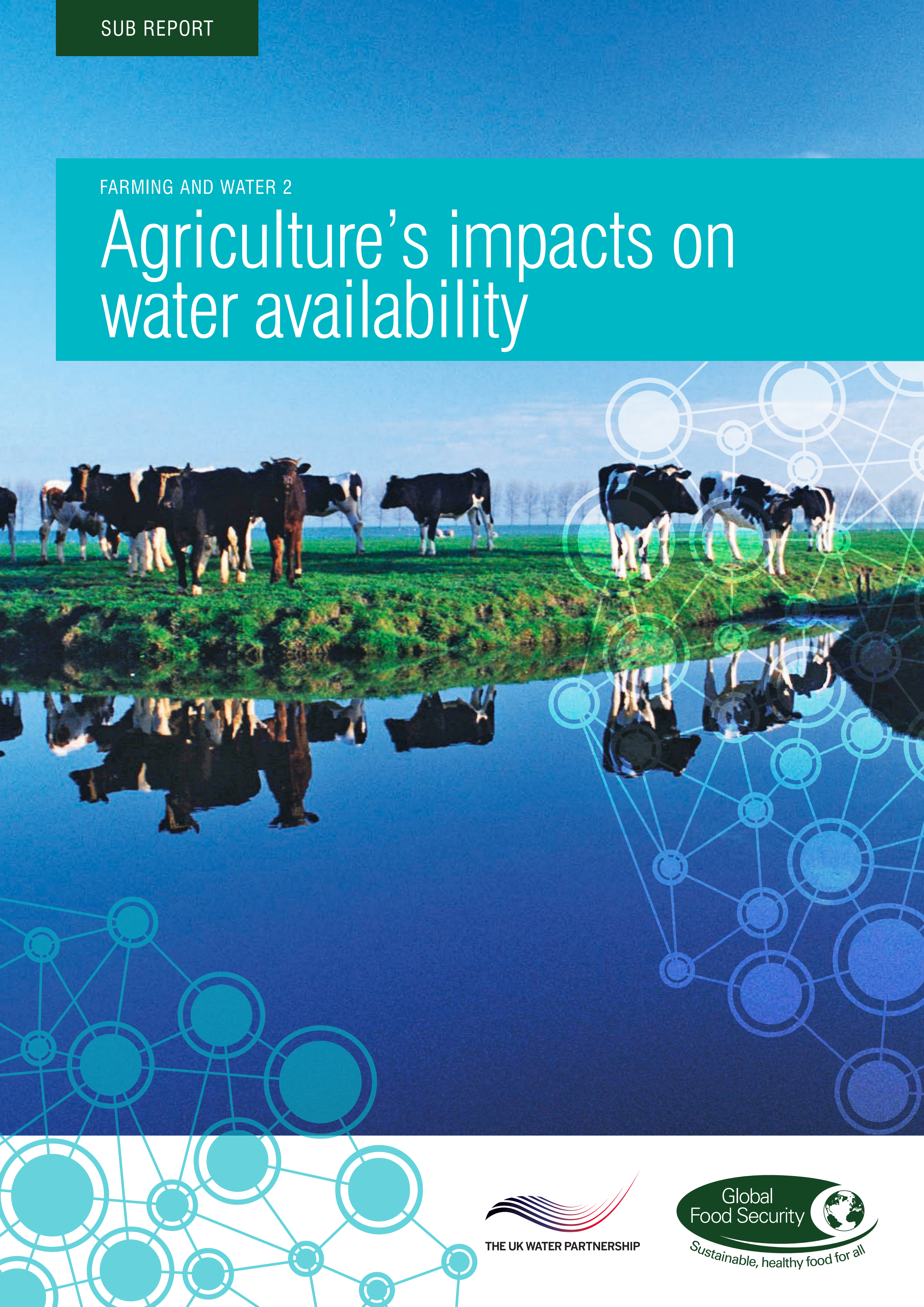
SUB REPORT

FARMING AND WATER 2

Agriculture's impacts on water availability



THE UK WATER PARTNERSHIP

Global Food Security

Sustainable, healthy food for all

Contents

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Executive summary

Pressures on the UK Water supply

The pressure on the UK water supply is increasing, mainly due to an expanding population, particularly in the south-east of England. Climate change is also creating one of the main long term pressures on water availability in the UK and is expected to intensify the global hydrological cycle, leading to more floods and droughts on average, though not in all regions. The pattern of change over the 21st century is not expected to be uniform, with the contrast in precipitation between wet and dry places and wet and dry seasons expected to increase.

