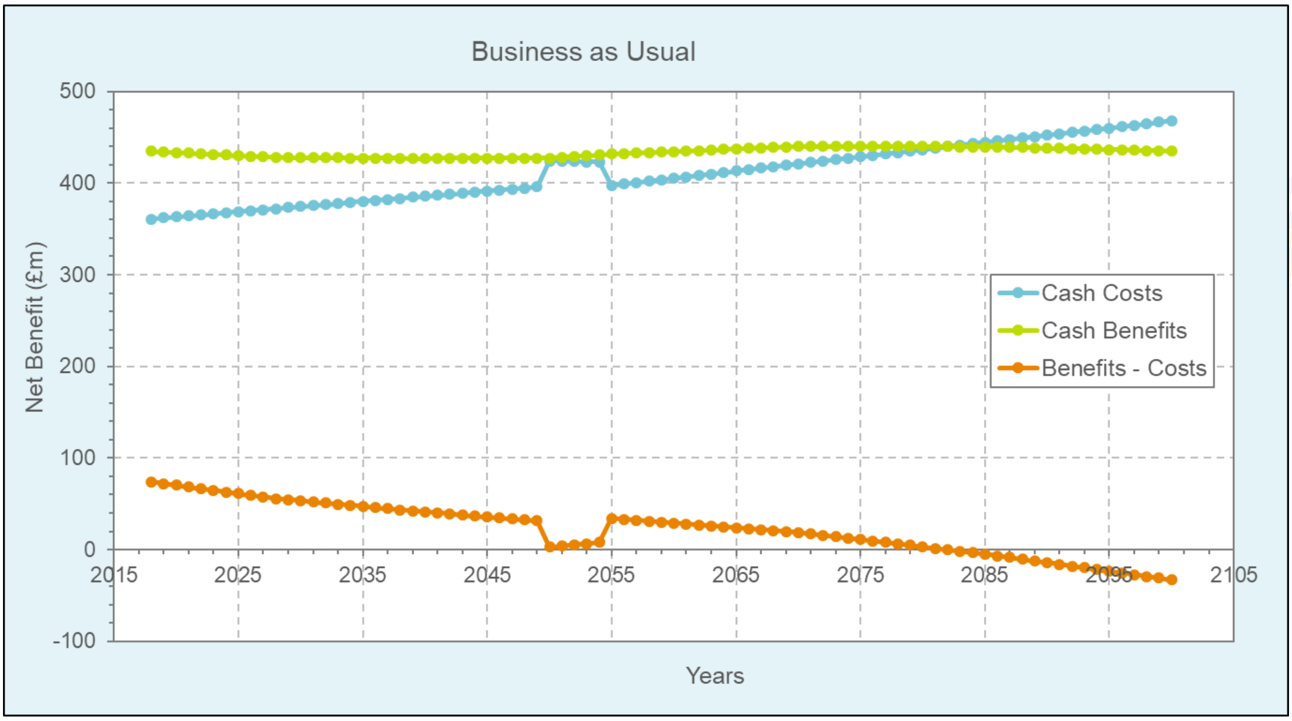


Figure 8-4 – Total costs and benefits for the Business as Usual scenario

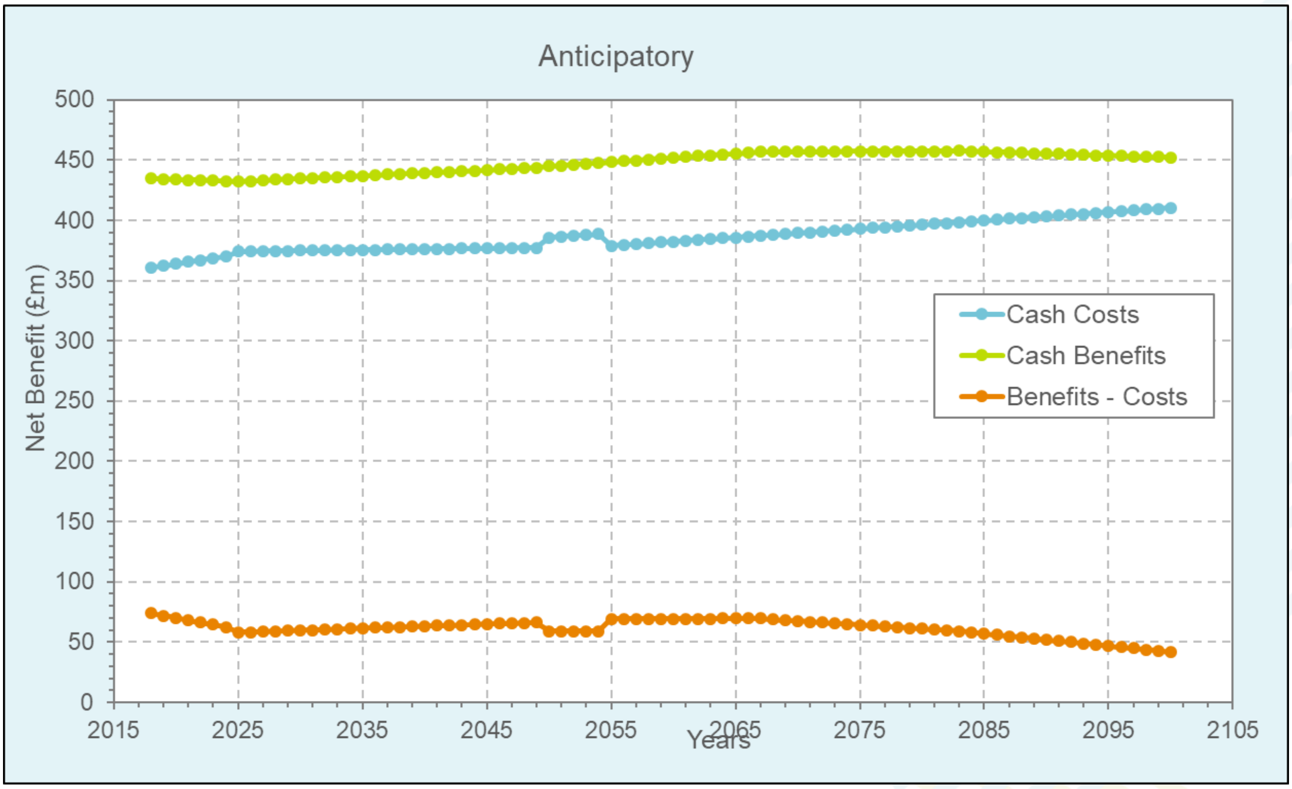


Figure 8-5 – Total costs and benefits for the Anticipatory scenario

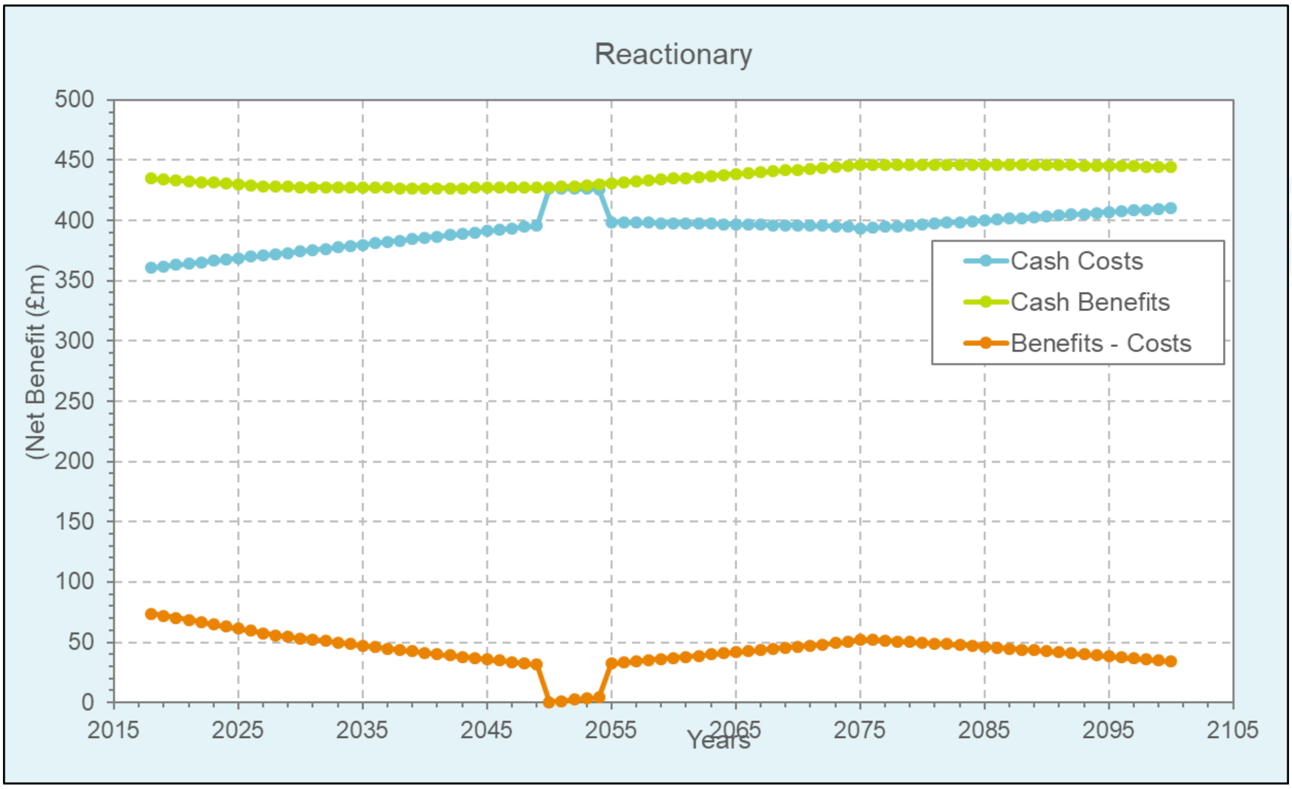


Figure 8-6 – Total costs and benefits for the Reactionary scenario

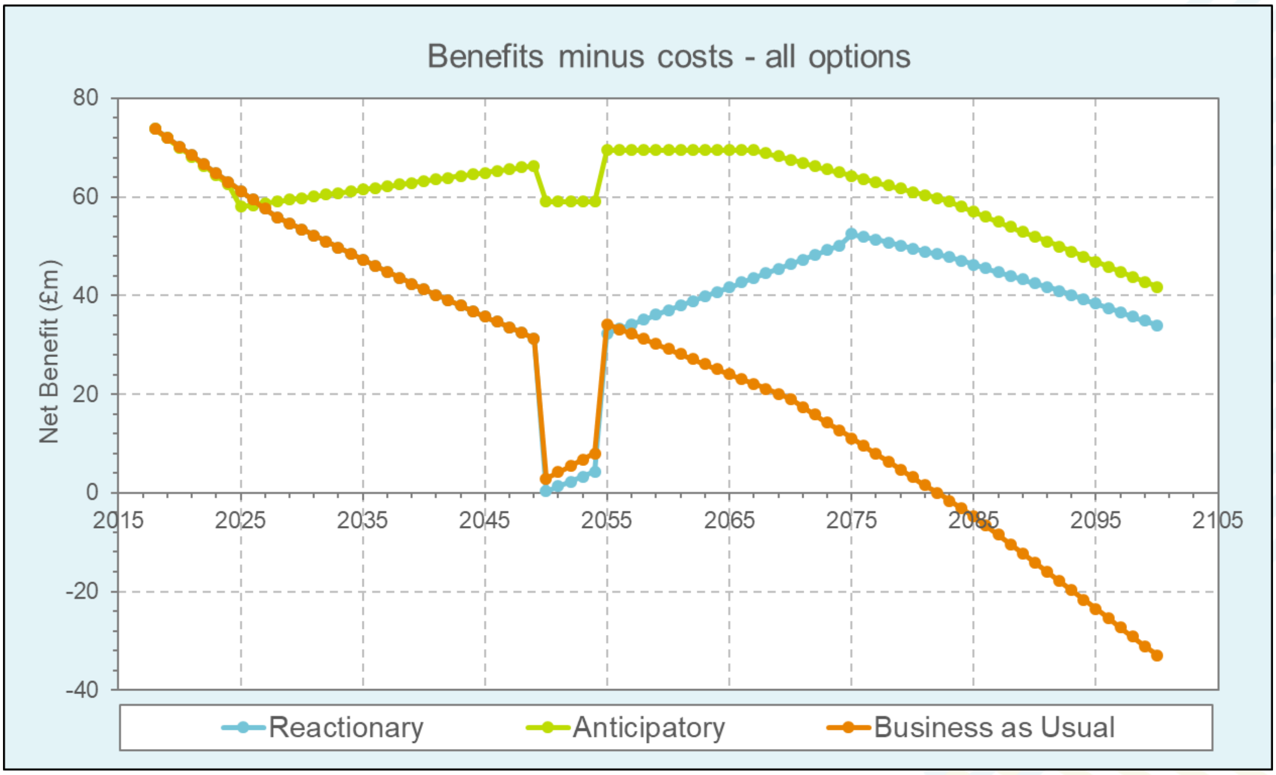


Figure 8-7 – Comparison of net benefits (cash) for each scenario

Total NPV's for each scenario are also provided in Table 8-4.

Table 8-3 – Summary of whole life Net Present Values (£m)

Scenario	PV Costs	PV Benefits	Net present value	Benefit of option
Business as Usual	£11,220	£12,390	£1,170	-
Anticipatory	£10,860	£12,680	£1,820	£650
Reactionary	£11,030	£12,410	£1,390	£210

The results can be summarised as follows:

- This case study is strongly influenced by the agricultural aspects included in the economic calculations. As such the results may be influenced by some of the assumptions used in the analysis. It is recommended that these are fully tested as part of further analysis.
- The BAU suggests that the overall costs outweigh the benefits early in the appraisal period due to the increase in agricultural costs and the reduction in productivity. Overall the net present values are negative for the majority of the appraisal period. The results exclude any agricultural subsidies – the retention of these is likely to extend the point at which costs exceed benefit; possibly beyond the period of analysis. Overall the whole life NPV equals £1,170m.
- The anticipatory of climate resilient land use and agricultural practices suggests that this enhances the overall benefits to the point that the benefits exceed the costs (albeit marginally) for the majority of the appraisal period. These leads to a positive overall net present value over the full appraisal period; suggesting that the anticipatory measures would be cost effective. Overall the whole life NPV equals £1,820m.
- The reactionary scenario suggests that the implementation of changes to land use and agricultural practices can offset the losses associated with the BAU scenario but not as efficiently as the anticipatory option. The benefits are less than the costs for the majority of the appraisal period but do narrow towards the end of the appraisal period. Overall the whole life NPV equals £1,390m.

