Agriculture and Forestry Theme – agriculture supplementary annexes CA0401

A REPORT PREPARED FOR DEFRA AND THE DEVOLVED ADMINISTRATIONS

February 2013
# Agriculture and Forestry Theme – agriculture supplementary annexes

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We are very grateful for the input of the following organisations who kindly gave their time to be interviewed to feed into this work:

Aberdeen University
ADAS
Agricultural Industries Confederation
Angus
ASDA
BPEX (pig levy board)
British Society of Plant Breeders
EBLEX (beef and sheep levy board)
HGCA (cereals and oilseeds levy board)
Marks and Spencer
National Farmers Union
Natural England
Potato Council
Savills Agents
Scottish Agricultural College
Syngenta
Tesco
Waitrose

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ADAS
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Campden BRI
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Cranfield University
Defra
EBLEX
Environment Agency
Food and Drink Federation
Home Grown Cereals Authority (HGCA)
Institution of Grocery Distribution
LEAF - Linking Environment & Farming
Leatherhead Enterprise Centre
National Farmers Union (NFU)
Natural England
Northern Ireland Assembly
Royal Horticultural Society
Welsh Assembly

Annex 1: Stakeholder list
Annex 2: Climate change projections

UKCP09 projections

The UK Climate Projections (UKCP09) provides projections of climate change for the UK. These projections cover changes in a number of atmospheric variables, using different temporal and spatial averaging. They are given for several future time periods under three future emission scenarios. Climate change over land includes more variables, at a higher resolution, than those over sea.

Projections of the climate variables in UKCP09 methodology are made using multiple climate models. The output of the climate models is used to estimate probabilities, rather than giving single values of possible changes. Probabilities are introduced to treat uncertainties associated with climate projections.

This annex begins with an explanation on the background on uncertainties associated with climate projections. It is followed by a paragraph that explains the UKCP09 methodology and how uncertainties are accounted for. The next paragraph explains how to interpret probabilities in UKCP09 output and the annex ends with a discussion on the limitations of UKCP09.

Background on uncertainties in climate projections

There are three major sources of uncertainties in estimating future climate change:

- Natural Climate Variability;
- Incomplete understanding of Earth System process and the inability to model the climate perfectly; and,
- Uncertainty in future greenhouse gas emissions

The major sources are discussed individually below.

Natural Climate Variability

Natural variability has two principle causes. One arises from natural internal variability which is caused by the chaotic nature of the climate system. Ranging from individual storms, which affect weather, to large scale variability due to interactions between the ocean and the atmosphere (such as El Nino). Climate can also vary due to natural external factors. The main causes are changes in solar radiation and in the amount of aerosols released (small particles) from volcanoes.

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1 This annex is largely based on Murphy et al., 2009 and UKCP09, © UK Climate Projections, 2009.
Representation of Earth’s System in Climate Models

The second main source of uncertainty arises due to modelling of the future climate. The only way we can calculate how the climate will change due to human activity is through the use of mathematical models of the earth’s climate system. These models are known as Global Climate Models (GCMs). They describe the behaviour of different climate components and interactions between them. The components include the atmosphere, the oceans, the land and the cryosphere. Each interacts to produce many types of feedbacks, both positive and negative. The net effect will determine how climate evolves in response to changes in greenhouse gasses.

Uncertainty in models is caused by an incomplete knowledge of the climate system and the inability to model it perfectly. Representations of physical processes within the climate system are based on a mixture of theory, observations and representation. Representations may be limited by physical knowledge, as well as by computing power, and lead to errors, which inevitably cause uncertainty. All modelling groups seek to represent climate processes in the best possible way in their models. This is based on subjective judgement, which causes different strengths of feedbacks in different models. This means that different models give different results, although they all use plausible representations of climate processes.

Future Greenhouse Gas Emissions and SRES

The final source of uncertainty arises due to future emission scenarios of greenhouse gases and aerosols. This will depend on many socio-economic factors such as changes in population, GDP, energy use and energy mix. The Intergovernmental Panel on Climate Change (IPCC) published a Special Report on Emission Scenarios (SRES) (Nakicenovic and Swart, 2000), in which climate-relevant emissions were calculated based on a number of storylines. Each of these storylines describes a possible way of how the world might develop. Differences between them arise due to the different assumptions about future socio-economic changes. They assume no political action to reduce emissions in order to mitigate climate change.

UKCP09 methodology

In UKCP09, uncertainties mentioned above are accounted for when doing climate projections. Uncertainties are treated by generating projections of change as estimated probabilities of different outcomes. This means that probabilities are attached to different climate change outcomes, which provides information on the estimated relative likelihood of different future results.

To do this, UKCP09 assumes that uncertainties manifest themselves in different climate projections from different climate models. Probability distributions of the
future climate can then be generated by using projections from a large number of models or variants from a single model.

UKCP09 use a combination of projections from the following models:

- A very large number of variants of the Meteorological Office Hadley Centre model; and

- 12 international models used in inter-comparison studies of the fourth IPCC report.

Probabilities are based on a large number (‘ensembles’) of climate model simulations, but adjusted according to how well different simulations fit historical climate observations. This is done in order to make them relevant to the real world. By presenting probabilities based on ensembles of climate models, UKCP09 takes into account both modelling uncertainty and uncertainty due to natural variability.

It does, however, not include uncertainty due to future emissions. Currently there is no accepted method of assigning relative likelihoods to alternative future emissions. UKCP09 therefore presents probabilistic projections of future climate change for 3 future emission scenarios. They are selected from three scenarios developed in SRES and referred to as Low, Medium and High emissions, which corresponds to A1FI, A1B and B1 scenarios in SRES. Figure 1 indicates these scenarios in terms of CO₂ emissions with solid lines (black: High Emissions, purple: Medium Emissions, green: Low Emissions). Each scenario also includes emissions of other greenhouse gases. Although the three UKCIP emission scenarios span the range of marker scenarios in SRES, there are additional scenarios, both higher and lower, that they do not encompass.
Figure 1. Global annual CO₂ emissions under the three IPCC SRES scenarios

Source: Murphy et al., 2009
Note: The dotted lines are two SRES emission scenarios used in previous UK Climate Projections, but not in UKCP09.

Probability in UKCP09

Probabilistic projections assign a probability to different possible climate change outcomes. Probability given in UKCP09 output is seen as the relative degree to which each possible climate outcome is supported by the evidence available. It takes into account the current understanding of climate science and observations.

Probability in UKCP09 does not indicate the absolute value of climate changing by some exact value. Instead it states the probability of climate change being less than or greater than a certain value using the Cumulative Distribution Function (CDF). This is defined as probability of climate change being less than a given amount. An example is given in Figure 2. The CDF (for the 2050s mean summer temperatures in the London area, with a medium emission scenario) shows that there is a 10% probability of temperature change being less than 1 degree and 90% probability of temperature change being less than 5 degrees. These statements also work inversely, where one could say there is a 10% probability of temperature change being greater than 5 degrees and a 90% probability of temperature change exceeding 1 degree.
Figure 2. Example of cumulative distribution function for 2050s mean summer temperatures in the London area for the medium emission scenario

![Cumulative Distribution Function](image)

Source: UKCP09

The figure above does not say that the temperature rise will be less than 5 degrees in 90% of the future climates, because there will only be one climate. It rather indicates that there is 90% probability (based on data and chosen methodology) that the temperature rise will be less than 5 degrees.

**Limitations**

The procedure used in UKCP09 to convert ensembles of climate models into probabilistic estimates of future climate also includes some subjective choices and assumptions. This means that the probabilities themselves are uncertain, because they are dependent on the information used and how the methodology is formulated. Furthermore, the system cannot be verified on a large sample of past cases. Current models are, however, capable of simulating many aspects of global and regional climate with considerable skill. They do capture all major physical and biochemical systems that are known to influence our climate.

**Mean summer temperature**

Climate projections indicate an increase in summer temperature. By the 2050s, for the central estimate (p50) of the UKCP09 medium emissions scenario, the southern part of England could see temperature rises of between 2.3 °C and 2.7 °C (Murphy et al., 2009). However, temperature increases will vary regionally. Parts of northern Scotland could experience temperature increases of around 1.5 °C for the p50 medium emissions scenario. UK-wide, the projections for increases in mean summer temperatures range from 0.9 °C under the p10 low emissions scenario, to 5.2 °C under the p90 high emissions scenario.

The projected changes in mean summer temperature in the UK for the p10 low emission scenario (left), p50 medium emission scenario (middle) and p90 high emission scenario (right) are shown in Figure 3.

Annex 2: Climate change projections
Mean winter precipitation

In the p50 medium emissions scenario, mean winter precipitation is projected to increase by 9 - 17% (depending on location) in the 2050s, relative to the 1961-1990 baseline. The spread in projections is wide however, ranging from -2% for the lower bound of the UKCP09 low emissions scenario in Scotland East to +41% for the upper bound high emissions scenario in South West England (Murphy et al., 2009).

Changes in winter precipitation for the p10 low emission scenario (left), p50 medium emission scenario (middle) and p90 high emission scenario (right) are presented in Figure 4.
Figure 4. Projected changes in mean winter precipitation by the 2050s (emissions scenario from left to right: low p10; medium p50; high p90)

Source: UKCP09

Sea level rise

According to the central estimates of relative sea level changes with respect to 1990s, sea level will rise between 18 and 26 cm between the low and high scenario in London and between 11 and 18cm in Edinburgh (Lowe et al., 2009).

As the earth’s crust is moving upward in the northern parts of the UK, relative sea level rise will differ over the regions. The north will be less affected by sea level rise compared to the south (Lowe et al., 2009).

Figure 5 combines the absolute sea level change estimates averaged around the UK for the medium emissions scenario and vertical land movement. Values are shown for 2095 (Lowe et al., 2009).

Annex 2: Climate change projections
Figure 5. Relative sea level rise (cm) around the UK for the 21st century

![Relative sea level rise map](image)

Source: Lowe et al., 2009
Note: This combines the absolute sea level change estimates averaged around the UK for the medium emissions scenario and vertical land movement. Values are shown for 2095

Table 1 displays the sea level rise forecast by the UKCP09 models by 2050, for the central estimates of the emissions scenarios. These estimates are equivalent to a sea level rise of roughly 1.8-4.3 mm per year.

<table>
<thead>
<tr>
<th>Low</th>
<th>Medium</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>London</td>
<td>18.4</td>
<td>21.8</td>
</tr>
<tr>
<td>Edinburgh</td>
<td>10.5</td>
<td>13.9</td>
</tr>
</tbody>
</table>

Source: Lowe et al., 2009

### Extreme weather events

As the climate warms, weather patterns and the frequency of extreme events may also change (Solomon et al., 2007). Heavy rain days (>25 mm) will likely to be more frequent over most of the lowland UK, central estimates show an increase by a factor of 2 – 3.5 in winter and 1 – 2 in summer by the 2080s under the medium emissions scenario (UKCP09).

The frequency and intensity of heatwaves could increase in future, especially in southern parts of England. The results of the ARCADIA project suggest that by the 2050s, one third of London’s summer may exceed the Met Office heatwave temperature threshold (32 °C). (CCRA: Capon and Oakley, 2012; Hall et al., 2009).

Annex 2: Climate change projections
Annex 3: Climate change threats and opportunities

Direct climate risks

Extreme weather events

A higher frequency of extreme weather events and weather variability are likely to cause significant challenges for the agriculture sector.

(a) Flood risk

The CCRA found that under the highest rates of relative sea-level rise for the 2080s high emissions scenario (average 57cm rise), a ten-fold increase is projected for arable/horticultural land that would be at regular risk of coastal flooding, making it untenable for normal agricultural use. There are also large increases projected in the amount of grassland at risk of frequent coastal flooding, though some of this may still be used for grazing.

Table 2. Area of agricultural land in England and Wales projected to be at risk of flooding from rivers and the sea in a medium emissions scenario (p50)

<table>
<thead>
<tr>
<th>ALC</th>
<th>Flooding risk</th>
<th>Baseline - Fluvial: 1961-90; Tidal: 2008 (ha)</th>
<th>2020s (ha)</th>
<th>2050s (ha)</th>
<th>2080s (ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-3</td>
<td>&lt;3 (&gt;33% annual frequency)</td>
<td>31,200</td>
<td>35,900</td>
<td>75,100</td>
<td>127,700</td>
</tr>
<tr>
<td></td>
<td>3 – 5 (20-33% annual frequency)</td>
<td>13,300</td>
<td>44,700</td>
<td>64,000</td>
<td>77,300</td>
</tr>
<tr>
<td></td>
<td>5 - 10 (10-20% annual frequency)</td>
<td>64,000</td>
<td>94,500</td>
<td>105,000</td>
<td>143,800</td>
</tr>
<tr>
<td>4-5</td>
<td>&lt;3 (&gt;33% annual frequency)</td>
<td>21,800</td>
<td>26,600</td>
<td>45,700</td>
<td>73,800</td>
</tr>
<tr>
<td></td>
<td>3 – 5 (20-33% annual frequency)</td>
<td>11,300</td>
<td>38,500</td>
<td>49,300</td>
<td>46,400</td>
</tr>
<tr>
<td></td>
<td>5 - 10 (10-20% annual frequency)</td>
<td>53,400</td>
<td>56,900</td>
<td>56,300</td>
<td>55,600</td>
</tr>
<tr>
<td>TOTAL</td>
<td>All</td>
<td>195,000</td>
<td>296,900</td>
<td>395,400</td>
<td>524,500</td>
</tr>
</tbody>
</table>

Source: Knox et al., 2012
An increase in flooding will negatively affect crop productivity. For example, the value of crop loss from the 42,000ha of agricultural land flooded during the 2007 summer floods has been estimated to be approximately £11.2m (medium scenario) (ADAS, 2007), and up to £50m (Chatterton et al., 2009). Posthumus et al. (2009) reported average flood damage cost at £1150 per flooded hectare when weighted by land use.²

In most cases, the main financial impacts will come from the direct losses of crop and fodder supplies. However other factors increasing costs include additional management time, impacts on livestock growth rates and milk production, costs of immediate and future land reinstatement, cash flow/finance issues, flooded buildings and contents, and impacts on diversification businesses. In some cases, these may be covered by insurance. The personal distress associated with the damage and the reparations should not be underestimated.