The UK is generally perceived to be wet; however water availability varies across the UK, and over time – in some places and at some times, water availability is heavily constrained. In addition to there being a gradient of rainfall from west to east England, there is also an increase in the population density in the South East of England, meaning that there is greater demand for water.

Agricultural Irrigation

Although the total volume of water used for agricultural irrigation is small relative to other uses, irrigation potentially has a large impact on water resources. Potatoes and other vegetables account for the majority of water used for irrigation in England and Wales, using 25% and 54% of irrigation water respectively[1]. Irrigation water use is consumptive (i.e. water is not returned to the environment in the short term) and is concentrated in the months and years when resources are most constrained and also the driest areas of the country (mainly in East Anglia, South East and parts of the East Midlands). As a result, in some dry summers, irrigation of food crops can be the largest abstractor in some catchments.

To ensure that the expectations for food production, water use and the environment can be met over the rest of the century, effective management of water supplies is required. Better forecasting of extreme weather events and how they may change over time is needed. Better knowledge is needed concerning extreme rainfall and flood risk and also the interaction between heat, drought and the length of time for groundwater to recover in terms of recharge. Efficiencies in water use need to be sought; for example in the horticultural sector, sensors can be used to determine the irrigation needs of covered crops.

There is currently an insufficient understanding of how agricultural practices could be adapted to cope with changes in the weather. There is also insufficient understanding of how the intensification of farming methods and new ways of production impact on the environment, by affecting water availability, both through the impact of usage and water management.

Water for livestock

Livestock farmers use water for drinking water, washing animals, cleaning yards and cleaning parlours. It is possible to reduce the volume of water consumed through new housing and adopting new production techniques. There is also scope to reduce water losses through maintenance (e.g. fixing leaks in water troughs) and good management (e.g. trigger sprayers when washing down) or reuse of cooling water.

Rainwater collection may be a viable alternative water source for livestock farms than extraction or using mains water, as many are located in the wetter parts of the country, have large areas of have surfaces and roofs and lower quality water can be used for washing-down and cleaning. However, whilst this may reduce on-farm water costs it does not create ‘new’ water and the water captured may otherwise have contributed to streams or aquifers. Livestock farms still require an adequate mains water supply to meet water requirements during periods of low rainfall and drought.

Reservoirs and water transfers

Reservoirs are increasingly viewed as the best way to secure reliable water supplies for agricultural irrigation and are the preferred adaptation for coping with the increased risk of water scarcity. They provide a secure water storage mechanism, because once water is in the reservoir, the farmer can plan the following year’s cropping and their supply contracts with supermarkets and processors with much greater certainty. They can also improve water supply for domestic and environmental uses by reducing abstraction during summer months. Larger reservoirs may help to attenuate peak flows when flows are high and maintain low flows during dry spells.

Investing in storage is always a more expensive option than direct summer abstraction, even though summer water charges are ten times higher than in winter. Most farmers find it difficult to justify costs in relation to returns they expect from the investment. Most reservoirs being built are supported by government grants in order that they are viable financially, or they are financed as part of an aggregate extraction package.

Water transfers are where there is an artificial movement of water from one water body to another. They can be an effective way of providing water for agriculture and public water supply, moving water form an area of surplus to an area where water is scarcer. Building a new transfer is expensive, usually requiring extensive engineering works over a large area. So, determining whether new transfers are worthwhile depends on the costs and benefits of the alternative sources of water. Research can potentially highlight the most promising circumstances for water transfers, where benefit-to-cost ratios are lowest. This requires better understanding future supply and demand.

Managing water availability

Water catchments provide a range of important ecosystem services to society as a whole, beyond simply the provision of food and water. For example: land management for flood prevention; access to land for recreation and leisure activity (including walking and fishing); and habitat for biodiversity. Any change in the management of one part of this complex system has the potential to lead to negative impacts in other parts. As water availability changes through both demand and supply-side drivers, such as climate change, the potential for negative interactions to intensify may increase. Further understanding of the wider impacts of climate change on water availability, including a better understanding of changing catchment hydrology, is therefore needed.