Table 8-4 shows that over the life of the appraisal period the benefits of shifting to an anticipatory option are high. Most of these benefits are as a result of a reduction in agricultural costs and greater agricultural income, with more marginal increases in carbon sequestration, other environmental benefits and reductions in the threshold costs. This is shown graphically in Figure 8-8.

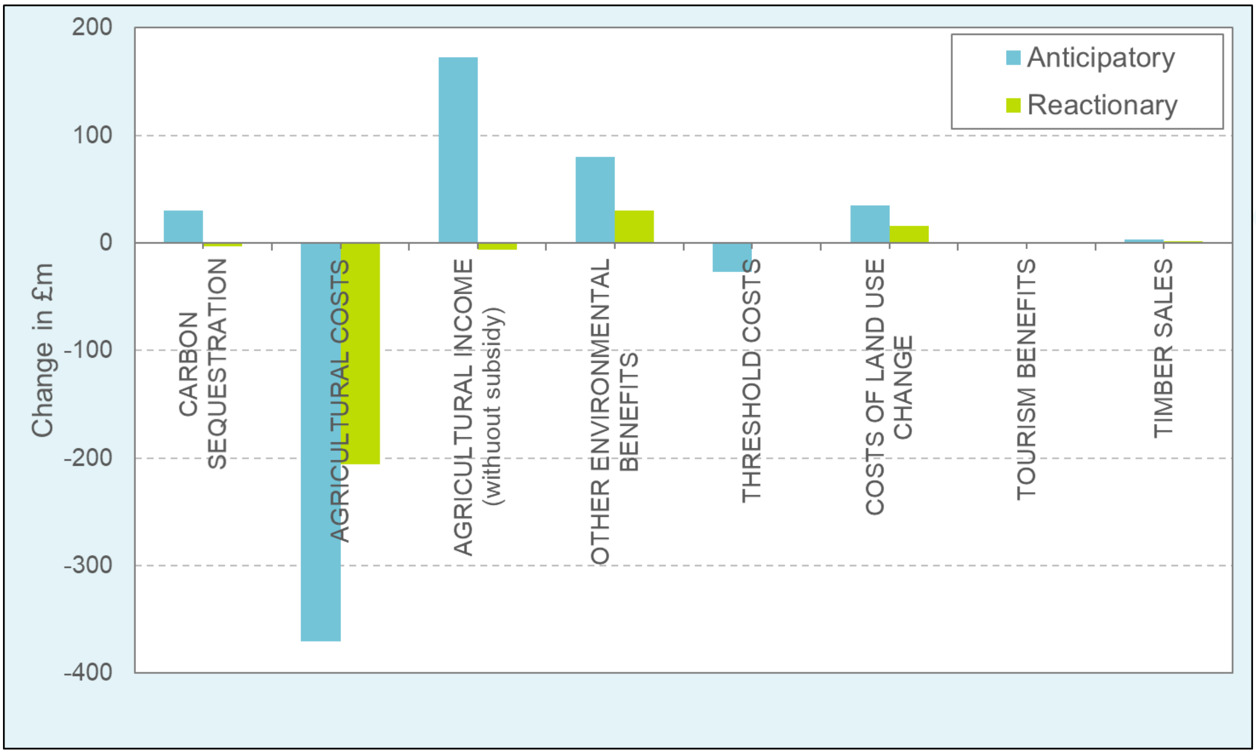


Figure 8-8 – Comparison of net present values for each scenario

8.4.3 Sensitivities

It is anticipated that both the costs of maintaining agricultural land types and the income received from these will increase and decrease respectively with climate change. Whilst it has been possible to estimate this impact for some land types under the business as usual scenario, a set of 'levers' have been used in the tool to force these impacts and to change them for each scenario. These are relatively blunt tools in the absence of more detailed information or more detailed methodologies (outside the scope of this assessment). They have therefore been subject to a sensitivity test to quantify the impact on the overall analysis.

The results of a test on a lower impact of agricultural costs and income are shown in terms of the long term NPV in Figure 8-10. This suggests that under this test, the overall Business as Usual case is more robust with higher benefits and lower costs. Overall the pattern between scenarios is similar although the anticipatory option and reactionary scenarios have much higher long term NPV's.

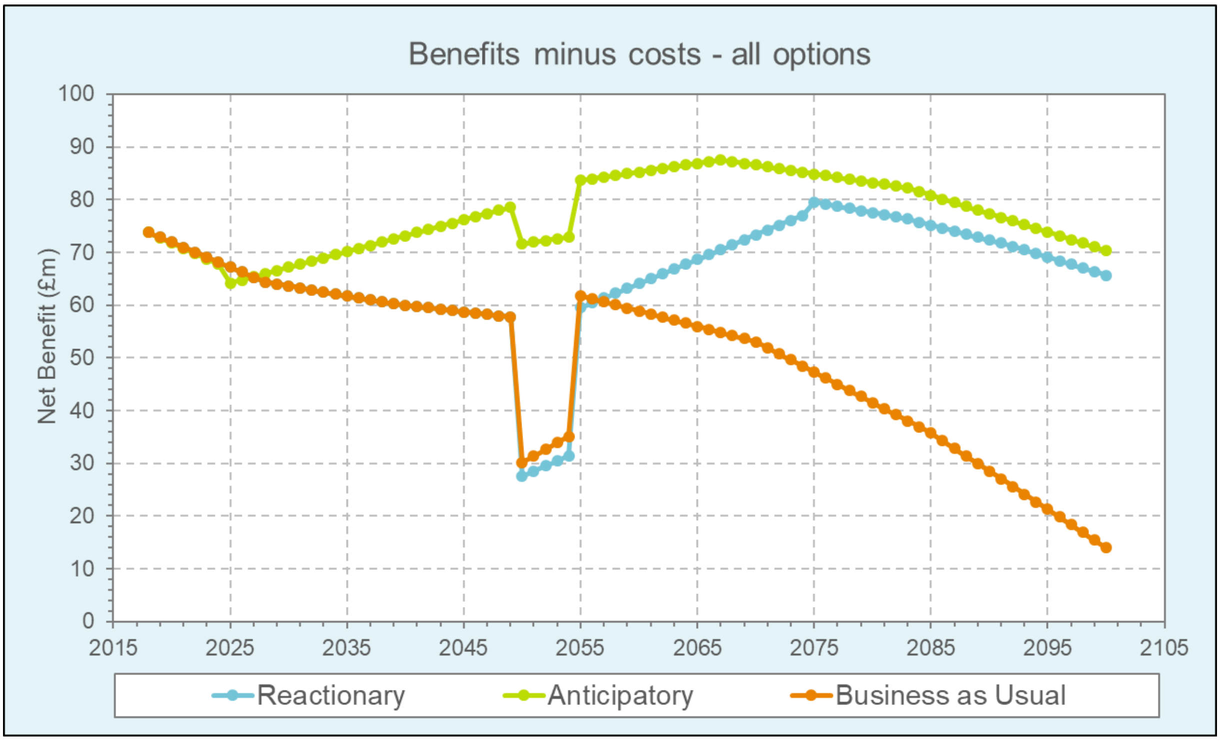
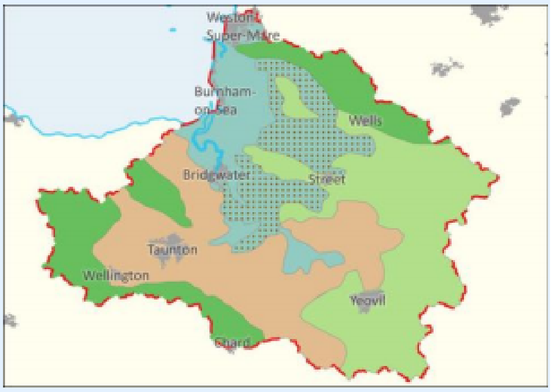


Figure 8-9 – Net benefit comparison between scenarios

8.5 Maximising carbon sequestration

A study carried out in 2009 on behalf of Somerset County Council found that the total carbon storage of the Somerset Levels was approximately 10.9 million tonnes, 3.3 million of which was held in the top 1m of peat, which is also the most vulnerable to erosion (Brown, 2009). The current drainage and cultivation by agriculture and extraction for horticulture and gardening contribute to a significant loss of peat, and consequently carbon storage (Deane, 2016). Therefore, to maximise carbon sequestration, these practices would be abolished and the land cover, land management and water management on the Somerset peatlands would be effectively controlled and maintained. Maintaining and increasing the woodland coverage would also help to enhance overall carbon sequestration in the catchment.