(b) Drought and heat waves

The 2003 heat wave, that affected much of Europe, accelerated crop development by 10 to 20 days, thus advancing ripening and maturity (Oleson and Bindi, 2004). The very high air temperature and insolation (especially in parts of July and August) resulted in an increase in the crops' water consumption. This led to increased evapotranspiration, leading to reduced soil moisture, depletion of water sources, increased likelihood of wildfires and lower crop yields. These physical processes that characterised the 2003 heat wave are projected to occur with greater frequency in the future (Beniston, 2004).

(c) Storms/wind

There is little evidence that the frequency, duration or intensity of storms affecting the UK will change markedly, however, it cannot be ruled out either. Severe windstorms have become more frequent in the past few decades, though not above a level seen in the 1920s. Damage can be caused to livestock and other animals, to buildings and equipment and to crops such that they are ruined entirely or cannot be sold. Other potential damage includes soil erosion, frosts and hail that lead to yield reduction by preventing crop development, repeat drilling due to crop failure, and the reduced effectiveness of fungicides.

Long-term change in climate variables

(a) Rising temperatures

Crop growth cycles are related to temperature. In general, increased temperature alone is projected to reduce the yield of cereals and annual

² Their estimate was higher than that derived by ADAS (2007) because more detailed and comprehensive estimation methods were used.

Annex 3: Climate change threats and opportunities
crops such as field beans (Thomas et al., 2008), although other crops (fruit, forage) may benefit. This is because increased temperature can cause earlier maturity of the crop and reduce growth phases (Thomas et al., 2008). However, long season or perennial crops such as fruit and forage may benefit from a modest increase in temperatures which speeds up development, for example, by shortening the duration between sowing and harvesting.

The negative effects of temperature may be offset by increased levels of CO$_2$ if, for example, the changes in temperature are modest. Results from research on the combined effect of CO$_2$ and temperature differ with some suggesting this is an offset (Wheeler et al., 1996) and some suggesting a small yield increase (Semenov, 2007).

(b) Effect of elevated carbon dioxide on crops

Rising CO$_2$ concentration has positive physiological effects by increasing the rate of photosynthesis (fertilisation effect), particularly in “C3” crops (wheat) which are more susceptible to CO$_2$ shortages than “C4” crops (maize). It can also lead to development of fewer stomata on plants and therefore reduce water usage (Wheeler et al., 1996). Studies have suggested that there is potential for improved production at leaf level being carried through to cropping systems over a growing season (HRI, 2008). For example, Long et al. (2006) found yield enhancements of 12-15% in wheat at 550ppm compared with 370ppm, and Craigon et al. (2002) found an increase of 17% at 689ppm in potatoes. These increased yields are not as high as the increased enzymatic activity would suggest, but this may be due to acclimation and other feedback mechanisms that limit the whole plant carbon uptake into yield.

There is a strong interaction between CO$_2$ levels and nitrogen utilisation, with high CO$_2$ expected to lead to lower levels of nitrogen in the crop. This could have impacts on seed crops and grass where nitrogen and protein content is reduced (HRI, 2008). Conversely, high nitrogen soil contents increase the relative response to elevated CO$_2$ concentrations.3

(c) Changes in rainfall

The CCRA assessed soil erosivity using the number of days with heavy rainfall and rainfall intensity and projected increases in erosivity in the UK, particularly in the south west and north of England. The CCRA projections4 indicate soil erosion potential and the areas that might be at risk but erosion depends on other factors too, including vulnerability of different soils and vegetation cover.

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3 FACE technology has now facilitated large-scale trials of the major grain crops at elevated CO2 under fully open-air field conditions.

4 The CCRA did not provide projections of the amount of soil that could be lost.

Annex 3: Climate change threats and opportunities
Indirect climate change risks

Climate change will have a significant impact on crop and livestock production through indirect effects resulting from combinations of direct risks.

(a) Aridity

Combined reduction in rainfall and increase in evapotranspiration increases aridity, leading to higher summer soil moisture deficits. The CCRA found that changes in aridity using Potential Soil Moisture Deficit (PSMD) as an agroclimate index suggest central projection increases (Medium scenario, p50) of 38% by the 2020s (Range -33% to +116%, for Medium p10 to Medium p90), rising to 118% by the 2080s (Range 4% to 277% for Low p10 to High p90), with significant spatial variability. This is expected to be a particular problem in the already water scarce areas of Eastern England. Based on a qualitative assessment, the CCRA considered the evidence available on the climate risks related to changes in agroclimate and aridity to be strong.

Changes in aridity could increase demand for irrigation. For some rain fed crops, irrigation would become necessary to maintain yields at current levels. Soil quality is also affected by increased aridity, e.g. cracking in high clay content soils, as are lowland and upland farming systems, notably in Scotland where the viability of farming marginal land could increase with rising yields.

(b) Waterlogging

The CCRA analysed risks from waterlogging, acknowledging the potentially severe impact on agricultural land and production it can have. Crops need oxygen in soil for respiration yet air is limited in waterlogged soil, reducing respiration. A crop’s demand for freedom from waterlogging may vary between seasons in a year. In irrigated agricultural land, waterlogging is often accompanied by soil salinity as waterlogged soils prevent leaching of the salts imported by the irrigation water. Waterlogged soil also has implications for management practices due to impacts on the workability and trafficability of soil and the tendency for poaching by grazing livestock.

(b) Water availability and demand

Reduced summer rainfall and the need to address unsustainable abstraction may cause increased competition for water resources in the summer. The CCRA estimated agricultural demand for water for spray irrigation by combining historical abstraction data with data on aridity (PSMD). CCRA projections are shown in Table 3.

Annex 3: Climate change threats and opportunities
Table 3. Future average % increase in agricultural water demand for spray irrigation in England and Wales against the CCRA baseline (2010)

<table>
<thead>
<tr>
<th></th>
<th>2020s</th>
<th>2050s</th>
<th>2080s</th>
</tr>
</thead>
<tbody>
<tr>
<td>% increase in</td>
<td>15% (Medium</td>
<td>34% (Medium</td>
<td>45% (Medium</td>
</tr>
<tr>
<td>agricultural water</td>
<td>p50)</td>
<td>p50)</td>
<td>p50)</td>
</tr>
<tr>
<td>demand</td>
<td>(Range -20%</td>
<td>(Range -9%</td>
<td>(Range -4%</td>
</tr>
<tr>
<td></td>
<td>to +52%,</td>
<td>to +75%,</td>
<td>to 108%,</td>
</tr>
<tr>
<td></td>
<td>Medium p50)</td>
<td>Low p10 to</td>
<td>Low p10 to</td>
</tr>
<tr>
<td></td>
<td></td>
<td>High p90)</td>
<td>High p90)</td>
</tr>
</tbody>
</table>

Source: Knox et al., 2012

Generally, studies indicate upward pressure on water resources as changes in agroclimate and increasing aridity combine with increased demands for food production. Agricultural water abstraction in England and Wales constitutes a very small proportion (1-2 %) of national water abstraction but it is concentrated in the driest catchments in the driest times of the year (East Anglia has the largest demand for spray irrigation). Demand for spray irrigation agriculture in 2008 was estimated to be 194 million litres a day, forming a major proportion of total amount abstracted for agriculture (Defra, 2010).

Box A2.1: Projected water constraints

Recent research has considered future agricultural demands under a range of socio-economic conditions that reported increases of water demand for agriculture of between 22 to 180% (Weatherhead et al., 2008). The Environment Agency has also undertaken work to project water demand and availability under a range of scenarios accounting for climate change (Environment Agency, 2011). This work found that extreme pressure on water (i.e. demand exceeding availability by up to more than 2.5 times) is likely in the Thames and South East region and in Anglia by 2050 (Environment Agency, 2011). Agricultural activity is relatively high in those areas, suggesting potential constraints.

(d) Pests and diseases

Climate change affects the ecology and development of pests and diseases. Existing pests/diseases will spread, some will develop resistance to current pesticides and treatment methods, and new species or strains will emerge (Gregory et al. (2009). For example, fusarium ear blight is linked to rainfall during wheat anthesis and temperature preceding it (Madgwick et al., 2011) reducing yield due to grain shrivelling.

Annex 3: Climate change threats and opportunities
The CCRA considered various marker diseases (yellow rust for wheat; beet mild yellow virus for sugar beet and blight for potatoes). It found no significant relationships between incidence of marker disease and climate variability which is largely due to treatment methods and improved crop agronomy within each of these subsectors having significantly reduced disease expression. Based on a qualitative assessment, the CCRA considers the evidence available on climate risks to the UK crop pests and disease to be weak.

However, the interactions between crops, pests and pathogens are complex, non-linear and poorly understood in the context of climate change, making the effects on crop productivity difficult to predict (Butterworth et al., 2010). Many problems such as Septoria and rust are expected to persist, epidemics like fusarium ear blight in wheat will increase and new insect problems such as orange blossom midge are also likely to get worse.

The impacts of disease on crop productivity will be significant in some cases, for example, current UK annual losses of oil seed rape from phoma stem canker are approximately £70–140M per growing season (at a price of £250 per tonne, despite expenditure of £12M on fungicides) (Barnes et al., 2010). Climate change related increase in disease severity is predicted to decrease yields in southern England and Wales by 50% (average of 0.2t/ha by 2020s) and increase in range up to Scotland (Evans et al., 2008).

(e) Impacts on ecosystem services

The recent UK National Ecosystems Assessment (2011) assessed pressures on broad habitats, including the impacts of farming on them. These include agricultural pollution (nitrogen emissions and pesticide residues from farms), overexploitation (over use or poor management of the habitats providing these services) and habitat change (due to land use change and changes in farm practice). The pressures on the main services, provisioning (farmed fish, wild species diversity), regulating (pollination, regulation of disease and pests, soil quality, hazard regulation) and supporting (soil formation, nutrient cycling and water cycling), on which agriculture relies are predicted to increase with climate change.

Agricultural activities are likely to affect these services either directly or indirectly, given the reliance of the sector on the natural environment.

Annex 4: IFPRI projections

The projections from IFPRI (as described in Nelson et al., 2010) reflect a wide range of plausible economic, demographic and climatic futures, along with international demand and supply conditions. Outputs are specific to the national level.
IFPRI’s modelling performs the complex task of modelling climate change by integrating components that range from the macro to the micro.

Expanding on the main report, IFPRI’s IMPACT modelling suite combines the following three main models:

- The International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT), which is a global model of supply and demand for agricultural commodities that emphasises policy simulations into which aggregated results from the following two models are applied. IMPACT is a partial equilibrium model with 32 crop and livestock commodities and has 115 country regions, with specified supply, demand, and prices for agricultural commodities. Within this large countries are further divided into major river basins resulting in 281 spatial units called food production units.

- A hydrology model which is incorporated into IMPACT; and

- The Decision Support System for Agrotechnology Transfer (DSSAT) crop model, which is an extremely detailed process model of the daily development of a crop, from planting to harvest-ready. As mentioned above, DSSAT runs for five crops – rice, wheat, maize, groundnuts and soybeans. The DSSAT requires the following detailed inputs:
  - **Climate data**: today’s climate is simulated using the WorldClim current conditions dataset, which is representative of 1950–2000 and reports monthly average minimum and maximum temperatures and monthly average precipitation. Site-specific daily weather data is generated stochastically using the SIMMETEO software built into the DSSAT software suite. The climate data are derived from downscaled GCM projections (discussed in Table 5) that provide monthly precipitation, average minimum temperatures, and average maximum temperatures for each location.
  - **Other agronomic inputs**: these include inputs such as description of the soil, physical and chemical characteristics of the field, and crop management information including crop, variety, planting date, plant spacing, and inputs such as fertilizer and irrigation. For further information soil characteristics, crop variety, cropping calendar, CO₂ fertilisation, water availability and nutrient levels please refer to Nelson et al. (2010).

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5 It is important to note that the DSSAT crop modelling suite is used for maize, wheat, rice, groundnuts and soya beans. It is then assumed that plants with similar photosynthetic metabolic pathways will react similarly to any given climate change effect in a particular geographic region.