In 2016, the "Reimagining the Levels, Making the Connections" prospectus was put forward by a group of local stakeholders who identified a spatial vision for future land use in the catchment, as outlined in Figure 8-10. Whilst many of the actions are not explicitly aimed at increasing carbon sequestration, there are definitely such benefits that would result from measures involving peatland and wetland restoration and increased tree planting.



Map of the Catchment showing suggested spatial divisions	Peatlands on the Levels and Moors	Other areas of the Levels & Moors	The middle catchment – mainly mixed farming	The middle catchment - currently mainly arable cropping	The uplands
All land maintained as permanent pasture. No maize or arable crops, in order to preserve peat soils and avoid further sinking of the land surface	✓				
High summer-pen water levels to prevent drying out of peat soils and enhance habitats for wildlife, including nesting wading birds	✓	✓			
Examination of necessity for long-term land use change in certain areas to create protective and productive wetlands (e.g. reed harvesting, aquaculture)	✓	✓			
Use of floodplain grassland for winter flood storage, with farmers receiving payments in recognition of additional reductions in flood risk to other areas	✓	✓	✓	✓	
The conservation and active management of traditional orchards (and markets for their fruit) to enhance landscape character, biodiversity and productivity	✓	✓	✓	✓	
Tight control of where maize is grown and when it is harvested to reduce run-off and erosion, to include consideration of no-planting areas and farm quotas		✓	✓	✓	✓
Reintroduction of grass leys to arable rotations (where they have been lost) to build the water-holding capacity and fertility of soils and improve water quality		✓	✓	✓	✓
Use of soil remediation measures (e.g. mole drainage, minimum tillage) to re-cover soil structure and organic-matter content where this has been degraded		✓	✓	✓	✓
Creation of wide field margins and hedges, especially beside rivers and water-courses, to enhance ecological connectivity and reduce surface run-off			✓	✓	✓
Naturalisation of river and stream channels, allowing build-up of vegetation and woody debris to enhance habitats and slow water flow			✓	✓	✓
Creation of wetland flood storage areas by blocking land drains and creating 'leaky' dams, reducing peak river flows and increasing summer base flows			✓	✓	✓
Increased woodland cover, especially on steep slopes and areas prone to ero-sion in order to intercept run-off and provide all the other benefits of woodland			✓	✓	✓
Reinstatement of woodland management to enhance wildlife habitats, provide wood fuel and support rural jobs			✓	✓	✓
Blocking of moorland 'grips' (drainage channels in peat soils) to increase the water-holding capacity of the upland mire habitats					✓

Figure 8-10 – Proposed land use changes in Reimagining the Levels Somerset

9 Discussion, Policy, Synergy, and Trade-offs

This research presented above is based around thresholds and that thresholds would cause a non-linear disruption to a functional relationship between land uses and producers. However, this research has found, similarly to research completed by LEEP and a group of climate scientists from Exeter and the Met Office, that perfectly standard, virtually linear climate change trends have the potential to produce what looks like an abrupt change in land use, which externally looks like a threshold relationship. This is caused by climate change slowly altering the relative probability of different agricultural activities to the point where one will outperform another by a large enough margin to trigger a threshold switch.

Ultimately, this research did illustrate that climate change has an impact on the long-term viability of land use and anticipatory, through our economic assessment, has shown higher benefits and lower costs than none or reactionary adaptation. Some of the land use changes presented (e.g. greater diversification, arable to pastoral, or pastoral to woodland) are likely to have benefits in different climate futures and should be considered in future policy-making.

This research also looked at the impacts of climate change on different land uses in isolation from other socioeconomic drivers of change. In reality, it should not and cannot be considered in isolation. For example, within crop production, the current adaptive responses are reactionary to market opportunities that arise. The change in policies regarding UK food security (food availability, price, safety, and nutrition for UK citizens, import/export balance) will provide a strong direction to how arable land may change. Furthermore, global flood and commodity markets will affect the economic performance of UK agricultural businesses, and the relative competitiveness compared with the rest of the world.

The following tables sets out and summarise a policy appraisal for each of the Case Study locations. The land use outcome for Business as Usual (BaU), the Early Adaptation and the Maximum Mitigation land use scenarios are appraised against Government Policy Objectives. The Government Policy Document relied upon substantially is the Government's A Green Future: Our 25 Year Plan to Improve the Environment.

The appraisal identifies whether the projected land use changes support policy objectives, do not support policy objectives, or are likely to be in overall terms policy neutral.

The purpose of the tables are to identify where particular positive or negative policy outcomes are likely. They were completed using expert judgement and further research and engagement would be necessary in order provide consensus. The legend is found below.

Legend	Description
-	Neutral, no change or not applicable impact on policy
✓	Positively supportive impact on policy
✓✓	Strongly positive impact on policy
X	Negative impact on policy
XX	Strongly negative impact on policy

Table 9-1 – Policy appraisal legend

Target/Objectives	Policy/Strategy	Scenarios		
		BAU	Early Adaptation	Mitigation
Mitigating climate change: Continuing to cut emissions from LULUCF and Agriculture Sectors	Paris Agreement ambitions, UK Carbon Budget Commitments	XX	✓	✓✓
Take all possible action to mitigate climate change, while adapting to reduce its impact.	25y EP	XX	✓	✓✓
Thriving plants and wildlife: e.g. Achieve a resilient land network that is richer in plants and wildlife	25y EP	X	✓✓	✓✓
Increasing woodland in England in line with our aspiration of 12% cover by 2060: this would involve planting 180,000 hectares by end of 2042	25y EP	–	✓	✓
Taking action to recover threatened, iconic or economically important species of animals, plants and fungi, and where possible to prevent human induced extinction	25y EP	X	✓	✓
Creating or restoring 500,000 hectares of wildlife-rich habitat outside the protected site network, focusing on priority habitats as part of a wider set of land management changes providing extensive benefits	25y EP	–	✓	✓
Clean and plentiful water - increasing water supply and incentivising greater water efficiency	25y EP	X	✓	✓
Clean and plentiful water - reducing the damaging abstraction of water from rivers and groundwater	25y EP	–	–	–
Reaching or exceeding objectives for rivers, lakes, coastal and ground waters that are specially protected, whether for biodiversity or drinking water as per River Basin Management Plans	25y EP	–	✓	✓

Target/Objectives	Policy/Strategy	Scenarios		
		BAU	Early Adaptation	Mitigation
Reducing the risks from environmental hazards: e.g. expanding the use of natural flood management solutions	25y EP	X	✓✓	✓✓
Clean air - build on progress made in protecting the environment through the new Clean Air Strategy	25Y EP	–	–	–
Agriculture - balancing the need to produce food with the need to maintain and enhance natural capital	25y EP, Post CAP reform – (Successor to Agri env schemes)	–	–	–
Improve the approach to soil management: by 2030 we want all of England's soils to be managed sustainably, and we will use natural capital thinking to develop appropriate soil metrics and management approaches	25y EP	X	✓✓	✓✓
Ensuring that food is produced sustainably and profitably	25y EP	–	–	–
Increase timber supplies	25y EP	–	–	✓
Enhancing beauty, heritage and engagement with the natural environment	25y EP	X	✓	✓

Table 9-2 – Policy Review, Trade-offs and Synergies for Moor House and Upper Teesdale for Increased summer temperatures and drought[24]

[24] Assessment is not completed for Threshold B (drought and fire) since the results would be the same.

Target/Objectives	Policy/Strategy	Scenarios		
		BAU	Early Adaptation	Mitigation
Mitigating climate change: Continuing to cut emissions from LULUCF and Agriculture Sectors	Paris Agreement ambitions, UK Carbon Budget Commitments	–	✓	✓✓
Take all possible action to mitigate climate change, while adapting to reduce its impact.	25y EP	–	✓	✓✓
Thriving plants and wildlife: e.g. Achieve a resilient land network that is richer in plants and wildlife	25y EP	X	✓✓	✓✓
Increasing woodland in England in line with our aspiration of 12% cover by 2060: this would involve planting 180,000 hectares by end of 2042	25y EP	–	✓	✓✓
Taking action to recover threatened, iconic or economically important species of animals, plants and fungi, and where possible to prevent human induced extinction	25y EP	–	✓	–
Creating or restoring 500,000 hectares of wildlife-rich habitat outside the protected site network, focusing on priority habitats as part of a wider set of land management changes providing extensive benefits	25y EP	–	✓	✓
Clean and plentiful water - increasing water supply and incentivising greater water efficiency	25y EP	X	✓	✓
Clean and plentiful water - reducing the damaging abstraction of water from rivers and groundwater	25y EP	X	✓✓	✓✓
Reaching or exceeding objectives for rivers, lakes, coastal and ground waters that are specially protected, whether for biodiversity or drinking water as per River Basin Management Plans	25y EP	X	✓✓	✓✓

Target/Objectives	Policy/Strategy	Scenarios		
		BAU	Early Adaptation	Mitigation
Reducing the risks from environmental hazards: e.g. expanding the use of natural flood management solutions	25y EP	X	✓	✓
Clean air - build on progress made in protecting the environment through the new Clean Air Strategy	25Y EP	–	–	–
Agriculture - balancing the need to produce food with the need to maintain and enhance natural capital	25y EP, Post CAP reform – (Successor to Agri env schemes)	X	✓	✓
Improve the approach to soil management: by 2030 we want all of England's soils to be managed sustainably, and we will use natural capital thinking to develop appropriate soil metrics and management approaches	25y EP	–	✓	✓
Ensuring that food is produced sustainably and profitably	25y EP	X	✓	–
Increase timber supplies	25y EP	–	✓	✓✓
Enhancing beauty, heritage and engagement with the natural environment	25y EP	–	✓	–

Table 9-3 – Policy Review, Trade-offs and Synergies - The Broads, Warmer drier summers generally with a 3 year drought

Target/Objectives	Policy/Strategy	Scenarios		
		BAU	Early Adaptation	Mitigation
Mitigating climate change: Continuing to cut emissions from LULUCF and Agriculture Sectors	Paris Agreement ambitions, UK Carbon Budget Commitments	–	✓	✓✓
Take all possible action to mitigate climate change, while adapting to reduce its impact.	25y EP	X	✓	✓✓
Thriving plants and wildlife: e.g. Achieve a resilient land network that is richer in plants and wildlife	25y EP	X	✓✓	✓✓
Increasing woodland in England in line with our aspiration of 12% cover by 2060: this would involve planting 180,000 hectares by end of 2042	25y EP	–	✓	✓✓
Taking action to recover threatened, iconic or economically important species of animals, plants and fungi, and where possible to prevent human induced extinction	25y EP	–	–	–
Creating or restoring 500,000 hectares of wildlife-rich habitat outside the protected site network, focusing on priority habitats as part of a wider set of land management changes providing extensive benefits	25y EP	–	✓	✓
Clean and plentiful water - increasing water supply and incentivising greater water efficiency	25y EP	X	✓	✓
Clean and plentiful water - reducing the damaging abstraction of water from rivers and groundwater	25y EP	X	✓	✓✓
Reaching or exceeding objectives for rivers, lakes, coastal and ground waters that are specially protected, whether for biodiversity or drinking water as per River Basin Management Plans	25y EP	X	✓✓	✓✓
Reducing the risks from environmental hazards: e.g. expanding the use of natural flood management solutions	25y EP	X	✓	✓
Clean air - build on progress made in protecting the environment through the new Clean Air Strategy	25Y EP	–	–	–

Target/Objectives	**Policy/Strategy**	Scenarios		
		BAU	Early Adaptation	Mitigation
Agriculture - balancing the need to produce food with the need to maintain and enhance natural capital	25y EP, Post CAP reform – (Successor to Agri env schemes)	X	✓	✓
Improve the approach to soil management: by 2030 we want all of England's soils to be managed sustainably, and we will use natural capital thinking to develop appropriate soil metrics and management approaches	25y EP	–	✓	✓
Ensuring that food is produced sustainably and profitably	25y EP	X	✓	–
Increase timber supplies	25y EP	–	✓	✓✓
Enhancing beauty, heritage and engagement with the natural environment	25y EP	–	✓	–

Table 9-4 – Policy Review, Trade-offs and Synergies - The Broads, Coastal storm events and flooding

Target/Objectives	Policy/Strategy	Scenarios		
		BAU	Early Adaptation	Mitigation
Mitigating climate change: Continuing to cut emissions from LULUCF and Agriculture Sectors	Paris Agreement ambitions, UK Carbon Budget Commitments	X	✓	✓✓
Take all possible action to mitigate climate change, while adapting to reduce its impact.	25y EP	X	✓	✓✓
Thriving plants and wildlife: e.g. Achieve a resilient land network that is richer in plants and wildlife	25y EP	X	✓	
Increasing woodland in England in line with our aspiration of 12% cover by 2060: this would involve planting 180,000 hectares by end of 2042	25y EP	–	✓	✓✓
Taking action to recover threatened, iconic or economically important species of animals, plants and fungi, and where possible to prevent human induced extinction	25y EP	–	–	–
Creating or restoring 500,000 hectares of wildlife-rich habitat outside the protected site network, focusing on priority habitats as part of a wider set of land management changes providing extensive benefits	25y EP	–	✓	✓
Clean and plentiful water - increasing water supply and incentivising greater water efficiency	25y EP	–	✓	✓
Clean and plentiful water - reducing the damaging abstraction of water from rivers and groundwater	25y EP	X	✓	✓
Reaching or exceeding objectives for rivers, lakes, coastal and ground waters that are specially protected, whether for biodiversity or drinking water as per River Basin Management Plans	25y EP	X	✓✓	✓✓

Target/Objectives	Policy/Strategy	Scenarios		
		BAU	Early Adaptation	Mitigation
Reducing the risks from environmental hazards: e.g. expanding the use of natural flood management solutions	25y EP	X	✓✓	✓✓
Clean air - build on progress made in protecting the environment through the new Clean Air Strategy	25Y EP	–	–	–
Agriculture - balancing the need to produce food with the need to maintain and enhance natural capital	25y EP, Post CAP reform – (Successor to Agri env schemes)	X	✓✓	✓
Improve the approach to soil management: by 2030 we want all of England's soils to be managed sustainably, and we will use natural capital thinking to develop appropriate soil metrics and management approaches	25y EP	–	✓✓	✓✓
Ensuring that food is produced sustainably and profitably	25y EP	X	✓	✓
Increase timber supplies	25y EP	–	✓✓	✓✓
Enhancing beauty, heritage and engagement with the natural environment	25y EP	–	✓	✓

Table 9-5 – Policy Review, Trade-offs and Synergies - The Petteril, Warmer and drier summers plus repeated summer droughts

Target/Objectives	Policy/Strategy	Scenarios		
		BAU	Early Adaptation	Mitigation
Mitigating climate change: Continuing to cut emissions from LULUCF and Agriculture Sectors	Paris Agreement ambitions, UK Carbon Budget Commitments	X	✓	✓✓
Take all possible action to mitigate climate change, while adapting to reduce its impact.	25y EP	X	✓	✓✓
Thriving plants and wildlife: e.g. Achieve a resilient land network that is richer in plants and wildlife	25y EP	X	✓✓	
Increasing woodland in England in line with our aspiration of 12% cover by 2060: this would involve planting 180,000 hectares by end of 2042	25y EP	–	✓✓	✓✓
Taking action to recover threatened, iconic or economically important species of animals, plants and fungi, and where possible to prevent human induced extinction	25y EP	–	–	–
Creating or restoring 500,000 hectares of wildlife-rich habitat outside the protected site network, focusing on priority habitats as part of a wider set of land management changes providing extensive benefits	25y EP	–	✓✓	✓
Clean and plentiful water - increasing water supply and incentivising greater water efficiency	25y EP	–	✓	✓
Clean and plentiful water - reducing the damaging abstraction of water from rivers and groundwater	25y EP	X	✓	✓
Reaching or exceeding objectives for rivers, lakes, coastal and ground waters that are specially protected, whether for biodiversity or drinking water as per River Basin Management Plans	25y EP	X	✓✓	✓✓

Target/Objectives	Policy/Strategy	Scenarios		
		BAU	Early Adaptation	Mitigation
Reducing the risks from environmental hazards: e.g. expanding the use of natural flood management solutions	25y EP	X	✓✓	✓✓
Clean air - build on progress made in protecting the environment through the new Clean Air Strategy	25Y EP	–	–	–
Agriculture - balancing the need to produce food with the need to maintain and enhance natural capital	25y EP, Post CAP reform – (Successor to Agri env schemes)	X	✓✓	✓
Improve the approach to soil management: by 2030 we want all of England's soils to be managed sustainably, and we will use natural capital thinking to develop appropriate soil metrics and management approaches	25y EP	–	✓✓	✓✓
Ensuring that food is produced sustainably and profitably	25y EP	X	✓	✓
Increase timber supplies	25y EP	–	✓✓	✓✓
Enhancing beauty, heritage and engagement with the natural environment	25y EP	–	✓	✓

Table 9-6 – Policy Review, Trade-offs and Synergies - The Petteril, Flooding

Target/Objectives	Policy/Strategy	Scenarios		
		BAU	Early Adaptation	Mitigation
Mitigating climate change: Continuing to cut emissions from LULUCF and Agriculture Sectors	Paris Agreement ambitions, UK Carbon Budget Commitments	X	✓	✓✓
Take all possible action to mitigate climate change, while adapting to reduce its impact.	25y EP	X	✓	✓✓
Thriving plants and wildlife: e.g. Achieve a resilient land network that is richer in plants and wildlife	25y EP	X	✓✓	✓✓
Increasing woodland in England in line with our aspiration of 12% cover by 2060: this would involve planting 180,000 hectares by end of 2042	25y EP	–	✓✓	✓✓
Taking action to recover threatened, iconic or economically important species of animals, plants and fungi, and where possible to prevent human induced extinction	25y EP	–	✓	✓
Creating or restoring 500,000 hectares of wildlife-rich habitat outside the protected site network, focusing on priority habitats as part of a wider set of land management changes providing extensive benefits	25y EP	–	✓	✓
Clean and plentiful water - increasing water supply and incentivising greater water efficiency	25y EP	–	✓	✓
Clean and plentiful water - reducing the damaging abstraction of water from rivers and groundwater	25y EP	X	✓	✓
Reaching or exceeding objectives for rivers, lakes, coastal and ground waters that are specially protected, whether for biodiversity or drinking water as per River Basin Management Plans	25y EP	X	✓	✓

Target/Objectives	Policy/Strategy	Scenarios		
		BAU	Early Adaptation	Mitigation
Reducing the risks from environmental hazards: e.g. expanding the use of natural flood management solutions	25y EP	X	✓✓	✓✓
Clean air - build on progress made in protecting the environment through the new Clean Air Strategy	25Y EP	–	–	–
Agriculture - balancing the need to produce food with the need to maintain and enhance natural capital	25y EP, Post CAP reform – (Successor to Agri env schemes)	X X	✓✓	✓
Improve the approach to soil management: by 2030 we want all of England's soils to be managed sustainably, and we will use natural capital thinking to develop appropriate soil metrics and management approaches	25y EP	–	✓✓	✓
Ensuring that food is produced sustainably and profitably	25y EP	X	✓	–
Increase timber supplies	25y EP	–	✓✓	✓✓
Enhancing beauty, heritage and engagement with the natural environment	25y EP	–	✓	–

Table 9-7 – Policy Review, Trade-offs and Synergies - Somerset, Warmer and drier with drought

Target/Objectives	Policy/Strategy	Scenarios		
		BAU	Early Adaptation	Mitigation
Mitigating climate change: Continuing to cut emissions from LULUCF and Agriculture Sectors	Paris Agreement ambitions, UK Carbon Budget Commitments	X	✓	✓✓
Take all possible action to mitigate climate change, while adapting to reduce its impact.	25y EP	X	✓	✓✓
Thriving plants and wildlife: e.g. Achieve a resilient land network that is richer in plants and wildlife	25y EP	X	✓✓	✓✓
Increasing woodland in England in line with our aspiration of 12% cover by 2060: this would involve planting 180,000 hectares by end of 2042	25y EP	–	✓✓	✓✓
Taking action to recover threatened, iconic or economically important species of animals, plants and fungi, and where possible to prevent human induced extinction	25y EP	–	✓	✓
Creating or restoring 500,000 hectares of wildlife-rich habitat outside the protected site network, focusing on priority habitats as part of a wider set of land management changes providing extensive benefits	25y EP	–	✓	✓
Clean and plentiful water - increasing water supply and incentivising greater water efficiency	25y EP	–	✓	✓
Clean and plentiful water - reducing the damaging abstraction of water from rivers and groundwater	25y EP	X	✓	✓
Reaching or exceeding objectives for rivers, lakes, coastal and ground waters that are specially protected, whether for biodiversity or drinking water as per River Basin Management Plans	25y EP	X	✓	✓
Reducing the risks from environmental hazards: e.g. expanding the use of natural flood management solutions	25y EP	X	✓✓	✓✓

Target/Objectives	Policy/Strategy	Scenarios		
		BAU	Early Adaptation	Mitigation
Clean air - build on progress made in protecting the environment through the new Clean Air Strategy	25Y EP	_	_	_
Agriculture - balancing the need to produce food with the need to maintain and enhance natural capital	25y EP, Post CAP reform – (Successor to Agri env schemes)	X X	✓✓	✓
Improve the approach to soil management: by 2030 we want all of England's soils to be managed sustainably, and we will use natural capital thinking to develop appropriate soil metrics and management approaches	25y EP	_	✓✓	✓
Ensuring that food is produced sustainably and profitably	25y EP	X	✓	_
Increase timber supplies	25y EP	_	✓✓	✓✓
Enhancing beauty, heritage and engagement with the natural environment	25y EP	_	✓	_

Table 9-8 – Policy Review, Trade-offs and Synergies - Somerset, Warmer and wetter with waterlogging and floods

10 Recommendations

This research has explored the economics of different case study locations reacting to or anticipating climate hazards of drought, heatwaves, wildfire, and flooding. This research was conducted using previous assessments, industry, academic research, and expert opinion to develop plausible impact and transformative adaptive measures. Further detailed research would be needed to understand the extent and resulting condition of land uses, using local expertise and environmental modelling to model impacts of thresholds.

Recommendations following this research include:

- Exploration of thresholds (further discussed in the conclusion)
- Research on the probability of the thresholds and when they may be projected to occur.
- Understanding in more detail how easy or difficult it is to anticipate thresholds before they occur, which is needed to undertake the anticipatory adaptation responses.
- Further engagement with local experts, landowners, regulatory and planning departments of the case study locations to better understand the willingness to change land use.