6 The baseline 1950-2000 differs from the baseline used by UKCP09.

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Annex 4: IFPRI projections
The climate scenarios explored are based on a range of models and assumptions. Differences in GDP and population growth define the key socio-economic assumptions that vary across the scenarios, with all other driver values remaining the same across the three scenarios. The GDP and population assumptions are described in Table 4.

**Table 4. GDP and population choices for the three overall scenarios in the IFPRI model**

<table>
<thead>
<tr>
<th>Category</th>
<th>Pessimistic</th>
<th>Baseline</th>
<th>Optimistic</th>
</tr>
</thead>
<tbody>
<tr>
<td>GDP, constant 2000 US$</td>
<td>Lowest of the four GDP growth rate scenarios from the Millennium Ecosystem Assessment GDP scenarios (Millennium Ecosystem Assessment 2005) and the rate used in the baseline (next column)</td>
<td>Based on rates from World Bank EACC study (Margulis et al. 2010)</td>
<td>Highest of the four GDP growth rates from the Millennium Ecosystem Assessment GDP scenarios and the rate used in the baseline (previous column)</td>
</tr>
<tr>
<td>Population</td>
<td>UN high variant, 2008 revision</td>
<td>UN medium variant, 2008 revision</td>
<td>UN low variant, 2008 revision</td>
</tr>
</tbody>
</table>

Source: Nelson, Gerald C. et al., 2010, page 8

Four climate models\(^7\) are used to translate three climate change scenarios as defined by the Intergovernmental Panel on Climate Change in their Special Report on Emissions Scenarios (SRES) (IPCC, 2001). The three scenarios are rapid and successful economic development (A1B); lower international trade or cooperation and slower technological change (A2), and a high level of environmental and social consciousness (B1). These reflect varying temperature and precipitation climatic futures. An additional scenario of ‘perfect climate mitigation’ is considered which looks at the outcomes if current climate were to continue into the future; these scenarios are summarised in Table 5.

The three socio-economic scenarios under the various climate scenarios result in a range of perspectives on the future that encompass a wide range of plausible outcomes. Results are presented for the UK.\(^8\)

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\(^7\) These make different assumptions about the extent to which CO\(_2\) in the atmosphere is translated into real climate change impacts (i.e. rainfall, temperature changes etc.)

\(^8\) We use the yield results for the British Isles FPU in each of these scenarios to develop a range of projections from 2010 to 2050 for wheat, sugar beet and potato. The results of the IFPRI model for British Isles are also minimally adjusted to reflect the yields for the UK by calculating the difference between the 2010 actual UK yield figure and the projected 2010 yield figure for the British Isles FPU from the model (baseline perfect mitigation scenario), c.3-5% in most cases. We assume this difference remains the same across scenarios for a given crop, and that it does not change over time.
### Table 5. GCM and SRES scenario global average changes, 2000-2050

<table>
<thead>
<tr>
<th>GCM</th>
<th>SRES scenario</th>
<th>Changes between 2000 and 2050 in the annual averages</th>
<th>Precipitation (percent)</th>
<th>Precipitation (mm)</th>
<th>Minimum temperature (°C)</th>
<th>Maximum temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CSIRO</td>
<td>B1</td>
<td>0</td>
<td>0.1</td>
<td>1.2</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>CSIRO</td>
<td>A1B</td>
<td>0.7</td>
<td>4.8</td>
<td>1.6</td>
<td>1.4</td>
<td></td>
</tr>
<tr>
<td>CSIRO</td>
<td>A2</td>
<td>0.9</td>
<td>6.5</td>
<td>1.9</td>
<td>1.8</td>
<td></td>
</tr>
<tr>
<td>ECH</td>
<td>B1</td>
<td>1.6</td>
<td>11.6</td>
<td>2.1</td>
<td>1.9</td>
<td></td>
</tr>
<tr>
<td>CNR</td>
<td>B1</td>
<td>1.9</td>
<td>14</td>
<td>1.9</td>
<td>1.7</td>
<td></td>
</tr>
<tr>
<td>ECH</td>
<td>A2</td>
<td>2.1</td>
<td>15</td>
<td>2.4</td>
<td>2.2</td>
<td></td>
</tr>
<tr>
<td>CNR</td>
<td>A2</td>
<td>2.7</td>
<td>19.5</td>
<td>2.5</td>
<td>2.2</td>
<td></td>
</tr>
<tr>
<td>ECH</td>
<td>A1B</td>
<td>3.2</td>
<td>23.4</td>
<td>2.7</td>
<td>2.5</td>
<td></td>
</tr>
<tr>
<td>MIROC</td>
<td>A2</td>
<td>3.2</td>
<td>23.4</td>
<td>2.8</td>
<td>2.6</td>
<td></td>
</tr>
<tr>
<td>CNR</td>
<td>A1B</td>
<td>3.3</td>
<td>23.8</td>
<td>2.6</td>
<td>2.3</td>
<td></td>
</tr>
<tr>
<td>MIROC</td>
<td>B1</td>
<td>3.6</td>
<td>25.7</td>
<td>2.4</td>
<td>2.3</td>
<td></td>
</tr>
<tr>
<td>MIROC</td>
<td>A1B</td>
<td>4.7</td>
<td>33.8</td>
<td>3</td>
<td>2.8</td>
<td></td>
</tr>
</tbody>
</table>

Source: Nelson, Gerald C. et al., 2010, page 15

Note: In this table and elsewhere in sections 5 and 6, a reference to a particular year for a climate realisation such as 2000, 2050 is in fact referring to mean values around that year. For example, the data described as 2000 in this table are representative of the period 1950–2000. The data described as 2050 are representative of the period 2041–2060.

Each of the model outputs are then downscaled to exclude the Republic of Ireland which accounts for the difference between British Isles FPU and the UK.
1.1.3 Projections – agricultural productivity without climate change

This annex presents a range of projections to illustrate “what-if there was no further climate change beyond current levels?” These projections are used as the base against which to compare the impacts of climate change in the main report (Section 3).

The projections below illustrate yields to 2050.

**Figure 6.** Historic wheat yields and range of wheat yield projections (t/ha) for the UK if climate change were perfectly mitigated

![Wheat Yield Graph](image)


In **Figure 6** we can see that actual wheat yields show significant volatility over the period from 1984 to 2010, with a year-on-year average rate of growth of 0.28%. This could be due to a range of factors such as prevailing market conditions (input price spikes) or climate events (extreme weather). Beyond 2010, the projections suggest an annual average growth rate of 0.22%, reaching around 8.4 t/ha in 2050 (compared with around 7.7t/ha today) under the medium socio-economic scenario. This sits within the range of projections shown in the chart by the dotted line, which reflects the upper and lower bound of socioeconomic growth scenarios.

Annex 4: IFPRI projections
For wheat, this suggests that in the absence of further climate change, socio-economic factors appear to have a relatively low effect on productivity.

**Figure 7.** Historic sugar beet yields and range of sugar beet yield projections (t/ha) for the UK if climate change were perfectly mitigated

Historic data source: Defra, Table 5.7, (Defra, 2011)


Similar to wheat projections, in **Figure 7** historic sugar beet yields show variation across years to 2010, with an average year-on-year growth rate of 1% from 1991-2010. The projections (which have been illustrated to be linear to 2050) suggest an annual rate of growth of 0.27% in the following 40 year period reaching around 60t/ha in 2050 (compared with 54t/ha today). This sits within the range of projections shown in the chart by the dotted line, which reflects the upper and lower bound of the socio-economic scenarios.

Annex 4: IFPRI projections
Potato yields, like the previous two crops, exhibit variation across years in their historical trends with an upward trend and an annual growth rate of 0.98% for the 10 years from 1991-2010. The projections (illustrated with linear growth) suggest a lower annual average rate of growth of 0.28% for the 40 years to 2050, reaching some 49t/ha (compared with 44t/ha today) with minimal variation across the pessimistic and optimistic socio-economic scenarios.

The key observations from Figure 6, Figure 7 and Figure 8 are that if there was no significant further climate change (other than that which has occurred over recent years), yields are projected to continue to increase but at slower rates than in recent decades. This conclusion holds across different socio-economic scenarios.
**Focus of the analysis**

The analysis is focused on agricultural productivity and production defined as yields and volumes produced. The four crops selected by Defra for the analysis are those that have been explored within the CCRA: wheat, sugar beet, potatoes and grassland (key to livestock).

The choice of the four outputs is in part driven by the availability of data, but also, importantly, the extensive analysis of climate risks facing them, as presented in the CCRA (2012).

**Table 6** presents the key statistics for the various factors on which this analysis focuses.

**Table 6. Key statistics for focus of analysis**

<table>
<thead>
<tr>
<th></th>
<th>Wheat (44% of UK arable crop land)</th>
<th>Sugar beet (3% UK arable cropland)</th>
<th>Potatoes (3% of UK arable crop land)</th>
<th>Grassland</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area occupied</td>
<td>1,939</td>
<td>118</td>
<td>138</td>
<td>10,000</td>
</tr>
<tr>
<td>(thousand hectares)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Productivity</td>
<td>7.7</td>
<td>54</td>
<td>44</td>
<td>-</td>
</tr>
<tr>
<td>(tonnes per hectare)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Volume of</td>
<td>14.9</td>
<td>6.9</td>
<td>6.0</td>
<td>-</td>
</tr>
<tr>
<td>harvested</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>production</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(million tonnes)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Value of</td>
<td>1.69</td>
<td>0.197</td>
<td>0.78</td>
<td>-</td>
</tr>
<tr>
<td>production</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(£ billion)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: Defra (2011)

The rationale for selecting each crop is primarily because they were the focus of the CCRA (Knox et al., 2012) but with further detail discussed below.

**Wheat**

Wheat is the most important crop that the UK produces in terms of cropped area and value. Of the 4.6 million hectares of cropped land in the UK, some 44% is occupied by wheat (1.9 million hectares, or around 10% of UK agricultural area). In 2010, of the total UK output of cereals (£2.27 billion), wheat accounted for some 74% (£1.69 billion). Wheat also represents around 22% of UK crop

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* Figures taken from *Production and income accounts data, 2010* (Defra, 2012b)

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Annex 4: IFPRI projections
output (by value) and was therefore chosen as a representative cereal crop in the UK. Yields are currently around 7.7 tonnes per hectare.

**Potatoes**

For the horticultural sub-sector, potatoes were chosen as the characteristic crop. They are the most important irrigated field crop in terms of cropped area and water use (Weatherhead, 2006), occupying some 138,000 hectares of UK land in 2010\(^\text{11}\). Average yields are higher than for wheat at around 44 tonnes per hectare. Although potatoes represent only around 4% of total agricultural output\(^\text{12}\) (in 2010), they represent around 10% of the value of UK crop output and are considered to be good representative of horticultural crops, given the importance of water for their growth and their susceptibility to particular climate risks.

**Sugar beet**

Sugar beet is an arable crop occupying 118,000 hectares in the UK\(^\text{13}\). The UK is the fourth largest EU producer of sugar beet with approximately 4500 growers contracted to supply British Sugar (the only UK buyer). UK farms provided 64% of UK’s refined sugar for food production. In 2010, the value of sugar beet was £196.5 million based on around 118,000 hectares predominantly in the East of England, East Midlands and to a lesser extent Yorkshire and Humberside. Sugar beet yields have increased steadily since 1990 and currently average at around 7 tonnes per hectare. Sugar beet represents around 3% of UK crop output but is a unique market in the sense that it only has one buyer – British Sugar. Choice of this crop allows analysis of this unique part of the sector.

**Grassland**

Grassland was selected for the purpose of this analysis as it is the major factor in animal production and land use. It occupies about 10 million hectares of permanent grassland, plus 1.2 million hectares of rough grazing\(^\text{14}\). It forms a key input to livestock as a source of food (silage grazing).

Grassland is the largest agricultural land category in the UK. Beef and sheep production is more reliant on grass (more than 70% feeding requirements) than dairy production. Productivity of grasslands is generally considered to be below its potential, partly due to the need to farm within environmental constraints and

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\(^{10}\) All data from Agriculture in the UK 2010 (Defra).

\(^{11}\) Table 3.2, Agriculture in the UK 2010 (Defra).

\(^{12}\) Some 6 million tonnes of potatoes were produced in 2010 with a value of some £780.2 million.

\(^{13}\) Table 3.2, A UK 2010 (Defra)

\(^{14}\) Table 3.2, Agriculture in the UK 2010 (Defra)
to promote sustainable production, e.g. greater fertiliser applications are not applied to avoid increasing nitrate/or phosphate pollution.

Production follows uneven seasonal distribution: cutting and conserving it as silage is necessary to feed demands in winter, and forage yields per hectare vary considerably between sites and between years. There is year-round feed requirement so availability of silage is a key determinant of farm output.

The John Nix Farm Management Pocketbook provides estimate forage yields for 2012, as summarised in Table 7 below.  

<table>
<thead>
<tr>
<th>Forage Yields Estimated for 2012</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yield (t/ha)</td>
</tr>
<tr>
<td>Dairy grass</td>
</tr>
<tr>
<td>Other grass</td>
</tr>
<tr>
<td>Grass Clover Ley</td>
</tr>
<tr>
<td>Forage Maize</td>
</tr>
<tr>
<td>Kale</td>
</tr>
<tr>
<td>Fodder Beet</td>
</tr>
<tr>
<td>Forage Rape</td>
</tr>
<tr>
<td>Main crop Turnips</td>
</tr>
<tr>
<td>Stubble Turnips</td>
</tr>
<tr>
<td>Swedes</td>
</tr>
</tbody>
</table>

Source: John Nix Farm Management Pocketbook, pages 83-85

Note: The figures are estimated for 2012 and relate to the 2012 harvest. The yields assume a ‘normal’ or average season, based on trends.

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Annex 5: Policy landscape

This annex presents further detail on the policies that form the policy landscape within which all agriculture activity sits.

UK agricultural policy

The implications of government policy on the sector’s ability to adapt vary greatly. The policy landscape in the UK can broadly be described in four areas as shown in Figure 9.

Figure 9. Agricultural policy landscape

<table>
<thead>
<tr>
<th>UK and EU sector support</th>
<th>• Common Agricultural Policy – fundamentally impacts on the whole sector</th>
</tr>
</thead>
</table>
| Water and flooding | • Nitrates Directive  
• Water Framework Directive  
• Catchment Sensitive Farming  
• Flood and Water Management Act  
• Water Act 2003  
• Water White paper  
• Abstraction Licensing |
| Environmental sustainability | • Climate change mitigation  
• Environmental Damage Regulations  
• Soil Protection Review  
• Rural Development Programme for England (Environmental Stewardship)  
• Biodiversity 2020: A strategy for England’s wildlife and ecosystem services |
• The Welfare of Animals (Transport) (England) Order 2006 |

Defra is accountable for agricultural policy at the UK level but agricultural policy in Scotland, Wales and Northern Ireland is devolved to the Scottish Government, the Welsh Government and the Northern Ireland Executive respectively. The following explains some specific variations across each states policy landscape.
Scotland

The Climate Change (Scotland) Act 2009 outlines an ambitious legislative framework to promote climate change adaptation in Scotland, mainly through the Scottish Adaptation Programme.

As with all the Devolved Administrations, agriculture in Scotland operates within the overall context of the Common Agricultural Policy (CAP) as well as other European policies. Under Pillar II of the CAP, the Scotland Rural Development Programme plays a significant role in facilitating adaptation in Scotland by helping farmers adapt their production to the changing climate.

As with the rest of the UK, agriculture in Scotland is shaped significantly by other EU directives, with the Water Framework Directive and the Nitrates Directive significantly affecting the Scottish agricultural sector through the control of pollution and nitrate use.

A key agricultural policy in Scotland is the General Binding Rules (GBR) for Diffuse Water. Introduced in 2008 under an amendment to Scotland’s Water Environment (Controlled Activities) Regulations 2005, the Diffuse Pollution GBRs were endorsed to reduce pollution from agricultural activities and help to protect and improve water quality.

The GBRs are based on existing codes of good practice that apply to land and water run-off management, focusing on specific activities that protect the water environment, such as fertiliser storage and application, land cultivation, pesticide application and keeping livestock.

Wales

The Climate Change Strategy for Wales (2010) and the Adaptation Delivery Plan (2010) outline the framework and delivery mechanisms that will promote sustainable adaptation throughout Wales. Specific Sector Action Plans will promote the integration of adaptation into sectoral policies, with agriculture, land use and forestry being incorporated into an overarching Natural Environment adaptation plan. Welsh agricultural policy more broadly is formulated and managed within the context of the EU’s Common Agricultural Policy (CAP) and this will feed in to the development of the Sector Action Plan.

Currently CAP supports adaptation through Pillar II and its various agri-environment and capital grant schemes. A significant part of the Rural Development Plan for Wales (under Pillar II) is the Glastir agri-environment scheme which provides substantial funding to improve water management, reduce the risks of flooding and improve and preserve the natural environment.

As with the whole of the UK, the EU Water Framework Directive shapes and influences water management in Wales.

Annex 5: Policy landscape
Northern Ireland

The Northern Ireland Executive is responsible for climate change adaptation under the Northern Ireland Act 1998 (HR Wallingford et al., 2012b).

As with all the Devolved Administrations, agriculture in Northern Ireland operates within the overall context of the Common Agricultural Policy (CAP) as well as other European policies. Under Pillar II of the CAP, the Northern Ireland Rural Development Programme supports farmers through agri-environment and capital grant schemes, helping farmers adapt their production to the changing climate. This includes, or has included, measures to promote the establishment of anaerobic digestion plants on farms, planting of short-rotation willow coppice and better slurry management.

On January 1st, 2007, in response to the Nitrate Directive, legislation was introduced in Northern Ireland to reduce the amount of nitrogen and phosphorus in Northern Ireland’s water courses coming from farms. The Nitrates Action Programme Regulations 2006 and the Phosphorus Regulations 2006 introduce manure storage requirements, record keeping, land application restrictions and closed spreading periods.

UK and EU sector support

The EU’s Common Agricultural Policy (CAP) plays a significant role in the EU agricultural sector, impacting on (and leading to) significant other UK regulation and legislation.

Pillars I and II of the CAP provide the general framework for EU agricultural policy:

i. **Pillar I** relates to direct payments (Single Farm Payments) that are conditional upon adherence with various requirements under cross compliance; and,

ii. **Pillar II** looks to enhance farmer competitiveness and improve social and environmental development through voluntary agri-environment schemes and targeted capital grants (European Commission, 2011).

**Pillar I** provides funding for market support and direct subsidies for EU farmers provided they adhere to a set of environmental standards, known as cross compliance.

**Pillar II** looks to enhance farmer competitiveness and improve social and environmental development through voluntary agri-environment schemes and targeted capital grants (Defra, 2011b).

CAP currently accounts for approximately 50 per cent of the EU’s budget, with the Commission currently proposing to allocate €281.8 billion under Pillar I and €89.9 billion under Pillar II in the period 2014-2020 (European Commission, 2011b).

Annex 5: Policy landscape


**Common Agricultural Policy: Pillar I**

The Common Agricultural Policy enables farmers to receive direct payments (Single Farm Payment (SFP)) for observing certain regulatory requirements and good agricultural and environmental conditions. The obligations (termed ‘cross-compliance’) relate to soil conservation, watercourse protection, grassland preservation and various other practices, all of which increase farmer awareness and adherence to good agricultural practices, so enhancing adaptation (European Commission, 2011).

Pillar I of the CAP does not require the SFP recipient to produce any kind of specified output on their land. This could dampen the incentive to adapt as the recipient receives payment irrespective of the commercial value/profitability of production on his/her land. The size of this disincentive depends on the proportion of direct payments that make up a farmer’s annual income (in 2010/11, this was just over 50% for the average UK farmer). The revenue streams from the CAP are a consistent source of income to farmers in a market facing increasing uncertainty, particularly over world commodity prices. From an economic perspective, the dependency on this revenue means that the CAP reform review currently being negotiated at the EU level creates uncertainties over future revenue streams. This could act as a barrier to longer-term adaptation actions.

The potential impact of Pillar I could therefore be negative, particularly for smaller farms which are dependent on CAP revenue streams.

**Common Agricultural Policy: Pillar II**

Under the current CAP framework, adaptation is primarily supported by various actions under Pillar II. Through the CAP’s rural development policy (Pillar II) there is significant financial support for land management measures that promote adaptation and mitigation options for climate change. These measures support the provision of a wide range of options that address a number of environmental and climate change objectives and are discussed in greater depth shortly (European Commission, 2011).

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16 Except where coupled payments exist (e.g. the Scottish Beef Calf Scheme). Here, the payments are paid under Pillar I.

17 On average in the UK, farmers each receive €29,507 in single farm payment with an average total income of €57,265. (Defra 2011c) Farm accounts in England 2010/2011,
Water and flooding

Water abstraction

In 2009, the consumption of water abstracted from non-tidal surface and groundwater in England and Wales fell to an approximate 33.6 thousand megalitres/day in 2009 to 41.2 thousand megalitres/day in 2000 (Defra, 2010b). Demand for irrigation water in agricultural production is projected to expand by between 25-180% by 2050 (Environment Agency, 2011). With continued access to abstracted water vital for food production, poor access to water could limit production and restrictions on abstraction are particularly expected in the East of England where over half of the total volume of water used for irrigated agriculture in the UK is abstracted and where the most significant issues of drought are likely to be faced (Environment Agency, 2011).

Government intends to reform the water abstraction regime19 and as such, these issues are not discussed in full in this report. That said, with policy uncertainty surrounding abstraction licensing, in the immediate term, farmers could be deterred from adapting because investments in irrigation systems require licences for abstraction. The UK Government set out a number of principles for transition to a new abstraction regime in the Water White Paper to reduce this uncertainty. In particular, it has stated that future licenses will systematically and equitably take into account current licences and actual use. However, increased water scarcity, combined with short-term policy uncertainty, could deter adaptation that relies on abstraction at low flows.

Agriculture is currently considered to be a lower priority than residential and industrial users of water in the event of drought, so a farmer’s access to water could be restricted even where they hold a licence. Uncertainty over the ability to access the water required could lower the case for investing in actions such as irrigation systems, however, it may also increase the case for investing in storage.

Water is a key input to agricultural production mainly from rainfall but with water abstraction making a substantial contribution also, mainly for high value crops such as potatoes (total agriculture reported abstraction was some 195 million litres a day on average in 2008 (Defra, 2011)).

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19 For further information, please refer to the UK’s Water White Paper: Water for Life
Water abstraction regime reform

The Government announced in the Water White Paper that it intended to reform the water abstraction regime. In order to do this, Defra, the Welsh Government, the Environment Agency and Ofwat are implementing a major programme of research to develop an evidence base to assess the impacts of different reform options. Key areas of work include improving our knowledge of:

- Future availability of water, particularly the effects on water availability on the energy and agricultural sectors’ future demands for water;
- The relationships between water levels and water ecological status;
- Regulatory design options and their technical feasibility; and
- Abstractor response strategies to changes in water availability under different regulatory options.

This work will be completed by June 2013 in order to feed into a formal consultation document and draft impact assessment to be published at the end of 2013.

Water Framework Directive

The Water Framework Directive sets ecological and chemical targets and covers both surface and groundwater bodies. Many of the WFD’s requirements are covered by existing regulation (such as Water Resources Act section 85, which makes it illegal to pollute water) and therefore farmers should already be acting on these issues (e.g. soil, nutrient, pesticide management). For additional measures such as land use change (e.g. buffer strips and forestry promotion), these will be incentivised through agri-environment, forestry and other non-government funded schemes, such as water company catchment schemes.

The WFD impacts agriculture by limiting agricultural practices that contribute to pollution discharge to water, such as the fertilisation of crops, slurry spreading and the spraying of pesticides. The WFD requires all Member States to aim to achieve “good chemical status” and “good ecological status” by 2015 and covers all major UK water bodies. Currently the UK shows that 29% of all assessed surface water bodies meet good ecological status or better, with agriculture contributing significantly to the UK’s poor ecological status. Consequently, there is likely to be greater emphasis on reducing the negative impact of agricultural practices on water quality and quantity in the WFD’s subsequent planning cycles.

Agriculture is a significant cause of diffuse water pollution, with agricultural land occupying over 70% of UK land (Environment Agency, 2011). The first cycle of actions to deliver the WFD contains mainly voluntary actions. As evidence on
the specific measures needed is strengthened, more action will be required by the farming sector to implement these actions in subsequent planning cycles (2015-2021 and 2021-2027), limiting the negative impact of agricultural practices on water quality and quantity. Action taken under WFD, which may incur some costs for farmers, is essential to maintain water for the future.

The effect of the WFD on the capacity of farms to adapt, particularly those which already face tight margins and operate in areas where stringent limits apply, could be a substantial barrier to taking adaptation action. This is because of the potential need to divert resources towards meeting legal requirements, which could reduce resources available for adaptation investment.

The Nitrates Directive

The Nitrates Directive aims to reduce water pollution from agriculture by improving the efficiency of nitrogen use and by reducing losses of nitrogen from agriculture, cost-effectively.

Defra has designated Nitrogen Vulnerable Zones (NVZs) in approximately 62% of land in the UK to address the problem of water pollution from nitrates. NVZs limit the use of nitrogen-based fertilisers, with the protection/improvement of water supplies expected to help farmers adapt to climate change in the long run.

In Wales, 2.3% of land is classified as a Nitrate Vulnerable Zone (Welsh Government, 2011), whilst 14.2% of Scottish land and 100% of Northern Ireland are covered by NVZs.

The use of nitrogen fertiliser in agriculture has enhanced productivity, but losses of nitrogen through water courses and the surrounding environment have impacted adversely on ecosystems, biodiversity and human health (Defra, 2011d).

The main costs associated with implementing the Nitrates Directive come from extending livestock loading, closed periods, increasing storage capacity and restricting spreading techniques.