- Explore other engagement and educational techniques to share best practice amongst landowners to reduce environmental impact, and emissions of greenhouse gas (GHG) emissions.
- Understand the impact of drought events on production and land management and adaptive decision making (either anticipatory or reactionary).
- Determine land uses and condition of land use which would maximise carbon sequestration.
- Conduct this research using the suite of GHG, since methane and nitrous oxide have a greater impact on climate change.
- Better understand how, where, and to what extent different low-regret and transformative adaptive measures could be implemented (through further engagement and research).

Further extensive economic assessment would also be recommended in order to provide a more comprehensive representation of the scenarios. The current economic assessment tool was limited to the factors described below, which had readily available data for land use categories used in CORINE and by area (hectare). Further recommendations include:

- Complete a baseline natural capital account for each case study.
- Include other natural capital assets and its ecosystem services (either monetised or non-monetised) to provide a complete picture.
- Include the condition of the natural capital asset in assessment.

11 Conclusion

This research, at a high-level, has explored the economics of land use change as a consequence of climate hazards, or thresholds, in four case study locations – Moor House and Upper Teesdale, Norfolk and Suffolk Broads, the Petteril, and Somerset. This research attempts to help policy makers, regulators, practitioners, and others to understand the importance of thinking about the long-term viability of current land use, and the benefits of taking action to improve the resilience of landscapes before impacts actually occur. The different low-regret and transformative adaptive measures were applicable across case study locations with similar land use. It should be noted that although both low-regret and transformative adaptive measures were identified in an abrupt and disruptive change in land use which may look like a threshold relationship, climate change can slowly alter land use and management to trigger a threshold switch. For example, the Moor House and Upper Teesdale case study illustrated a threshold that is likely to cause a greatest impact from constant gradual change, destroying the active living surface which causes peat regeneration.

The economic assessment concluded that early adaptation would have greater total benefits than both the business as usual and reactionary scenario and throughout the 100-year appraisal period. Further research and a comprehensive economic assessment, including natural capital accounting is recommended to provide a more comprehensive assessment of the multiple benefits of land use change.

Lastly, further input of how, to what extent, and the impact of these adaptive measures will differ depends on the local landscape and acceptance of change. It is pertinent to understand how producers perceive the relative importance of climate change together with other pressures they face and whether they are able to make the changes they would like to or are locked into current practices through various forms of barriers (i.e. policies) (Wreford and Adger, 2010).

Appendices

A Project Principles

NOTE TO FILE

2017s7100
Economics of Land Use Change
Adaptation Sub-Committee to the Committee on Climate Change
10 January 2018
Susie Goddard
PGA Project Principles

1 INTENT

The purpose of this document is to establish key parameters which will be applied to each Particular Geographical Area. These are the climate consequences of a 2° and 4° rise in temperature and the basis for establishing a relevant Business as Usual Scenario and determining a High Resilience Scenario for each PGA.

The purpose of determining key parameters is to:

- Establish the most likely climate and weather-related consequences from a 2° and 4° rise in temperature for each PGA; and
- Establishing guidance for each PGA team on how a Business as Usual (BAU) and a High Resilience scenario should be determined.

1.1 This document sets out the key parameters applicable to each PGA and outlines the methodology under which these were established, for context.

1.2 Where possible and appropriate, principles will be spatially specific in relation to the four PGAs: Somerset Levels, Moorhouse, Norfolk Broads, Petteril Catchment.

2 CLIMATE CHANGE FUTURES

2.1 The ASC requires that the characteristics and costs/benefits for each scenario should be analysed assuming a global temperature rise of approximately **2ºC and 4ºC by the end of the century.** The UK Climate Change Risk Assessment (CCRA) 2017 sets out a "best case" global temperature rise scenario of 2ºC based on implementation of the Paris Climate Change Agreement in which all participating nations implement processes to limit global surface temperature change to "well below" 2ºC. However, if these national commitments are not fulfilled, global temperatures could rise by 4.1–4.8°C, with a temperature increase of 6°C remaining plausible (CCC, 2015).

2.2 The CCRA 2017 derives its 2° and 4° futures by interpolating between UKCP09 future projections for different emissions scenarios, each of which is associated with a global warming figure. These are outlined in the table below (extracted from the UKCP09 Projections report[1]).

2.3 For the purpose of this project, and aligned with CCRA methodology, we propose that the following CP09 future projections are used:

- 2° global temperature rise scenario: 2080s (2070-2099) Low emissions 50% probability.
- 4° global temperature rise scenario: 2080s (2070-2099) High emissions 50% probability.

[1] UK Climate Projections, Climate Change Projections. v3 December 2010

	2020s			2050s			2080s		
Emissions	10%	50%	90%	10%	50%	90%	10%	50%	90%
High	1.0	1.3	1.6	2.1	2.7	3.3	3.4	4.3	5.3
Medium	1.0	1.3	1.6	1.9	2.4	3.0	2.6	3.4	4.2
Low	0.9	1.2	1.6	1.6	2.1	2.6	2.0	2.6	3.4

2.4 Greenhouse gas emissions contribute to the warming of the earth's atmosphere and affect how the climate might change in the future. It is impossible to predict exactly how much greenhouse gas emissions will be released in the future. In light of this climate projections are given for a number of different plausible scenarios for greenhouse gas emissions.

2.5 High, Medium and Low emissions scenarios are used within COP09. These scenarios are based on a set of assumptions about factors such as socio-economic development and technological change and were developed by the Intergovernmental Panel on Climate Change (IPCC). UKCP09 treats these scenarios as equally plausible. When presenting UKCP09 projections you may want to present findings for a range of scenarios to show the range of possible outcomes.

2.6 50% probability is used as a central estimate, denoting a 50% level of confidence, based on what is currently known, that the change in temperature will be above or below the quoted change.

2.7 Based on the Low Emissions scenario (2°) and High Emissions scenario (4°) at the end of the century (2080s), the following futures are provided by OKCP09 data for the geographic location in which each PGA is situated.

Note: summary data only is presented below. Full data sets and customisable outputs can be accessed via the Climate Change Projections User Interface: http://ukclimateprojections-ui.metoffice.gov.uk/ui/start/start.php

Table 1: 2° temperature rise by end of the century (UKCP09 Low emissions 2080s 50% probability)

PGA	Administrative region (as defined by COP09)	Mean winter temp (°C)	Mean summer temp (°C)	Summer mean daily max (°C)	Summer mean daily min (°C)	Mean winter precipitation (% change)	Mean summer precipitation (% change)	Sea level rise (cm)[2]
Somerset Levels	South West England	2.4	2.9	4.1	3.1	19	-15	28
Norfolk Broads	East of England	2.6	2.7	3.7	3.0	15	-13	26
Petteril Catchment	North West England	2.3	2.8	3.6	2.8	15	-17	NA
Moorhouse	North East England	2.4	2.8	3.6	2.7	12	-13	NA

[2] Source: UK Climate Change Risk Assessment 2017: Evidence Report: Flood risk: Appendix C – Climate Change Projections October 2015: Sayers and Partners LLP https://www.theccc.org.uk/publication/sayers-for-the-asc-projections-of-future-flood-risk-in-the-uk/
Lyme Bay data used for Somerset Levels, Lincolnshire data used for Norfolk Broads

Table 2: 4° temperature rise by end of the century (COP09 High emissions 2080 50% probability)

PGA	Administrative region (as defined by COP09)	Mean winter temp (°C)	Mean summer temp (°C)	Summer mean daily max (°C)	Summer mean daily min (°C)	Mean winter precipitation (% change)	Mean summer precipitation (% change)	Sea level rise1
Somerset Levels	South West England	3.4	5.0	6.9	5.3	31	-30	66
Norfolk Broads	East of England	3.6	4.4	6.2	5.0	25	-25	64
Petteril Catchment	North West England	3.1	4.7	6.0	4.6	26	-28	NA
Moorhouse	North East England	3.1	4.7	5.9	4.6	19	-23	NA

3 BUSINESS AS USUAL

This project will follow the definition of Business As Usual (BAU) generally accepted within UK environmental policy making. That is, that future development trends follow those of the past, with limited changes in policies and nothing additional done to adapt to climate change over and above what is already being undertaken.

3.1 Specifically, the following BAU principles are aligned to the Adaptation Sub-Committee (ASC) mitigation project: *"Quantify the impact of future land use scenarios to 2050 and beyond"* which is currently being undertaken by CEH. The mitigation project explores how the use and management of land, soils, crops and livestock could deliver longer-term deeper emissions cuts, increased supply of bioenergy feedstocks and increased GHG removals in the UK land use, land use change and forestry (LULUCF) sectors to 2050 and beyond, whilst at least maintaining resilience and other outputs. The table below outlines the principles for BAU (i.e. low ambition). The mitigation project has developed two documents relating to land use scenario development and assumptions[3][4] which are saved on JBAs project folder and available from the Project Manager should they be required.

Table 3: Business As Usual Principles

Metric	**Multi-functional land use – Ambition (CEH mitigation project)**	**Implications**
Agricultural farming practices	Low	• Current N application rates and use efficiency maintained. • Current livestock management, and therefore emissions, maintained. • Livestock numbers meet Food and Agricultural Policy Research Institute (FAPRI) projections. • Current manure management practices continue.
Agriculture technology development e.g. yields, Feed Conversion Ratios (FCRs)	Low	• Current crop yields maintained. • Significant indoor horticulture not developed. • Livestock numbers meet FAPRI projections. • Current levels for food waste maintained. • No change in livestock stocking densities.
Multi-functional land use e.g. agro-forestry	Low	• Current levels of agroforestry maintained at 1% cover with hedgerows and shelter belts. • Current length of hedges maintained.
Afforestation, reforestation and forest management	Low	• Current rates of planting (based on average for last 3 years). • Current management rates- conifer 100% managed, broadleaf 20% managed). • Current mix of HWP for conifers. Broadleaf Harvested Wood Products (HWP) used for fuel.
Bioenergy crops and harvested	Low	• Current planting rates for 2G biomass and current

[3] CEH "LU project Scenario development_v2" doc. Provided by Janet Moxley, CEH
[4] CEH "Scenario assumptions from Workshop v2 clean (003)" doc. Provided by Janet Moxley, CEH

Metric	Multi-functional land use – Ambition (CEH mitigation project)	Implications
wood products		area of 1G biomass. • Current yields maintained at 10 t/ha.
Peatlands mitigation	Low	• In line with IPCC Wetland Supplement project Central scenario[5]. • Restore 50 kha of peatland in Scotland by 2020 and 250 kha by 2030. • Restoration of peat extraction at planned dates.
Diet change	Low	• Food waste at current levels. • Food production as for FAPRI projections.
Food output per capita	BAU	• Food output per capita maintained.
Food imports/exports ratio	??	• Domestic food output per capita assumptions are met first and allow import/export ratio can vary. • Proportion of meat in imported food should not exceed current levels to avoid exporting emissions.

3.2 These metrics and assumptions outlined above are part of the CCC's mitigation project. This project will go beyond these assumptions, and further in each PGA. However, any further assumptions made should be clearly set out by each PGA lead with justification that will be confirmed with the ASC's stakeholders during the London workshop.

4 HIGH RESILIENCE

The principles of High Resilience are aligned to those developed by CEH for the CCC/ASC mitigation project currently being undertaken. Principles are aligned to assumptions developed by CEH for "multi-functional land use". Of the scenarios developed by CEH "multi-functional land use" is best aligned to the concept of increasing natural capital to enhance resilience, and thereby is considered a suitable proxy for High Resilience in this project. Other mitigation project scenarios developed by CEH follow different pathways to mitigating climate change that do not typically focus on enhancing natural capital. For example, the "innovative- technology push" scenario focuses on maximising land use change to mitigate climate change, rather than maximise natural capital.

The table below outlines the principles for "multi-functional land use" based on the CEH mitigation project (see BAU section for references).

Table 4: High Resilience Principles

Metric	Multi-functional land use – Ambition (CEH mitigation project)	Implications
Agricultural farming	(ambition aligned	• Measures including loosening, compacted soils,

[5] IPCC 2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Inventories: Wetlands.

Metric	**Multi-functional land use – Ambition (CEH mitigation project)**	**Implications**
practices	with) 5th Carbon Budget	precision farming and increased legumes 20% improvement in N use efficiency in 2050. • Precision livestock farming, including improved diets and monitoring weight, results in a 5% reduction in livestock emissions per unit production by 2050. • Reduction in ruminants by 2050 consistent with a 20% reduction of domestic consumption of red meat and dairy and exports at current levels due to dietary change. Increase in number of pigs and chickens to replace red meat loss. • Proportion of nutrition formerly supplied by red meat at dairy replaced by pork and chicken, and a proportion from plant-based protein. • Decrease in volume of manure in line with ruminant number decrease. Manure management improves.
Agriculture technology development .e.g. yields, FCRs	Medium	• Improved crop yield through plant breeding, GM crops with improved disease control. Wheat yields reach 10 t/ha by 2050. • Some move to indoor horticulture. 10% of horticulture moves indoors by 2050. • Reduction in land required for grazing/fodder production. (Not quite by 20% because of requirements for extra pigs and chickens and meat and dairy exports remaining as current). • Reduce food waste by 20% by 2025 (WRAP) • Refocus from extensive to intensive grazing (particularly for sheep) and possibly mob grazing. Increase in average stocking density for different types of grazing livestock.
Multi-functional land use e.g. agro-forestry	High	• High levels of agroforestry. In excess of 5% of land used for agroforestry (including hedges and shelterbelts) by 2030. • Length of hedge on agricultural land increased to 10% above 1984 levels by 2050. • 30% of hedge length managed for biomass.
Afforestation, reforestation and forest management	High	• 1970s planting rates. 50kha/y planting UK wide to 2100. • 30% conifer, 70% broadleaf. • Afforestation will occur on semi-natural grassland, which is capable of supporting trees, but **not** peat or priority habitats. • Increase in actively managed broadleaf woodland

Metric	Multi-functional land use – Ambition (CEH mitigation project)	Implications
		– 80% actively managed by 2050. • Increase proportion of broadleaf used for construction through novel products e.g. gluelam and cross-laminated timber. 75% of broadleaf HWP used as sawn board by 2040 (including novel products e.g. gluelam) by 2040 with remainder used for fuel.
Bioenergy crops and harvested wood products	Medium	• Increased planting of 1G and 2G biomass on cropland and improved grassland. • Maintain current area of 1G biomass, and expand miscanthus and Short Rotation Coppice (SRC) initially with Short Rotation Forestry (SRF) from 2030. • Could also include reeds from paludiculture on rewetted lowland peat. • Miscanthus and SRC on cropland and improved grassland. SRF on grassland. • Yield increases due to good agronomy and plant breeding. Yield increases to 15t/ha oven dry material by 2050.
Peatlands mitigation	Medium/High	• 25% (med) – 50% (high) area rewetting of degraded lowland peat, restoration of 50% of area of degraded upland peat and restoration of 25% (med) – 50% (high) of forest on peat with less than Yield Class 8 for all administrations by 2050. • Half of the rewetted lowland peat area to be used for paludiculture (reeds, SRC, sphagnum) and half restored to semi-natural habitats. • Partial rewetting of lowland peats will not be included in this scenario, as it is likely to be more complex to implement, and could distract from full rewetting. • (High) Plus partial rewetting by raising the water-table on unrestored lowland peats either permanent or seasonal basis.
Diet change	Medium	• Reduce food waste by 20% by 2025 (WRAP). • Reduce consumption of red meat and dairy products consistent with Cranfield study (20%) by 2050. • Nutrient value of diet maintained by increased consumption of pork, chicken, fish and vegetable products.
Food output per capita	BAU	• Food output per capita maintained.

Metric	**Multi-functional land use – Ambition (CEH mitigation project)**	**Implications**
Food imports/exports ratio		• Domestic food output per capita assumptions are met first and allow import/export ratio can vary. • Proportion of meat in imported food should not exceed current levels in order to avoid exporting emissions.

These metrics and assumptions outlined above are part of the CCC's mitigation project. This project will go beyond these assumptions, and further in each PGA. However, any further assumptions made should be clearly set out by each PGA lead with justification that will be confirmed with the ASC's stakeholders during the London workshop.

B Method B: Vulnerability Assessment

B.1 Definitions of exposure and sensitivity

Climate change hazard	High (3)	Medium (2)	Low (1)	None (0)
Flooding (describe frequency, extent, antecedent conditions)	Recent evidence of this climate hazard occurring in the last 10 years and is certain to occur.	Evidence of this climate hazard occurring in the last 50 years and is likely to occur.	Little evidence of this climate hazard occurring in the past and could be imaginable.	Has not and could not happen at this location.
High rainfall and storm events				
Higher summer temperatures and reduced rainfall				
Wetter winters				
Droughts and possible fire risk				
Sea level rise				
Coastal erosion				
Soil erosion				

Table 11-1 – Definitions of exposure

<table>
<tr><th>Climate change hazard</th><th>High (3)</th><th>Medium (2)</th><th>Low (1)</th><th>None (0)</th></tr>
<tr><td>Flooding (describe frequency, extent, antecedent conditions)</td><td rowspan="8">When the demands of existing land management and the demands on primary assets (soil) are significantly pressured in response to climate-related hazards.</td><td rowspan="8">When the demands of existing land management and the demands on primary assets (soil) are notably pressured in response to climate-related hazards.</td><td rowspan="8">When the demands of existing land management and the demands on primary assets (i.e. soil) may face a slight pressure in response to these climate-related hazards.</td><td rowspan="8">When the demands of existing land management and the demands on primary assets (i.e. soil) will not change in response to these climate-related hazards.</td></tr>
<tr><td>High rainfall and storm events</td></tr>
<tr><td>Higher summer temperatures and reduced rainfall</td></tr>
<tr><td>Wetter winters</td></tr>
<tr><td>Droughts and possible fire risk</td></tr>
<tr><td>Sea level rise</td></tr>
<tr><td>Coastal erosion</td></tr>
<tr><td>Soil erosion</td></tr>
</table>

Table 11-2 – Definitions of sensitivity

Exposure

Changing Climate hazard	Current exposure	Future (2100) exposure
Flooding (describe frequency, extent, antecedent condition)	1	2
High rainfall and storm events	3	3
Higher summer temperatures and reduced rainfall	2	3
Wetter winters	3	3
Droughts and possible fire risk	2	3
Sea level rise	0	0
Coastal erosion	0	0
Soil erosion	3	3
Warmer winters	2	3

Sensitivity

Changing Climate hazard	Soil	Grassland	Agroforestry	Arable land
High rainfall and storm events	3	2	2	3
Higher summer temperatures and reduced rainfall	2	2	1	2 (+)
Wetter winters	1	1	1	2
Droughts and possible fire risk	3	2	2	3
Soil erosion	3	2	2	3
Wetter Winters	3	2	1	3

Figure C-1 – Screenshot of exposure and sensitivity assessment for Petteril

Changing Climate hazard	Sensitivity	Exposure	Vulnerability	Sensitivity	Exposure	Vulnerability	Exposure	Vulnerability
	Soil			Farmed Grassland			Arable land	
High summer temperature and reduced rainfall	2	3	6	2	3	6	3	6
Erosion	3	2	6	2	2	4	3	9
High rainfall, storm events	3	3	9	2	3	6	3	9
Drought	3	2	6	2	2	4	3	9
Wetter winters	2	3	6	1	3	3	3	6
Warmer Winters	2	3	6	1	3	3	3	6

Figure C-2 – Screenshot of vulnerability assessment for Petteril

Changing Climate Hazard	Soil	Arable land	Pasture	Woodland - Agro Forestry
High summer T and reduced rainfall	Vegetation and crop covers adapted to conditions; deep-rooted species low summer water demand crops	Farm crops adapted to conditions, better water management to hold water in soils and on farms for crops that require it	Likely to lead to lower productivity in grassland systems	Existingwoodlands reasonably well adapted to change. New planting (species/cultivars)to be adapted to changed climatic conditions.
Erosion	Vegetation cover such as permanent pastures to promote soil structural development, also deeper-rooted species to promote deeper drainage and maximise leaf area index	Maximise crop cover and minimise soil exposure during critical periods particularly winter.	Permanent grasslands provide resilience	Land use well adapted to minimise risks
High rainfall, storm events	Vegetation cover with maximised leaf area index also deep-rooted species to promote deep drainage	Maximise crop cover and minimise soil exposure.	Permanent grasslands provide resilience	Land use well adapted to minimise risks
Drought	Plant low water demand crops and species; pastures, deep-rooted species (i.e. woodland agroforestry)	Crops tolerent to conditions, better water management to hold water in soils and on farms for crops that require it.	Likely to lead to lower productivity in grassland systems	Land use well adapted to minimise risks
Warmer winters	Promote vegetation to take advantage of longer growing season as soils warm after winter	Take advantage of longer autumn window for planting	Could lead to more productivity in grassland systems	Existing woodlands reasonably well adapted to change. New planting (species/cultivars)to be adapted to changed climatic conditions.

Figure C-3 – Screenshot of adaptive measures for Petteril

C Economic assessment methodology

C.1 Introduction

The overall objective of the economic analysis was to understand how different land management and land use choices in specific geographic areas in England, compared to the situation today, could deliver net benefits for both resilience to climate change and maintenance and enhancement of natural capital.

This appendix provides some background information on the assessments of benefits and costs for land management. It discusses the methodologies employed, the type of assessment and a summary of the valuation methods used for each of the key natural capital components valued.

C.2 Initial assessment of key indicators

An initial assessment of the selected natural capital components has been assessed through an appraisal summary table type assessment (see Table C-1). The following components and the type of information required to undertake the assessment was identified at the outset. The table below also describes additional benefits that may be applicable and require qualification and discussion as part of the case study workshop outputs.

Table C-3 – Appraisal summary table

Components	Detail	Inputs	Units	Other / comments
Total carbon	Quantifiable	Land-use type and area in each case study for Baseline, each scenario and each epoch of assessment.	Carbon gains/losses per ha by land use type, valued using DECC carbon values	
Net change in woodland area	Quantifiable	Net change in woodland area at different time periods.	£/ha	What mechanism for change is anticipated – active (planting) or passive (natural succession)?
Net change in improved peatland	Quantifiable	Net change in improved or restored peatland area at different time periods.	£/ha	Cost of implementing this assumed. Benefits assessed via carbon sequestration and other environmental benefits
New coastal habitat created	Quantifiable	Hectares of new coastal habitat created and timing of change at different time periods.	£/ha	What mechanism is proposed – active or passive?
Change in surface water risk	Quantifiable if existing information exists from stakeholders (unlikely)	Numbers of properties protected at each time horizon. Existing flood damage reductions. FHRC 'initial assessment' data.	N/A	Out of scope to quantify. If no data, present anticipated reduction in runoff/peak flow reduction (if known).
Agricultural losses from soil erosion	Qualification only	Reduction in land lost at each time period, or anticipated	N/A	
Condition of priority habitats	Qualification only	N/A	N/A	
Condition of SSSI	Qualification only	N/A	N/A	
Total agricultural productivity losses	Quantifiable where information exists	Farm Business Survey gross margins and information on loss of agricultural land	Costs and income per ha by agricultural land type	Assumes new land-use types replace productive agricultural land
Drinking water colour levels	Qualification only		N/A	Limited information and data to quantify this aspect.