The Nitrates Directive places restrictions on crop nitrogen requirements and spreading techniques. However, in broad terms, crop and livestock production is not affected by these nitrogen requirements, according to an ADAS study.

Furthermore, the improvement to the UK’s water supply from limiting the use of nitrogen based fertilisers is expected to outweigh any loss in fertiliser use, facilitating adaptation.

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20 Closed periods are imposed when there is little or no benefit in applying fertiliser, due to the needs of the crop, and exceptions are made for crops, such as oil seed rape, where nitrogen fertiliser is needed in the autumn

Annex 5: Policy landscape
Catchment Sensitive Farming

Catchment Sensitive Farming (CSF) aims to improve soil and land management practices in areas that are important for the provision of aquatic ecosystem health. Included in the CSF is a Capital Grant Scheme (funded by the Rural Development Programme), which provides farmers in priority catchments with the resources and support they need to improve or install facilities that reduce pollution from agricultural practices. These grants have the potential to facilitate adaptation, with finances frequently provided for issues such as water provisioning for grazing livestock and the management of run-off and drainage water.

It is one of the main mechanisms along with the Nitrates Directive used in the UK to implement the aims of the WFD. These measures have the effect of improving nutrient management and agricultural water sources, which in turn enhance adaptation.

The 85 recommendations proposed to farmers in the ‘An inventory of methods to control Diffuse Water Pollution from Agriculture’ manual vary for farm type and local conditions; they include cultivating land for crops in spring rather than autumn, establishing in-field grass buffer strips, using anaerobic digestion for farm manures and using slurry injection application techniques. Cultivating in springtime reduces nitrate and particulate phosphorous losses, but also facilitates adaptation as rising temperatures mean that rotation patterns need to be brought forward (IGER and ADAS, 2006).21

The impact of reducing fertilisers containing phosphorous would be expected to be greatest for crops that are particularly responsive to the nutrient, such as potatoes and some vegetable crops. Qualitative evidence suggests that where fertiliser use is restricted, the potential implications for soil should be recognised as in turn, this impacts on crop productivity. Furthermore, for winter wheat, a 10% reduction in nitrogen fertiliser (from the economic optimum) would result in a 1 – 3% reduction in yield (IGER and ADAS, 2006).

Overall, CSF is expected to facilitate adaptation activity.

Environmental sustainability

Climate change mitigation

The Climate Change Act 2008 sets the UK a target to reduce greenhouse gas emissions by at least 80% from 1990 levels by 2050 and the 4th Carbon Budget requires emissions fall by 50% between 2021 and 2027.
Climate Change mitigation policies will lead to fundamental changes in all sectors, including agriculture. Some mitigation policies specifically focus on agricultural production, such as reducing emissions by focusing on decreasing nitrogen additions, better livestock management, using practices which use and store carbon, etc. All of which can complement adaptation (Smith et al., 2007).

A number of schemes under the RDPE improve both mitigation and adaptation (ADAS, 2011). For example, some mitigation measures relate to nutrient management, several of which are supported under Axis 1 of the RDPE through advice and training that can enhance adaptation (ADAS, 2011).

Whilst increased mitigation potentially decreases the need for adaptation, this is not always the case. The EU Renewable Energy Directive creates a binding EU-wide target for members to source 20% of their energy needs from renewables, including biomass and biofuel. This can lead to conflicts over mitigation and adaptation and increased competition for land with agriculture.

**Rural Development Program**

The **Rural Development Programme** allows for flexibility in the provision of adaptation that isn’t available under Pillar I schemes. Under the RDP, farmers can identify bespoke actions that are applicable to their situation at the local level.

Claimants of **Rural Development Programme** payments need to meet standards of good agricultural and environmental practice to ensure that soil, water, habitats and landscape features are protected under cross compliance.

The Rural Development Programme in England (RDPE) is a 7-year funding programme with a budget of £3.7 billion. The RDPE comprises mainly the voluntary initiatives under Pillar II, the most significant of which is the environmental stewardship scheme\(^\text{22}\). Currently, applications for funding are received under the RDPE’s axes of:

- Axis 1 improving the competitiveness of the agricultural & forestry sector
- Axis 2 improving the environment and the countryside;
- Axis 3 improving the quality of life in rural areas and diversification of the rural economy; and

\(^{22}\) The main elements to the Environmental Stewardship Scheme:

About £400 million each year is paid to England’s land managers through Agri-Environment Schemes designed to protect soils and water, with the majority of funding provided through two strands of Environmental Stewardship: Entry-Level Stewardship and Higher-Level Stewardship.\(^\text{22}\) **Entry Level Stewardship** (ELS) allows for flexibility in the environmental actions delivered, whilst **Higher Level Stewardship** (HLS) is more targeted, but both provide support to farmers to address the specific effects of climate change (e.g. by supporting actions to tackle soil erosion and run-off, and by providing funding for buffer strips for water courses on cultivated land.)

Annex 5: Policy landscape
Axis 4: The LEADER Approach and Leader Maps

The Rural Development Programmes can enhance adaptation by improving competitiveness under axis 1 as well as environment and land management practices under axis 2, for example afforestation, wetland creation, establishing buffer strips and irrigation efficiency/precision farming. Naturally, enhanced targeting through environmental stewardship will increase the effectiveness of these options (ADAS, 2011).

Funding through axis 3 provides capital grants to, amongst other things, facilitate diversification from agriculture. This may help some farmers to adapt to more volatile incomes from farming by diversifying income sources. Funding provided under axis 1 also facilitates climate change adaptation through helping farmers understand how to achieve sustainable production and improved water and soil management. In addition, funding for local action groups (Axis 4, or the ‘LEADER’ approach) enhances the capacity of farms to adapt to the new market opportunities and new environmental responsibilities arising from climate change.

The Rural Development Programmes for England and the Devolved Administrations cover the same four areas - or axis of activity - as each other, as discussed shortly.

The Scotland Rural Development Programme 2007-13 is worth approximately £1.5billion and is very different from its predecessor. It includes measures to address economic and social goals as well as environmental measures through schemes such as the Skills Development Scheme and the Food Processing, Marketing and Co-operation Grant Scheme.

In Wales, Glastir is replacing the existing agri-environment. It is funded by the Rural Development Plan for Wales 2007-2013, which has a total budget of £795 million (Welsh Government, 2012), and delivers better water management, reduced flood risk, and conserved and enhanced biodiversity through its five key elements:

1. the All-Wales Element – a whole farm land management scheme;
2. the Targeted Element – a scheme intended to deliver improvements to the environmental status of a range of habitats, species, soils and water;
3. the Common Land Element – designed to provide support for the delivery of environmental benefits on common land;
4. the Woodlands Element – designed to support land managers who wish to create new woodland and/or manage existing woodlands; and
5. the Agricultural Carbon Reduction and Efficiency Scheme (ACRES) – a capital grant scheme available to farmers and land managers who hold an AWE contract.

The Northern Ireland Rural Development Programme is designed to provide rural areas and rural populations with support through funding from the EAFRD.
and Voluntary Modulation of 330 million Euros. The Northern Ireland Rural Development Programme 2007-13 contains a number of measures under each axis, including:

1. Vocational Training and Information Actions, and Modernisation of Agricultural Holdings under Axis 1;
2. Supply Chain Development, Less Favoured Areas Compensatory Allowances, Agri-Environment Programmes and First Afforestation and Forest Environment schemes under Axis 2;
3. A scheme to promote diversification into non-agricultural activities, Support for Business Creation and Development, and fund for Conservation and Upgrading the Rural Heritage.

**Soil Protection Review 2010**

The Soil Protective Review 2010 is one of a set of requirements within cross compliance designed to improve soil management practices.

Implementation of the SPR10 requires the identification of soil type based on soil texture and the risk to the soil from land use. Based on the risk identified, the farmer must adopt a minimum number of land management measures to mitigate the risk.

As climate change affects the UK’s soil structure, adoption of best practice measures, like those required by the SPR, would be expected to bring large benefits to those who adopt them. As different climatic issues arise, the SPR10 is designed to be responsive to farmers needs and help them adapt to the climatic and soil conditions by providing advice that aligns with the changing climate. This improves farm practices as climatic and other conditions change, naturally improving farmers’ capacity to adapt.

**Pesticides Directive**

The Pesticides Directive sets maximum application rates and prohibits the use of certain pesticides in defined periods to encourage their sustainable use. As rising temperatures are likely to increase the severity of crop disease epidemics, the Directive could inhibit farmers’ ability to adapt to the changing climate.

For example, total production of fungicide-treated winter oilseed rape is projected to increase to 2.90 Mt by 2050 in the high emissions scenario, while untreated oilseed rape production in England would fall to 1.04 Mt by 2050 under the same assumptions (Butterworth et al., 2010).

This illustrates the potential implications of climate change on a pesticide free agricultural sector. The restrictions on volume and application of pesticides could significantly constrain (and in some extreme cases remove) farmers’ adaptive options, therefore impacting yield.

Annex 5: Policy landscape
With recent changes to the industry and regulatory requirements, gaps are appearing in pesticide provision for particular crops and this is expected to be exacerbated by climate change. Smaller crops, such as carrots and ornamentals, are expected to be the most vulnerable.

The EU Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) regulation provides a single regulatory framework for the control of chemicals, which can significantly affect fertiliser use as well as the use of components of preparations and related materials like ammonia, acids (nitric, sulphuric and orthophosphoric) and several by-products of chemical use (fluosilicic acid and phosphogypsum), limiting their use as an adaptive action (European Commission, 2006).

**Animal welfare**

*Welfare of Farmed Animals (England) Regulations and the Welfare of Animals (Transport) Order 2006*

The 2007 *Welfare of Farmed Animals (England) Regulations* and the *Welfare of Animals (Transport) Order 2006* regulate animal health and welfare in the EU and consequently the United Kingdom. Rising temperatures, increased inclement weather, water logging and changes in precipitation will impact both directly (thermal conditions etc.) and indirectly (feed availability and land use) on animal well-being. Consequently, animal welfare legislation would be expected to have an increasingly significant role to play in climate change adaptation.

The UK CCRA highlighted new and emerging diseases, particularly vector borne disease, as a threat to animal health. This largely stems from the changing distribution of disease – be it endemic or exotic. Surveillance for new emerging disease is therefore required with suitable control plans for endemics. This is covered in the EU Animal Health Law Chapter VII (not yet in place) on disease prevention, surveillance, control and eradication.

It is suggested that ‘animal transportation is perhaps the component of livestock production most directly vulnerable to the immediate effects of climate change’ (SAC, 2011), as significant mortality rates exist under present conditions due to thermal stress.

It is likely that rising temperatures and more frequent extreme events, particularly heat waves, will have reckonable impacts in the UK pre 2020, particularly in southern and eastern regions (SAC, 2011) as well as countries outside the UK.

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**Annex 5: Policy landscape**
Adaption will therefore be necessary to meet the requirements of the animal welfare acts and ensure a good yield as thermal stresses from either heat or cold will have similarly negative impacts on welfare and production traits.

Thus, as climate change impacts both directly and indirectly on animal well-being, animal welfare legislation has a potentially direct impact on the requirement to adapt to climate change.

**Genetic Modification (GM) legislation**

EU regulations on genetically modified food and feed, impact directly on a range of business sectors. However, as GM crops are not currently grown commercially in the UK, there is not expected to be a direct impact on British farmers from this legislation (beyond the restrictions in technologies available to farmers to respond to changing conditions).²⁴

GM crops currently in development could offer traits such as disease-resistance, drought-tolerance and nitrogen-use efficiency which could play a role in improving adaptation in British agriculture. The use of GM can also speed up the time it takes to develop varieties adapted to new environmental conditions. It is difficult to reach any firm conclusions about the scale of the potential benefits that might accrue to UK farmers from adopting this technology. However, despite favourable safety assessments from the European Food Safety Authority, the EU authorisation process operates very slowly in approving GM crop seeds for commercial use (only one product has been approved since 1998). This inefficiency could delay climate adapted technologies from entering the market.

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²⁴ Ibid
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Evidence on agricultural sector adaptive capacity

Structural adaptive capacity

The analysis of structural adaptive capacity has been derived from evidence from published studies and qualitative evidence from interviews with a wide range of experts within the sector and the outputs of the Adaptation Forum. Adaptive capacity of the sector overall is considered to be relatively high, however, it varies significantly within and between sub-sectors. Adaptive capacity of the sector is weakened by its complexity including high variety of farming types, size, and business models.

This description of structural adaptive capacity can be used to identify specific types of decisions where further assessment of climate change implications will be important. These include:

- Development of new varieties specific to the UK (where there is a long consequence time)
- Decisions such as water storage and irrigation where capital costs are relatively high and many different parties can work together
- Approaches to incorporate value of ecosystem services into decision making
- Supply chain management including relationships between retailers and producers

(i) Sector complexity

The agricultural sector is extremely complex. This means that decisions may be more difficult to make as there are more people/organisations to consult and their agendas differ (Ballard et al., 2011). This also means that there will be greater variability in the context of risk tolerance.

The extent of influence of each actor in the value chain will depend on the particular products in question. In a general sense, they include:

- **Farmers** – They physically produce the outputs, making choices about how they do this. They have the most direct impact over adaptation to climate change in their day to day farm practices and longer-term crop planning.
- **Researchers and breeders** – They develop the knowledge that underpins the design and characteristics of key factors of production that get to market (such as seeds, technological developments etc.).
Industry associations, trade bodies, levy boards – They support those in the sector to make the most of opportunities and increase resilience through knowledge sharing and best practice actions.

Government – It sets the policy environment in which all parts of the sector must operate.

Retailers, food processors and wholesalers – Retailers and food processor / food wholesalers demand certain products and standards of quality from farmers and they influence the choice available and choices made by consumers.

At farmer level, the complexity grows, as farms may be split by:

- **Product:** Sub-sectors based on product have different agendas. In England, just under half of all holdings are pigs, poultry, livestock or dairy, with around 25% accounted for by cereals and crops. This differs in the DAs: in Wales 44% holdings are pigs, poultry, livestock or dairy and in Northern Ireland this is 90%. In Scotland 30% holdings are cereals and cropping (Defra, 2011).

- **Farm size:** Within each sub-sector, there are also significant differences in terms of size of farm and business model.

- **Farmer type:** The sector is segmented in relation to the types of farmer, as can be illustrated by Defra’s segmentation approach (Wilson et al., 2010) that segments farmers into custodians, lifestyle choice, pragmatists, modern family business and challenged enterprise, each of which has different drivers and characteristics.

Although agriculture is a complex sector, complexity is reduced by the structure of the supply chain, which consists predominantly of large and powerful retailers, agrochemical companies, and the few very large agribusinesses (Renwick et al., 2012). Complexity has also been reduced by the consolidation of many sub-sectors (e.g. the number of commercial pig farmers has decreased) and their supporting services (such as the number of abattoirs) as well as farm size, with in 2010, the largest 20% of farms (those holding more than 100 hectares) holding

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25 For example, of the sample in the Farm Business Survey:

- 53% were PRAGMATISTS: av 140ha, Farm Business Income (FBI) £48,000;
- 21% were MODERN FAMILY BUSINESS: av 182ha, FBI £88,000;
- 14% were CUSTODIANS: av 119ha farm, FBI £32,000;
- 7% were LIFESTYLE CHOICE: av 106ha, FBI £14,400;
- 4% were CHALLENGED ENTERPRISES: av 76ha, FBI £30,200
over 73% of UK agricultural land. The smallest farms (less than 20ha) account for 47% of holdings but together hold just 4% of agricultural land (Defra, 2011).

**These small farms are more vulnerable to climate change and tend to have less capacity to plan for longer-term or access to finance to respond to risks.** A significant barrier for smaller farms is a lack of economies of scale so that substantial investments are disproportionately more costly. The trend for consolidation is therefore likely to increase having adverse impacts for the agriculture sector in terms of maintaining rural livelihoods and employment, but having a much less significant impact on productivity.

The agricultural sector has many **interdependencies** with other sectors (particularly land use and planning, and natural environment and energy). The interdependencies lead to significant trade-offs between food production and environmental protection and the underlying institutional arrangements (Angus et al., 2009) that increase the complexity of the sector, weakening adaptive capacity.

The sector’s **reliance and interaction with international markets** (commodity prices and energy/oil price for equipment and fertilisers) and the instability of global food and energy prices limit the sector’s focus on medium and long-term climate change pressures.

According to industry experts, future productivity will involve closer relationships between water, soil, varieties and inputs requiring many different parties to work together. There is also an increasing requirement for local co-operation for shared infrastructure/equipment, securing inputs and managing waste (e.g. straw, silage, slurry).

**(ii) Decision lifetime**

Where the outcomes of decisions are long-lasting, i.e. a water storage reservoir may be used for several decades, the decisions need to take into account a longer term future that is inherently uncertain, but may have more severe impacts (Ballard et al., 2011).

Farmers tend to have a **lead time of less than one year for operational decisions** (e.g. planting times, varieties, choice of inputs etc). **Exceptions to this include longer structural decisions where large investment (infrastructure and machinery), significant business decisions (e.g. changing products grown), permits and stakeholder engagement (e.g. reservoirs require planning permission and EA approvals, construction of processing facilities) are required.**

Consequence time is short for many farm-based decisions, however, important exceptions include building up soil function (e.g. it can take five years to improve soil quality by 0.5% according to an industry expert) and improvements to ecosystem function (such as planting trees or restoring natural river profiles).

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Consequence time is long within the wider sector, for example, in the development of new varieties, which for horticultural crops can take 10-15 years from synthesis to market.

(iii) Activity levels

Adaptive capacity is strong where activity levels are high, i.e. when assets are replaced or new assets are created relatively often. The short-term nature of most farming decisions means that activity is relatively high. For example, farmers replace equipment regularly, plant arable and horticultural crops most years, so there are regular opportunities to make adaptation decisions, such as introducing different varieties/crops and different management techniques. Supermarkets make produce-buying decisions frequently, so can move from suppliers in different locations almost immediately (according to an industry expert). However, activity levels are lower in other parts of the sector such as breeding, where new varieties take a long time to develop and are not quickly replaced.

Activity levels are lower when it comes to equipment which is not frequently replaced, and some farm-based infrastructure is used for several decades and incrementally improved (e.g. livestock housing) rather than being replaced entirely.

(iv) Maladaptation

Actions that will not aid climate change adaptation, and in fact, may exacerbate the negative impacts of climate change, are said to be maladapted. In some cases adaptive capacity can be lowered as scarce resources need to be diverted to undoing maladapted decisions (Ballard et al., 2011).

A particular area of maladaptation that must be avoided is potential conflict between mitigation and adaptation. Agriculture as a sector offers opportunities to mitigate the portion of global greenhouse gas (GHG) emissions that are directly dependent upon land use, land-use change, and land-management techniques (Rosenzweig and Tubiello, 2007). Although it is not the purpose of this project to consider mitigation measures, it is extremely important to consider the links between adaptation and mitigation to avoid conflicts and to find synergies where possible, e.g. reducing use of fossil fuels and fertilisers, increasing carbon sequestration in soil and vegetation (Glendining et al., 2009). All adaptation options must be considered in terms of emissions and any option must satisfy both mitigation and adaptation goals.

In agriculture, retailers and food processors tend to specify the products they want (often reflecting consumer demands) and this can result in maladaptive actions by farmers. For example, encouraging aesthetically pleasing/high quality horticultural crops that require significant water use, or in the case of sugar beet, specifying harvesting times to maximise processing plant efficiency.

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Another area of maladaptation is through the increasing specialisation and use of contractors. For example, specialist equipment is required for harvesting potatoes on waterlogged soils and when the equipment is in high demand, it can mean some farmers use it when it is available, i.e. when soil should not be worked, thereby doing damage to the soil structure.

Maladaptation may also arise due to the sector’s dependency on natural resources and a lack of co-operation between different enterprises with the potential to over-exploit these resources (e.g. water abstraction in a catchment). The interdependency with other sectors can lead to maladaptation when decisions are made from the perspective of one sector only. For example, land use planning decisions should be made taking into consideration all those affected, e.g. built environment, natural environment, agriculture etc.

1.1.5 Evidence on actions within the sector

Summary

This section includes description of adaptation actions which are farmer-led and relatively low cost as well as more directed longer-term strategies:

- Examples of farmer-led changes include those that are part of good farm management practice (such as altering planting dates), although there may still require some government and industry investment, in the form, for example, of information and promotion of best practices.

- More directed longer-term adaptation strategies require increased co-ordination between different organisations in the sector, investment in research and development and efforts to de-risk capital investments.

Introduction

This section provides an overview of the actions different actors in the sector are expected to take to maximise opportunities or minimise risks. The information below has been compiled through expert assessment, stakeholder interviews, a one-day Adaptation in Agriculture Forum, and an assessment of the peer reviewed and grey literature. The adaptations range from practical, well tested methods to more innovative adaptations.

Many of these adaptation actions relate to building the adaptive capacity of the farming sector, such as raising awareness. For the purposes of this report, building adaptive capacity is not described as a separate action in itself, but is an integral part of each adaptation option, as the greater the capacity of the individual, the more likely it is for an action to be taken.

The list of actions set out here is not exhaustive, but is intended to illustrate the key types of responses to climate change that actors in the agriculture sector are
taking/will take without government intervention. The actions focus on the farmer and site-specific actions.

Related individual actions have been grouped into ten categories:

1. New breeds and varieties
2. Storage infrastructure and buildings
3. General farming practices – crops
4. General farming practices – livestock
5. Responding to pests and disease
6. Water management
7. Soil management
8. Managing ecosystem services and the agri-environment
9. Knowledge transfer
10. Financial risk management

Key actions already taken by farmers

(i) New breeds and varieties

Description of measures within category

A changing climate brings a need for crops/livestock that are better adapted to their new conditions. This category considers the role of developing and using new varieties and breeds. Specific measures include:

- Develop new crop breeds/cultivars e.g. drought resistant crops
- Use new varieties of crop e.g. drought resistant crops, earlier maturing varieties, or new crops (wine grapes, soft fruits)
- Breed and use new varieties of forage

Extent of adoption of adaptation actions

The HGCA Recommended Lists of new varieties are primarily based on yield, which according to industry experts, is the main trait of interest for any breeder or farmer at present, combined with quality. At present there is little evidence that breeders are developing new traits for climate resilience as they are not saleable.

More breeding research and development is happening internationally, largely because the markets are larger (e.g. for soya and maize). However, internationally developed varieties do not always address the specific conditions experienced on UK farms.

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**Key barriers**

There are several market failures in relation to the development of climate-adapted varieties. Research for new varieties requires significant funding, as well as translation of research knowledge into findings suitable for commercial development. Breeders only have the incentive to invest where the returns from doing so are likely to justify the costs. A recent study for the British Society of Plant Breeders (DTZ, 2011) suggests that where the return does not reflect wider society benefits – such as being able to adapt to climate change – then there is no incentive for breeders to invest in the relevant research. While the annual royalty income of UK crop breeders is approximately £40m, the annual cost of a competitive wheat breeding programme is £1 - £1.5m. This high cost relative to income limits the ability of breeders to develop a broad portfolio of varieties in anticipation of future uncertainties (pests/diseases, droughts etc).

A further market failure relates to information asymmetry across the supply chain as farmers respond to retailer demand, but are constrained by what is available to them to grow. Breeders have different incentives for what they develop and for which they invest in research. These asymmetries in information across the chain can lead to a lack of action on developing climate change adapted products. The long lead times for breeding (new varieties take 10-15 years to develop) can also be a barrier to having the right information and products available for farmers when they need it to adapt to climate change. Furthermore, take-up in sub-sectors varies. For example, sugar beet farmers have immediate take up (given the monopoly control), whereas smaller farms can be resistant to use a new variety.

With respect to changing dairy breeds, efficiency (improved milk production per unit feed input) is the driver and new breeds are taken up rapidly when the economic incentive is there. However, there are some examples of maladaptation, such as payments for woodland grazing by traditional livestock breeds under HLS schemes rather than more efficient (e.g. fewer GHG emissions) modern breeds.

Processors or supermarkets (and consumers) have specific requirements in terms of taste and appearance of their products and will put these criteria above sustainability advantages, often creating an incentive to grow maladapted or vulnerable varieties where they look better. For example, blight-resistant potatoes are not as popular with consumers as other varieties, and whisky processors in Scotland have very specific requirements in terms of the barley they accept.

**Effect of response**

The benefits from improved crop varieties are to a large extent the result of research and development. Since 1982, 90% wheat yield increases have been almost exclusively due to improved varieties (NIAB, 2009). A yield increase of

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1.9t/ha has been achieved due to plant breeding, with an estimated gross value of £373 - £445 million per annum in 2010 prices (DTZ, 2010). The gross return on industry investment for this is an extremely high 40 to 1.

Development of new fungicides or new cultivars that will be resistant to diseases in the changed environment both take 10–15 years to implement; thus decisions need to be taken now to plan for the future (Barnes et al., 2010). A survey of 600 farmers at the Oxford Farming Conference 2012 singled out plant breeding as the most important scientific development for future agricultural production. However, the dissemination and uptake of the research is driven by capacity for translation of findings into marketable products. This capacity is currently limited by the knowledge transfer capability within the UK.

(ii) Storage infrastructure (buildings)

Description of measures within category

Increased temperatures, heavier rainfall and increased extreme weather events will demand increased storage and protection for crops, seed, and silage and also better housing for animals in terms of protection (extensive farming) or ventilation (intensive farming).

The measures within this category include:

- Increase/improve seed, crop and silage storage and protection as well as facilities to dry crops
- Use of in-store cooling, ventilation, insulation for better refrigeration to cool crops
- Appropriate livestock housing
- Secure and covered storage for animal wastes

Extent of adoption of adaptation actions

Adoption of these measures is expected to be very high with investment occurring on all farms as a market decision: without protection, production will suffer (e.g. ADAS, 2008; Defra, 2011b).

Key barriers

The different type of investment, e.g. incremental investments vs. one-off large construction projects, will depend on farm margins. This is evident in the large range of tenant-type capital26 which can vary from under £164,000 to £600,000.