Components	Detail	Inputs	Units	Other / comments
Other environmental benefits	Quantifiable	Range of data sources available	£/ha for core habitat types	
Recreation	Quantification but limited information on how this will change.	Data available (via ORVal tool) but predicting change in recreational usage poorly understood	Whole PGA welfare values	

C.3 Framework for the assessment of economic impacts

In order to assess the economic impacts of changes in land use within each CASE STUDY, monetisation of a range of indicators or natural capital components (or ecosystem services) is required. This requires the following aspects:

- Qualification of the impact of land use change (e.g. increase in more climate resilience land use offset by losses associated with the costs of creation and loss of arable land).
- Data quantifying the change in indicator (e.g. hectare change in land use)
- Monetary information on the impact of indicator changes (e.g. carbon sequestration rate changes associated with each land use type).

Each of the above has been assessed for a range of key indicators or services. Key natural capital components of the costs and benefits assessed include the following:

- Carbon sequestration rates associated with key land use types;
- Agricultural margins;
- Other environmental benefits associated with key land use types;
- Recreational benefits;
- Timber sales or market values.

In addition to the above, there may be costs associated with the conversion of land use (and possible land purchase costs) in cases where this is managed rather than via natural succession. Furthermore, there will be the costs of responding to the identified threshold events.

Each scenario assessed (business as usual, anticipatory and reactionary) may lead to either positive (benefits) or negative (costs). The framework for each component and where they sit within the analysis is shown in Figure C-1.

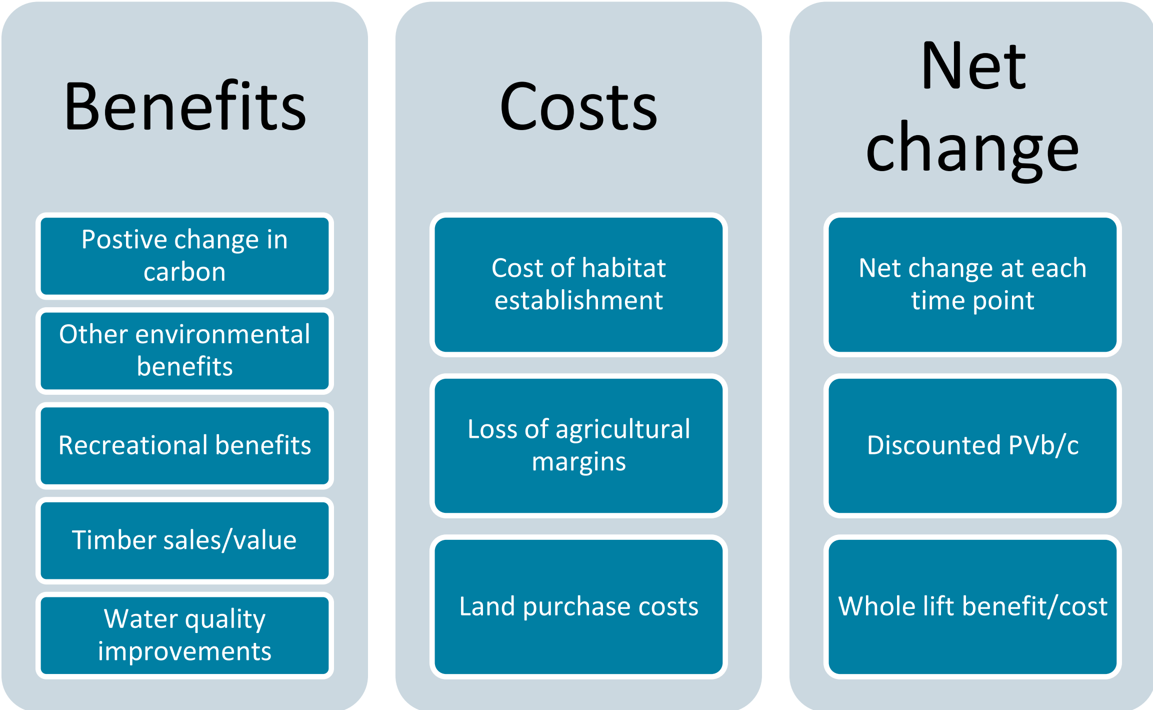


Figure C-4 – Framework for the assessment of costs and benefits

Each of the above indicators has been quantified and assessed in terms of monetary aspects and are discussed further in the sections overleaf. Other indicators identified by the project include the following, however, little or no information is available to quantify these benefits:

- Education
- WFD classification
- Wild food
- Aesthetics
- Air quality
- Flood protection

C.4 Monetisation of natural capital components

The key inputs for the cost-benefit analysis will be the outputs from the analysis for each CASE STUDY. A key output of this will qualify the total area each land use types (or net change) at each epoch of assessment. For example, the net change in woodland area for each case study 'x' is anticipated to increase by 'x' hectares under a 2° temperate rise when compared against a BAU baseline.

Monetisation of benefits will therefore require the following:

- Qualification of the impact of land use change (e.g. increase in more climate resilience land use offset by losses associated with the costs of creation and loss of arable land).
- Data quantifying the change in indicator (e.g. hectare change in land use)
- Monetary evidence on the impact of indicator changes (e.g. unit rates or carbon sequestration rate changes)

The data presented in the preceding chapters has been used to value all benefit and cost components where data exists. Average values will be used where multiple research suggests a range of values. Alternatively, an upper and lower limit or band could be assessed to present a range of possible monetary impacts, so that the analysis remains impartial. This will also help with the sensitivity testing aspects in providing a band against which the benefit values can be tested against.

C.5 Methodology and key datasets

C.5.1 Carbon sequestration

The basic methodology for assessing total carbon uses existing research on carbon sequestration rates established for a range of different habitat types. This approach values the total carbon in each CASE STUDY at each epoch of interest and thus the net change anticipated.

Data sources used for estimated carbon sequestration are as follows:

- White, C., Dunscombe, R., Dvarskas, A., Eves, C., Finisdore, J., Kieboom, E., Maclean, I., Obst, C., Rowcroft, P. & Silcock, P. (2015), 'Developing ecosystem accounts for protected areas in England and Scotland: Technical Appendix', Department for Food, Environment & Rural Affairs/ The Scottish Government.
- Dr Mike Christie, Dr Tony Hyde, Rob Cooper, Dr Ioan Fazey, Dr Peter Dennis, Dr John Warren, Dr Sergio Colombo and Prof. Nick Hanley. 2010. Economic Valuation of the Benefits of Ecosystem Services delivered by the UK Biodiversity Action Plan. Final report to Defra.
- Beaumont et al. 2010. National Ecosystem Assessment (NEA): Economic Analysis. Coastal Margin and Marine Habitats, Final Report.
- Natural England (2010). England's peatlands: carbon storage and greenhouse gases (NE257).

Final values extracted from the above studies and used for each CASE STUDY are provided in Table C-2 overleaf. It should be noted that the values used below represent typical carbon sequestration rates that may vary significantly depending on the type and condition of the land use, and indeed the resilience of each land use type to climate change. Upper and lower values may be available to help test the sensitivity of these assumed values as part of further future assessments but have not been used for the purposes of this assessment.

Table C-4 – Carbon sequestration rates by habitat type

Land use type	Carbon sequestration rate (t/CO2e/ha/yr)
Woodland (deciduous)	4.97
Woodland (coniferous)	12.66
Arable land	0.107
Pastoral land	0.397
Peatland - Undamaged	4.11
Peatland - Overgrazed	-0.1
Peatland - Rotationally burnt	-3.66
Peatland - Extracted	-4.87
Grassland	0.397
Heathland	0.7
Shrub	0.7
Saltmarsh	5.188
Urban	0
Green urban	0.397

Carbon sequestration rates for peatland and under alternative conditions were obtained from Natural England to support a more refined analysis for the Moor House CASE STUDY, particularly as the release of carbon can occur due to extraction/loss of peatland and fire situations.

Converting carbon sequestration rates/losses to monetary values for inclusion in a benefit-cost assessment will be undertaken using standard methods and the non-traded DECC carbon values which are calculated based on the abatement cost per tonne of carbon. Emissions arising from FCERM schemes should be valued using the 'non-traded price of carbon' (NTPC). Department of Energy and Climate Change (DECC) carbon valuation guidance is applied to the value of sequestered carbon, using the non-traded price of carbon schedule (DECC, 2018[25]). The NTPC for the key time horizons being assessed are given in the table below.

[25] DECC (2018). Updated short-term traded carbon values, January 2018

Table 11-5 – DECC carbon values

Year	Valuation of equivalent carbon £/t CO2 e
2018	66
2028	77
2038	138
2048	212
2058	288
2068	337
2078	349
2088	337
2098	310
2108	304 (assumed to be the same as 2100 as value not provided beyond 2100)
2118	

C.5.2 Mechanism for change

The mechanism for change that is anticipated for each land use change will also need consideration. For example, any new or a change in land use could be either active (planting) or passive (natural succession). The implications of this in terms of costs will be significant. To assist with this, a number of key data sources have been sought.

Habitat replacement costs are available from Environment Agency (2015)[26] which include replacement costs per hectare for a wide range of habitat types. Indicative estimates are summarised in Table C-4.

[26] Environment Agency (2015). Cost estimation for habitat creation – summary of evidence. Report –SC080039/R14.

Table C-4 – Environment Agency habitat creation cost estimates

Habitat type	Replacement cost (per hectare)	Replacement cost (per hectare) without land purchase
Inland water bodies and lagoons	£23,174	£17,000
Wet grasslands	£15,174	£9,000
Drier grasslands	£7,174	£1,000
Bogs, marshes, fens	£14,424	£8,250
Heath, scrub and open vegetation	£11,174	£5,000
Grazing marsh – low		£250
Grazing marsh – medium		£890
Grazing marsh – high		£4,000
Broad-leaved and mixed woodland	£9,174	£3,000
Broad-leaved woodland – low		£5,000
Broad-leaved woodland – high		£7,500
Wet woodlands	£9,674	£3,500
Coniferous woodland	£8,674	£2,500
Reedbed habitat – low (freshwater)		£2,800
Reedbed habitat – high (freshwater)		£7,700
Mudflats – low		£5,500
Mudflats – medium		£15,000
Mudflats – high		£45,000
Hedgerow		£2/metre
Hedgerow		£4/metre

In addition to the above, peatland restoration costs are available from the Environment Agency (2015) 'Cost estimation for land use and runoff management - summary of evidence'. Further, more refined estimates for woodland planting have been used as follows:

- Nix (2013) 'The John Nix Farm Management Pocketbook, Agro Business Consultants Ltd; 47th Revised edition' provides unit rates for woodland establishment costs. These costs exclude land purchase costs and grants for woodland planting.
- Woodland planting costs provided by Nix are as follows:
  - Deciduous (farm woodland) £5,000 to £6,000
  - Coniferous (upland sites) £1,800 to £3,800

Furthermore, the FarmScoper[27] dataset provides some valuable cost estimates for a range of farm management and NFM type approaches that may be of use for some sites. The methods for which data may be of use include items such as management of woodland edges and in-field ponds, establishment of new hedges and artificial wetlands, and intensive ditch management. These costs may be of use for future studies, but have not been used for this study as they require more

[27] http://www.adas.uk/Service/farmscoper

detail on the type and extend of adaptation measure that is at a scale not appropriate to the case study's being assessed.