26 Tenant type capital includes closing valuations for: machinery, livestock, glasshouses, permanent crops, crops, forage, cultivations, stores, liquid assets, and Single Payment Scheme entitlements

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(Wilson et al., 2011). The adaptive capacity of different types of farmer will therefore affect the extent to which these measures are adopted.

Postponement of investment may occur where there is uncertainty in climate change and its associated indirect impacts (and therefore unclear payback periods).

Effect of response

If the capital investment is not made, it could lead to an inability to secure a premium on crops due to inadequate crop drying and storage. For example, barley meeting malting standards can command a £15/tonne premium (historically as high as £25/tonne), and milling wheat experiences a premium of £25/tonne over feed wheat (Nix, 2012).

Plastic silage covers are cheap, but creating the pit is expensive (more than £100,000 according to experts). However, making silage on-farm is considerably more cost-effective than having to buy it in, e.g. silage dry matter is 12p/kg, compared with dry matter concentrate of 25p/kg (Nix, 2012).

The capital investments required for livestock housing should prevent loss in productivity due to overheating and the costs of non-compliance with animal welfare regulations.

These actions require capital expenditure, so, if they became essential for adaptation to climate change, a lack of finance make enterprise commercially unviable..

(iii) Farming practices - crops

Description of measures within category

There are many farming management practices in limited use today that will become more necessary and widespread to strengthen farmers’ resilience to climate change, e.g. practices that deliver soil conservation and input (fertiliser, pesticides) efficiency and reduction. These operational measures include:

- Precision farming to optimise inputs (e.g. nitrogen, potassium, phosphorous)
- Focus on existing good management practices for crops, e.g. adjust planting times, change crop mix, adjust harvesting times

Extent of adoption of adaptation actions

There is some variation in adoption of these measures. The Farm Practices Survey 2011 for England (FPS 2011) indicates that despite being able to improve productivity and efficiency today, some of the practices listed above are still not widely followed. For example, Farming Futures (2011) reports 8% of farmers

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adapting to climate change are changing their crop practices and the Farming Practices Survey (2011) shows that only 15% of respondents are taking advantage of longer growing seasons (and 23% are considering taking action in the future). However, some practices are increasingly being adopted, e.g. 62% of respondents to the FPS have a nutrient management plan in 2011 (cf. 46% in 2006).

**Key barriers**

The main reason for lack of take up appears to be that farmers think there is no need at present to change practices or the measures are too impractical or not relevant (ADAS, 2008).

Lack of capacity is another reason for changing crop practices not being more widespread, with larger farms consistently taking more action than smaller farms (FPS, 2011).

**Effect of response**

The practices listed above are straightforward, low cost, ‘low-adaptation’ strategies that will be important short term no –regrets options. There will be several benefits of such practices, both from the economic benefit of an increase in yield as well as a reduction in inputs, and an environmental benefit from better land use, soil quality and targeting of chemicals. Awareness and use of these practices is spreading as a result of environment regulation driving behaviour change and with the introduction of new technologies, particularly in the new generation of farmers in horticulture/arable farming. Over a longer time period, it is reasonable to expect that the agricultural sector will adapt to the predicted threats and adopt strategies to negate some of the projected disease-induced decreases in yield (Nelson et al., 2009).

There are a number of examples illustrating that changing farming practices can lead to increased yields. For example, a combination of farmer-led adaptation practices (changing planting date etc) can improve oilseed rape yield from an average of 3 t/ha to 6.5 t/ha (e.g. Berry and Spink, 2006). However, this also requires further government investment in applied research to improve productivity of the crop and to effectively transmit knowledge (Gladders et al., 2006). Barnes et al. (2010) found that yields of oilseed rape could increase 30% by an achievable combination of present knowledge, practice and directed production-specific information.

Precision agriculture also provides yield benefits. The average improvement in wheat yield due to precision farming was calculated to be £22/ha.27 Other

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27 Using a nitrogen price of £0.3/kg and a wheat price of £65/t (in 2001). The costs of precision farming systems range £5/ha to £18/ha depending on system chosen (at an area of at least 250ha). The fields were located in Southern and South Eastern England and represented soils similar to 30% of the arable growing area of England and Wales.

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studies show savings from precision applied herbicide use ranging between £0.5 and £20.7/ha (Godwin et al., 2003). Common problems such as waterlogging and fertiliser application error can also be corrected by use of precision agriculture.

(iv) Farming practices – livestock

Description of measures within category

There are a number of measures that livestock and dairy farmers can take to improve livestock productivity and manage risks associated with management of waste. Specific practices include:

- Increase grassland production and grow pasture with diverse range of plant species
- Better use of farm waste, i.e. manure, slurry
- Focus on existing good management practice in livestock, e.g. provision of shade,

Extent of adoption of adaptation actions

Established farming practices to improve grassland productivity include increased use of rotation and short term leys, use of old permanent pasture, use of mix forage including catch crops (ADAS, 2008). These practices are particularly important in Scotland, Wales and Northern Ireland where grassland is an important land-use. Many of these practices are not widespread among farmers and adoption is low (e.g. 8% farmers adapting to climate change are changing husbandry practices (Farming Futures, 2011)). It is likely to increase in the future, as approximately half of dairy, sheep and beef farmers think climate change will affect their farms in the next 10 years (Farming Futures, 2011).

Key barriers

Lack of awareness of best practice is a particular difficulty with adoption of these sorts of measures. Small beef/dairy farms tend to have less adaptive capacity than large ones and farmers can be resistant to change.

Effect of response

The benefits of climate change on grassland may not be fully realised on the basis that grassland productivity is under-developed. However, increasing productivity and thereby reducing dependency on the purchase of dry matter concentrate could improve margins. For instance a farmer able to produce 13-14 t/ha dry matter could achieve a 3,600kg liveweight gain/ha in beef and sheep (EBLEX, n.d.).

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Better use of farm waste such as using slurry as a fertilizer can reduce input costs and prevent non-compliance penalties, e.g. according to a sector expert, farmers based in Nitrogen Vulnerable Zones who do not use appropriate slurry storage can lose between 3-5% of their payments. General best practice management such as rotational grazing, preventing livestock having direct access to water courses to avoid run-off/erosion and also fecal pollution of water courses and keeping them off fields when they are waterlogged are important no-regrets measures.

(v) Pests and diseases management

Description of measures within category

There are a number of measures used today to respond to changes in pests and diseases as a result of climate change. The measures considered include:

- Optimising pest/disease management, e.g. monitoring, integrated pest management
- Increased use of pesticides/herbicides/fungicides

Extent of adoption of adaptation actions

Measures to respond to pests and diseases are already being taken. For example, in the FPS 2011, action to counter pests/diseases was the most responded to climate risk (29%). Increased use of pesticides/herbicides/fungicides to deal with risk is the immediate adaptation response of most farmers. Stakeholders indicated that farmers are very aware of issues around resistance to plant protection products, particularly given regulatory restrictions and the reduction in available, cost-effective options.

Measures that are already being taken to optimise pest/disease management include integrated pest management28, use of biological controls and natural predators, as well as changing planting dates or harvesting times, better identification and monitoring of pests/disease, and also increased use of chemicals. These short-term strategies should be combined with longer term strategies, such as breeding for disease-resistance.

Key barriers

Limitations on the extent to which the measures will be adopted include the uncertainty of how diseases and pests will evolve and the time lag in developing

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28 See examples on the Endure Information Centre website that disseminates information on pest management. It offers a European quality selection (European Best Practices) of practices with validated Integrated Pest Management (IPM) measures including prevention, chemical pest and disease control as well as non-chemical alternatives such as biological control measures.
disease-resistant varieties (discussed in (i) above). IPM is still relatively new and needs further understanding, as is being carried out by the PURE project29. Increased use of chemicals will be further limited by new legislation controlling plant protection products reducing the number of alternative products available (and indirectly allowing for pests/diseases to build up resistance).

**Effect of response**

Increasing use of chemicals may be effective in the short-term, but longer term there may be difficulties due to regulatory restrictions on plant protection products; adverse impacts associated with chemical use, particularly with regard to GHG emissions; and environmental pollution from run-off into water bodies. Increased use of chemicals also drives resistance. Optimising pest management strategies will therefore be extremely important.

Pest management strategies can be extremely effective, for example, there was a significant reduction in the severity of damage caused by *Tuta absoluta* on tomatoes two to three years after its arrival, due in part to farmers having learned how to identify and deal with it, especially where IPM responses were developed (Endure, 2011).

Increasing the use of current knowledge for disease limitation could have immediate benefits, for example, such practice could increase UK average winter oilseed rape yield by 0.5t/ha (Spink et al., 2009). Other studies have estimated that with increasing EU regulation and increasing resistance to existing products, a lack of alternative plant protection products may result in increased costs/yield reductions so that production of a crop may no longer be viable. Crops affected like this include outdoor lettuce, winter barley, wheat and oilseed rape – with gross margins for all potentially falling by 40% or more (ADAS, 2010).

There are synergies that can be made between mitigation and adaptation with respect to disease control. Disease control treatments have been found to reduce GHG emissions as they increase yield per tonne of seed (Fitt et al., 2011; Smith et al., 2008).

In terms of specific crops, measures to address climate change related yield loss from phoma stem canker in oil seed rape could result in benefits ranging from £24m to £100m (Barnes et al., 2010). A study by Evans et al. (2010) showed that if stem canker and light leaf spot were effectively controlled in oilseed rape, the value of the crop would increase by £13m in England and £2.5m in Scotland by the 2050s under a high CO₂ emissions scenario.

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29 http://www.pure-ipm.eu/taxonomy/term/5

**Annex 6: Adaptation**
(vi) Water management

**Description of measures within category**

Water management includes managing water availability and use. The immediate reactive adaptation option where water is scarce is to abstract more water, where licences allow. Other planned measures considered include:

- Improve irrigation efficiency
- Increase water storage capacity
- Establish sustainable drainage systems to reduce flooding

**Extent of adoption of adaptation actions**

Farmers in locations where droughts (and floods) are frequent (e.g. more than once in 3 – 5 years), are already pursuing opportunities for irrigation/ water storage where it is feasible. In the face of restrictions on abstraction, competing water users, and increased flooding, farmers are taking more significant measures to manage water, for example, switching to new irrigation technologies, water storage reservoirs, or sustainable drainage systems.

Different crops require different amounts of water. While there is often a clear case for water storage and irrigation for (East Anglian) horticulture farmers, for cereals irrigation it is less clear cut (e.g. for some farmers irrigation is only a necessity in one year in ten.)

Co-operation between landowners and farmers can mean that capital costs are shared and have the potential to improve implementation rates for water catchment area management\(^{30}\), for example, in the Anglian Region, 16% of farmers surveyed were active in a Farmer Organised Abstraction Group and 33% were keen to join (Rudge and Gowing, n.d.)

**Key barriers**

Access to abstraction licences, and tightening conditions on the licences, could be a barrier to adaptation action where significant investments, such as irrigation systems, and the business case for those investments, rely on them.

Measures may not be pursued in the event of uncertainty (unclear frequency of droughts or floods), a lack of ability to secure access of water resources (e.g. current challenges of winter abstraction) and requirements for significant infrastructure and expenditure. Earthworks costs only of clay-lined reservoirs are

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\(^{30}\) An example of this form of collaboration is the United Utilities and RSPB led Sustainable Catchment Management Programme (SCaMP) that worked to improve water catchment management by for example, providing fencing for livestock, and new waste facilities to reduce run-off etc.
approximately £1-2 per m³ of gross storage capacity and earthworks and lining costs of plastic-lined ones are around £2-6 per m³ of storage capacity (UKIA, 2010a). In addition, there are site investigations, various permissions and professional fees that bring the costs even higher. There are also a number of other barriers for investment including technical feasibility for reservoirs/ponds, permitting requirements and operating costs (annual opex for reservoirs are approximately 1% of capex (UKIA, 2010a)), and timeframe (i.e. it takes 2-3 years to build a reservoir).

Effect of response

An immediate reactive response to dealing with increased temperatures and soil aridity is to increase water abstraction. As all farmers with irrigation will also increase abstraction at the same time and in the same catchment areas, this places significant demand on water availability and is arguably a maladaptive response (though it should be regulated by the EA licensing regime). This means that other adaptation measures need to occur, such as winter abstraction and storing water, or drip irrigation.

Irrigation efficiency can be cost-effective, for example, implementing irrigation scheduling with weekly analyses of crop growth and water use, carrying out water audits etc. However, experts have told us that sophisticated irrigation systems do not always lead to better performance, and the management skill of the irrigator is key. Costs of irrigation systems are relatively high, for example capex can be between £1,150 - £2,250/ha, and opex can be between £70-£130/ha (Nix, 2012). In addition, long-term they may be maladaptive as farmers may need to move areas leaving the infrastructure behind.

Three themes have been identified as part of a successful irrigation strategy: working together, making best use of available water and developing a knowledge base (Knox et al., 2009). Given the local nature of water issues, neighbouring farmers are beginning to work together to manage their water resources, for example, the Lincoln Water Transfer company holds one abstraction licence in common for its 19 members (UKIA, 2010b).