C.5.3 Land purchase

In addition to the mechanism for change, compensation for land may also need to be considered. This is a very complicated aspect and unlikely to be well understood or qualified by this assessment. However, if short term information is available land values could be used to estimate the cost of purchase or compensation.

The Department for Communities and Local Government (2015) 'Land value estimates for policy appraisal' provides estimates of agricultural land by region (per hectare) are provided should the inclusion of these costs be required or to test the sensitivity of the inclusion or exclusion of these costs.

C.5.4 Agricultural margins

Higher costs associated with trying to keep agricultural productively level under the stresses of climate change or the loss of productivity if this cannot be achieved will result in a net loss in agricultural margins. In order to take these aspects into account both the costs and benefits of agriculture need to be considered for each case study and have been separated in the analysis tables.

Data sources on agricultural land incomes and margins are available from the Farm Business Survey[28]. Data on gross margin, fixed costs and Basic Payment Scheme (BPS) incomes allow the disaggregation of costs and income; both with and without subsidies. Data is available for 2016/17 broken down by region and the following agricultural types:

- Cereals
- General cropping
- Horticulture
- Dairy
- LFA Grazing
- Lowland Grazing

This data will be used where information on the type of land being lost to new climate resilient land use types is known and quantified. An example of the data for the north west is given below (2015/16 data).

Table C-6 – Example of agricultural net margin calculations (£/ha)

Farm type	Total income	Variable costs	Fixed costs	Basic Payment Scheme	Total costs (fixed + variable)	Income (with subsidy)	Income without subsidy
Cereals	904	397	541	164	938	1068	904
General cropping	3500	1976	1203	163	3179	3663	3500
Horticulture	1353	765	583	149	1348	1502	1353
Dairy	7046	2806	2738	134	5544	7180	7046

[28] http://www.farmbusinesssurvey.co.uk/regional/index.asp

Farm type	Total income	Variable costs	Fixed costs	Basic Payment Scheme	Total costs (fixed + variable)	Income (with subsidy)	Income without subsidy
LFA Grazing	322	201	194	138	395	460	322
Lowland Grazing	799	421	459	158	880	957	799

The above margins have been applied to each case study using the area of each agricultural land type multiplied by the above cost or income values. The area of farm types for each case study have been estimated by scaling the total area of arable and pastoral land uses by the estimated % of farmed areas for each farm type by regional provided by Defra statistics (2018)[29].

C.5.5 Flood benefits

Although not assessed as part of this assessment, if properties at risk are known and can be predicted in the future as part of any climate resilience land use planning (additional wider research may be available for some case studies) we will use Flood Hazard Research Centre's Weighted Annual Average Damages to assess the flood damages.

C.5.6 Other environmental benefits

A range of datasets are available to monetise the biodiversity benefits of new climate resilient habitats and land use. A key source of data is the Eftec (2010)[30] 'Economic Valuation of Environmental Effects' and the more up to date EVL tool[31]. Both provide a range of indicative economic values for inland marsh, saltmarsh, intertidal mudflats and peat bogs. Indicative values and a range are provided allowing the data to be tested as part of the sensitivity testing stage.

Whilst the values provided are relatively easy to apply (inputs are the new habitat area alone), the values incorporate a range of aspects including water quality improvements, recreational benefits, biodiversity and aesthetic amenity values. As a result, care will need to be applied when using these values to avoid any double counting. The EVL benefits appear to provide lower values than the indicative values suggested by the Eftec (2010) study.

Other datasets for woodland benefits that have been used include the following:

- Eftec (2016) 'Assessing the wider benefits of the Woodland Carbon Code' which suggests values of £1,480 - £1,030 per ha per year for broadleaf and conifer planting respectively.
- Eftec (2010) 'Cost effectiveness of woodlands for CO_2 abatement' suggested the following:
    - Biodiversity and cultural benefits of woodland were estimated to average £300/ha/year for priority sites, reducing to £30/ha/year for non-priority sites.

[29] Defra (2018). Defra Statistics: Agricultural Facts, England Regional Profiles, February 2018
[30] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/487240/LIT_10352.pdf
[31] https://www.eftec.co.uk/project/%20%09environmental-value-look-evl-tool

- Aesthetic benefits were considered to average £40/ha/year, but only £10/ha/year where woodlands were managed for timber.
- Recreational value of accessible rural sites are £300/ha/year.

C.5.7 Recreational benefits

The ORVal (Outdoor Recreation Value) Tool[32], developed by the Land, Environment, Economics and Policy (LEEP) Institute at the University of Exeter and DEFRA, was used to derive indicative recreation benefits. The tool allows users to explore greenspace site distribution and derive estimated visit numbers and welfare values (defined as the monetary estimate of the welfare enjoyed by adults accessing the sites). The greenspace site data can be sorted by catchment or Local Authority (LA)

The methodology for each case study, as advised by Brett Day (the tool developer), entailed selecting the catchment(s) which covered the case study boundary in the tool and then filtering the results by all of the land use types of interest: agriculture (used to represent arable land), woods, natural grass, fen marsh (used to represent peatland), wood pasture, moors heath (used to represent heath/shrubland) and saltmarsh. This produced results for welfare values and estimated visits for the catchments selected. For comparison of data, results were then obtained by sorting the data by catchment and then by land use types.

Whilst the tool is of value in providing indicative recreation welfare values and visit numbers, it does not allow users to define areas of interest. Thus, as the area of the catchments (and LAs) selected are larger than those of the case studies, the results were scaled by case study area (km2) once extracted from ORVal. For example, the Somerset case study area represents 89% of the total area of the 4 LAs selected which cover the Somerset case study boundary, thus the estimated visits and welfare values for Somerset case study is calculated as 89% of the estimated visits for the 4 LAs. The results are shown below in Table 2-6 and Table 2-7.

A limitation of the tool is that the results derived cannot be broken down into visit numbers or welfare values for each land use type selected - instead a single value is produced for the visit number and a single value for welfare value. Also, when sorting the data by catchment the results vary considerably from those derived when sorting the data by LA. Thus, an average has been taken of the results for visit numbers and welfare values for each case study - this is shown in Table 2-8.

32 ORVal Tool (2018) https://www.leep.exeter.ac.uk/orval/ [accessed July 2018]

Table C-7 – Visit numbers and welfare values derived from Local Authority dataset

		Petteril	Moor House	Somerset	The Broads
% of case study within LAs selected		5	9	89	59
Values of LAs selected	Welfare values	£16,369,864	£90,546,874	£62,860,114	£148,971,607
	Visits	5,299,352	28,925,432	19,553,531	46,671,119
LA values scaled to case study	Welfare values	£818,493	£8,149,219	£55,945,501	£87,893,248
	Visits	264,968	2,603,289	17,402,643	27,535,960

Table C-8 – Visit numbers and welfare values derived from catchment dataset

		Petteril	Moor House	Somerset	The Broads
% of case study within LAs selected		7	4	83	95
Values of LAs selected	Welfare values	£15,013,042	£301,162,945	£81,114,851	£93,585,942
	Visits	4,936,311	98,962,902	25,248,967	29,550,706
LA values scaled to case study	Welfare values	£105,091	£12,046,518	£67,325,326	£88,906,645
	Visits	34,554	3,958,516	20,956,643	28,073,171

Table C-9 – Average visit numbers and welfare values

		Petteril	Moor House	Somerset	The Broads
Average Values	Welfare values	£461,792	£10,097,868	£61,635,414	£88,399,947
	Visits	149,761	3,280,902	19,179,643	27,804,565

An alternative approach to calculating recreation benefits was considered with reference to the Aecom (2015) 'Developing ecosystem accounts for protected areas in England and Scotland: Technical Appendix' report which provides some useful data on recreational benefits for the following land use types (value per person per trip):

- Woodland: £3.53
- Enclosed farmland: £1.63
- Semi-natural grassland: £1.63
- Freshwater and floodplains: £1.92

- Mountains, moors and heathlands: £5.32
- Coastal margins: £4.19

However, this would require visit numbers in order to derive the valuation from each land use type. It is unlikely that recreational visit numbers will be available for the case studies that has not been based on data that has been scaled from larger datasets, nor is it likely that predictions under each epoch will be available. As a result, we anticipate that whilst this information is useful, the assessment is more likely to be qualified rather than quantified.

C.5.8 Threshold event costs

The occurrence of the threshold event(s) will result in a number of losses and loss types including peat fires, flood damage and drought damage. Of these three, only the fire and flood losses are readily available:

- Davies et. al. (2016)[33] provides estimates of carbon loss per unit area of burnt peatland of 96 ± 15 t/ha (equivalent 352 t/CO2/ha/yr).
- Morris et. al. (2009)[34] provides event damage costs agricultural land types for flooding. These have been used to estimate the threshold event damages by estimating the area of land affected and the damage per hectare to calculate total annual damages (assuming 1 event per year).

C.5.9 Timber sales

Timber sales will relate to the type of woodland, the management of this and the rate of thinning and clear-felling (if applicable). Timber prices have been obtained from Nix (2016) 'The John Nix Farm Management Pocketbook, Agro Business Consultants Ltd; 47th Revised edition'.

Timber sales are based on the following assumptions:

- Price of wood based on a conservative value for broadleaved and coniferous wood from Nix (2016). £20/m^3 for coniferous and £28/m^3 for broadleaved.
- A Thinning estimate of 6-15m^3/ha/yr for broadleaved and coniferous woodland respectively (Nix, 2016).
- Total thinning value based on the area of woodland multiplied by the thinning volume and the price per m^3.
- Additional clear-felling income is based on the assumption that woodlands are felled at an age of 50 years generating a total volume of 383m^3/ha. A relatively low percentage of total area is assumed to be felled annually to ensure that the total area of woodland does not reduce.

11.1 Timing of benefits

Each of the benefits or costs will be incurred either annually or in some instances as a one off cost/benefit. For example, the carbon sequestration benefits would be annual benefits, whereas the costs of woodland planting would be incurred for a period of time during the appraisal period. A summary of the type and relative timing of each natural capital component is given in the table below.

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Table 11-10 – Timing of benefits/costs

Natural capital component	Benefit/cost type	Comment
Climate regulation	Annual benefit	
Other environmental benefits	Annual benefit	
Agricultural margins	Annual benefit	
Timber sales	Annual benefit	Thinning and periodic clear-felling
Threshold costs	Annual costs over the threshold event	Typically assumed to be a 5 year period
Recreational	Annual benefits	Excluded from analysis.
Habitat creation costs	Annual costs over a short period of time	Costs assumed to be spread over a number of years for the anticipatory and reactionary cases

11.2 Present value benefit/costs

Whole life (present value benefits and costs have been estimated using standard HM Treasury rules for discounting and assume the following:

- Standard HM Treasury variable discount rates have been used (3.5% to 2.5%)
- The discount rates used have been applied over a 100-year appraisal period.

Total Present Value costs and Present Value benefits have been collated by summing each cost or benefit component. Annual net present values (NPV) and total whole life NPV's have also been generated so that these can be plotted and compared against each scenario assessed.

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