Where there is sufficient water demand, storage is an effective response as costs of abstraction in winter are a tenth of that in summer.

(vii) Soil management

Description of measures within category

Soil management includes a range of measures to maintain and enhance soil organic matter and soil function (e.g. to aid carbon sequestration, nutrient management and prevent erosion). Specific measures considered include:

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- Use soil conservation techniques (e.g. no-till farming, cover crops, contour ploughing)
- Increase soil organic matter levels and soil structure; this also includes use of mulches to conserve water in cultivating crops
- Measures to avoid soil erosion or compaction (with consequences for water management) from grazing livestock

**Extent of adoption of adaptation actions**

The level of awareness of the importance of soil structure in agriculture is growing. Nevertheless, there are still reported low-levels of uptake (e.g. 23% of FPS 2011 respondents state that they are adapting to increased soil erosion).

**Key barriers**

Difficulties associated with soil conservation include the impact of some techniques on short-term productivity and margins; in the arable sector the use of fewer cultivations to keep soil organic matter at the top reduces short-term yields. It takes considerable time to realise the benefits of soil improvements: only after approximately five years are benefits seen. In addition, stakeholders feel there is still a lack of underlying science and information on benefits realised from good soil management.

**Effect of response**

There are a number of examples illustrating the considerable benefit of improvements of soil function to productivity. For instance, over five years, potatoes can experience 0.75t/ha (or £100/ha) (WRAP, 2011) benefit through more available water associated with soil organic matter, and the use of compost as a mulch on apple trees has increased yields by 50% (WRAP, 2008), generating up additional profits of £5,250/acre. Another study that sought to value soil organic carbon determined that the net value of soil organic carbon management in Europe is €30-80/ha/year (Sohi et al., 2010).

There are also many co-benefits associated with improving soil quality. For example, cost reductions from reduced fertiliser use (e.g. one study indicated average potential reductions in nitrogen losses from the soil of between 2.1% and 4.3%, and a reduction in phosphorous losses of 4.0% from the Entry Level Scheme (Boatman et al., 2008)).

In addition, efforts to improve soil function can have very significant non-production related benefits, including reducing flood risk, reducing run-off and pollution of water bodies, benefits to biodiversity within the soil, and improved carbon sequestration thereby aiding mitigation policy. The many co-benefits of this group of adaptation actions make it important.
(viii) Protecting ecosystem services

Description of measures within category

Given the close interface between agricultural productivity and the natural environment, many of the adaptation actions discussed under other categories (e.g. pest management and soil management) will have positive or negative implications for the natural environment. Further measures to protect ecosystem services include:

- Action taken to compensate for reduced ecosystem services (e.g. reduction in bee pollination)
- Protecting and maintaining ecosystem services through habitat protection and restoration, e.g., restoring natural river profiles, establishing sustainable drainage systems to reduce flooding, and maintaining high water tables in peatlands
- Actions taken in response to implementation of codes, for example on farm animal grazing
- Actions taken directly to improve ecosystems services on farm, e.g., plant trees as wind break, plant buffer strips to protect surface water bodies and encourage biodiversity

Extent of adoption of adaptation actions

Action taken to preserve or enhance ecosystem services (such as planting trees and buffer strips or managing soils for water retention) is likely to have a higher take up in farms in agri-environment schemes than those without them. There is evidence that farmers have responded well to the incentives offered by Entry Level Schemes, however the schemes are time limited so some farmers, fearing legacy costs, may be reluctant to put permanent features on their land.

Key barriers

A key market failure which acts as a barrier to agriculture taking further action is the absence of a market for ecosystems services. This lack of market means that there is no economic valuation derived through market mechanisms, in turn meaning that there is little incentive for farmers to take particular action to minimise adverse effects or to enhance ecosystems services.

Effect of response

Agriculture and the natural environment are intrinsically linked. Agriculture has a significant impact on the natural environment in all habitats: such as very high levels of pollution and nutrient enrichment on coastal margins/moorlands/semi-
natural grasslands, and high and increasing levels of overexploitation of wetlands (NEA, 2011)

There are various schemes in place to ensure that farmers minimise their adverse impacts, for example the Environment Stewardship schemes. However, the total area in England under environmental schemes as a whole as of 2009 was around 5.5 million ha under the entry level scheme (ELS) and around 500,000 ha under the higher level scheme (HLS). There is clearly further scope for action given that agriculture area is around 18.3 million hectares.

Management measures such as protecting river margins play an important role in improving and maintaining crucial ecosystem services. The impact of agri-environment schemes has been well documented (Boatman et al., 2008). For instance:

- For arable farming, initiatives (e.g. for rare arable flora, bird species) have been considered effective (and are supported by a strong evidence base).

- For grassland, evidence from evaluations in England, Wales, Scotland and Northern Ireland suggest that semi-natural grassland quality has generally been maintained under agri-environment agreements; however there is less indication of enhancement. The condition of hay meadows and BAP priority grasslands significantly improved following initiatives.

- For low-land heath and moorland, there are some individual successes, but a number of case studies where the benefits are mixed.

- For wet grassland, the condition has either been maintained or improved.

- Other benefits including protection of archaeological sites, landscape protection, and access are also identified in assessments of schemes.

Generally, protecting ecosystem services has many co-benefits in other sectors. It encourages tourism, maintains rural livelihoods and landscapes, provides amenity value, protects water quality, provides flood defence and encourages biodiversity.

Addressing reduced ecosystem services is a longer-term risk, but it will be an extremely expensive one should it become necessary. A replacement cost scenario (focusing on the financial cost of providing man-made substitutes) was used to estimate the value of insect pollination to the UK apple market and suggested a value of £82m (90% of the total market value of the crop) (Marris et al., 2009).
(ix) Knowledge Transfer

Description of measures within category

This category includes identifying and communicating information to farmers, including the extent to which knowledge is taken up by farmers and then implemented, and the extent to which information supports decision making. These adaptation actions include:

- Translational research of academic findings into commercially usable findings
- Education and support networks to share information and experiences (e.g. advisory services, extension services, demonstrations to farmers, farmer networks)
- Planning for Extreme Weather Events (e.g. use of services such as early warning systems)

Extent of adoption of adaptation actions

A wealth of information exists for farmers, such as the Farming Advice Service, that signposts users to certain tools and guidance. However, at the farm level, awareness of climate change is still relatively low (e.g. Farming Futures, 2011).

Numerous technological and non-technological issues are known, and may be applied, but require governance and education to put them in place (Pereira, 2011). Many experts interviewed referred to a reduction in the extent of knowledge transfer activity over recent decades, particularly with the removal of extension services. Larger farms rely on expert advice (e.g. agronomists, agents, vets, feed mixers), and there is much advice and guidance available to farmers in the UK from free, government initiatives e.g. Defra’s Farming Advice Service, to membership funded bodies e.g. Country Land and Business Association (CLA), the Agricultural Industries Confederation (AIC), the agricultural levy boards and private sector consultancies.

According to the FPS 2011, the key sources that farmers use for climate change advice are (i) farming press (55%), (ii) NFU (48%), (iii) Defra (37%) and (iv) EA (36%).

Key barriers

Farmers are concerned about the vague, and often conflicting, messages that they receive through advice programmes and other sources (AEA, 2010). To address such concerns, it is vital that climate change is mainstreamed into other matters rather than being seen as a standalone issue (IGER, 2002). Farmers are unclear what the effects will be and many do not know what to do to adapt or find the

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information overwhelming (Farming Futures, 2011). There is little incentive to adapt unless there is clarity that the action would be worthwhile. This is more pronounced in some sectors, such as livestock, which are more resistant to change.

Other barriers to effective knowledge transfer include the highly fragmented nature of the knowledge and social networks of farmers leading to an absence of common values, a need for hands on experience rather than theoretical advice, and the existence of other influences on the uptake of advice, such as values (Buttel, 2001).

**Effect of response**

Knowledge transfer affects every adaptation measure and is a cross-cutting issue. All the adaptation responses discussed in this report will benefit from applied research to effectively transmit knowledge to change farming practices (Gladders et al., 2006). Adaptation strategies require funding from public and private sectors on knowledge exchange mechanisms to fully realise these gains (Barnes et al., 2010). Building farmers’ adaptive capacity in this way will improve the ability of all farmers to make climate-resilient decisions, increasing the adoption and effect of all adaptation responses.

It is essential to understand the reasoning behind farmers’ decisions and behaviour (e.g. legal means, financial rewards, voluntary collective actions (Wondolleck and Yaffee, 2000) in order to assess the most effective channels for providing advice (Blackstock et al., 2009).

Knowledge transfer can be extremely effective. However, this depends on the mechanism and the extent to which farmers are involved. It also depends on being based on a coherent structure and avoiding disparate (or even contradictory) information. Based on feedback, 68-88% of farmers attending 12 Farming Futures events in 2011 had an improved understanding of technical matters, 33% plan to take action because of the event, 21% farmers have taken action to adapt to/mitigate climate change after one of the events (Farming Futures, pers.comm.).

Evidence from past initiatives suggests that knowledge transfer alone does not necessarily address barriers, as there may still be a lack of access to finance. The England Catchment Sensitive Farming programme (covers 33% agricultural land in England) has brought improvements to soil and farming practices; however in addition to advice, this also includes funding mechanisms to encourage uptake of schemes (i.e. a capital grants scheme) (Defra, 2008).
Financial risk management

Description of measures within category

Farmers will face a number of production risks from climate change that can make their incomes volatile from year to year. Furthermore, extreme weather events can create challenging financial problems. This is compounded by the need to respond to market risks which can often be strongly influenced by international drivers. This category includes a number of measures including:

- Development and purchase of crop & farm insurance
- Involvement in futures and options markets
- Further diversification of both production and non-production income

There are a number of other measures which have been used or considered in the past such as price stabilisation mechanisms; these are not considered here.

Extent of adoption of adaptation actions

Financial risk management is an area where major agribusiness is able to respond but smaller farms are less able to exploit mechanisms. There is very little availability of insurance in the UK to cover crops against weather risks.

Where they exist, insurance products are primarily damage-based, and these tend to focus on the single higher value crops (Northern Ireland Assembly, 2008; Hazell, 2011). In 2008 the area of crops that was insured was 370,000 ha with a premium amount of €11.1m (Northern Ireland Assembly, 2008). Specific issues covered by insurers include hail, frost and infrastructure related insurance (e.g. polytunnels and glasshouses).

Insurance for livestock is treated differently compared to crops. The uptake of insurance is much higher for the dairy and livestock sector - especially in intensive farming. Farmers who lose animals due to specific listed diseases can receive ad hoc compensation from national government as well as supported by private schemes; though compulsory slaughter could hinder the development of the private sector market.

While very few farmers are actively involved in the futures and options markets, forward price contracts are common. Given the volatile commodity markets, farmers want security and there is an incentive to set prices. Where investment in markets occurs, it tends to be limited to markets where there is a close correlation between prices prevailing in national markets and those in international markets so that foreign exchange risk is managed (Hazell, 2011).

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Key barriers

The adoption of insurance across the sector is driven in part by lack of demand due to price (Morgan, 2007) (and farmers consider managing variability as an intrinsic part of their job) and lack of supply of appropriate insurance products.

This is because weather risks tend to be written as parametric insurance. This type of insurance does not indemnify the insured against their pure loss, but rather agrees to make a payment if a specified event triggers the policy. In the case of crop insurance, the trigger would be an extreme weather event. This requires a different approach to underwriting and there is a shortage of underwriters with such skills in the UK (a different approach to claim handling is also required, particularly as this type of cover is prone to fraud). However, insurance seems to be increasing: the sector is reporting considerable interest (30-50%) in insurance against storm and flood damage to grain in-store (Morgan, 2007).

Investing in futures markets may be used by larger commercial agribusiness or commodity crop farmers, but will not be used by smaller farmers. Qualitative evidence suggests that there is limited knowledge among farmers on the price of volatility and alternative responses. By developing a more informed understanding of the price of risk, farm planning and use of instruments can respond to critical climate change impacts.

Effect of response

In the past, diversification (into different products and income streams) has been a critical management strategy to reduce income risk. However, in selected examples, where insurance is provided, there is an incentive for farmers to specialise in the insured high value crops as they are protected to some extent by the insurance (Kimura et al., 2010). In general, insurance is extremely effective in dealing with specific risks such as damage hail storms.

Key issues not adequately addressed by insurance include flooding and drought. For the latter, a mechanism which has proven effective in the US (but not widely available in the UK) is use of weather derivatives – where farmers receive payment if rainfall is less than a certain amount.

Forward pricing arrangements are effective in hedging against downside risks rather than reducing the variability of a price. Unlike involvement in futures markets, forward pricing allows the development of a tailored contract (e.g. in terms of quantity, quality, time, location) though does incur higher transaction costs. However there is a risk that farmers forego income when locked into a lower price.

Income tends to be higher in diversified farms, as illustrated by the fact that the 52% of farms that have diversified their activities (in 2010) account for some 64% of total farm income (Defra, 2011). This higher level of income could be an
important factor in assessing the capacity of those farms to adapt to projected climate change.
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