The management of the competing demands on water resources needs to incorporate advances in thinking around public and private policy. Flexibility and responsiveness will allow new information and methods to be used as they are developed. Any management aimed at addressing water quantity in agriculture needs to take into account other requirements of the wider water system. Catchment management approaches, where methods are used to move water from places or times when it is not scarce to places or times when it is scarce, can be used to achieve this.

Key findings

The main challenges were identified as: 1) allocating water to farming, for domestic and industrial water supply, and the environment in a way that meets the wider needs of society, 2) using water efficiently, especially in times of scarcity, and 3) looking to the future to make sure that expectations for food production, the environment and other water use continue to be met over the rest of the century.

There is the potential for market failure to occur with respect to water use. This can arise from a variety of routes. Farmers often lack information on current and future water availability and their possible options to manage these better. In such a complex area, people may not fully understand or manage the risks they face, and policies set in one area can have unexpected impacts in other places. Finally, managing water and food production needs a long-term view, but many of the decision-makers inevitably have to take short term decisions about cropping patterns and varieties. All of this suggests that more work is needed to understand the risks and potential solutions to this important problem, and that these must translate into practical action that protects both food and water security.

A number of key evidence gaps exist across the catchment and throughout the supply chain which could aid water management on the farm. These are:

- An increased understanding of the link between farming practices and run-off at both high and low flows in order to develop appropriate mitigation actions for water management; this requires new research.
- Identification of opportunities for saving water on the farm and new innovations to make them viable.
- Better management of the demand for water generated by the food supply chain, both in the UK and globally for food imported into the UK, in order to improve water use efficiency and reduce environmental and social issues.
- Significant improvements in forecasting of short and medium term water availability in order to improve water management.
- A better understanding of the wider impacts of climate change on future water availability, including changing catchment hydrology. This will enable better long term planning.
- Improvements in mechanisms to allow the reallocation of water between different uses, to the wider benefit of society.

Introduction

1.1 This report explores the tension between the availability of water and the production of food in the UK. The report aims to identify the challenges, evidence gaps and potential solutions around the linkage between water availability and food production, with particular regard to farming and environmental impacts. Companion reports explore the issues around managing jointly for food and water quality, and our sourcing of food from overseas on supply chain risks and for on water availability in the producing countries.

1.2 In this report we start by examining the overall context of how water and agriculture are linked and water use managed, we then take a detailed look at agricultural use of water and the routes by which agriculture can change its demand on water. Finally, we look to the future and discuss knowledge needs and potential actions.

1.3 World demand for food is expected to rise by 60-100 % by 2050[2], driven by growing population and changing diets. The projected 2bn extra people by 2050 is the equivalent of 250 cities with the population of London which clearly requires significant land area for housing and urban infrastructure. At the same time, the world is changing rapidly. For example, changing weather patterns, particularly increasing extremes of weather (drought, heat, and intense rain leading to floods), are expected to undermine the ability to increase crop yields. This impact on agriculture will vary across the world, but a globally-linked trading system means that reduction in yields in some places (e.g. Africa, Asia) will send economic signals to intensify production in other places where there is potential for yield increases (e.g. NW Europe). Thus, from the food perspective, we can expect strong pressure on UK land for food production increases.

1.4 In the UK, demand for water is increasing mainly because of a growing population. The increasing economic growth, and linked population growth, especially in the drier SE of England, is putting growing pressure on water resources in some areas. Industry is also a significant user of water and as consumption of goods increases (not only manufactured goods, but also energy) so does the demand for water supply. Increasing weather variability, as shown by the droughts of 2010-11 and the floods of 2013-14, indicates that we have to plan for both increasing and decreasing water availability.

1.5 Both water supply and food production are ecosystem services mediated by the land. There is, therefore, something of a tension between them. Intensifying agricultural production may impact on water availability in times of drought by increasing the competition for a scarce resource that others want, and may increase downstream risk in times of flooding by accelerating flow of water from drained lands upstream. Managing land to maximise availability of water in terms of drought, or minimise flooding in terms of excess, may trade-off against agricultural production potential and vice versa. This report explores this linkage.

Water and agriculture: the situation now and in the future

How do agriculture and water interact?

Water availability for agriculture

2.1 Agriculture, food production and water are inextricably linked. On the one hand, water is an essential input for crop production, livestock and food manufacturing. On the other, the nature of agricultural land use affects the hydrological cycle in terms of the partitioning of rainfall between evapotranspiration, runoff and groundwater recharge, and the quality[3] of runoff water in terms of, for example, nutrients and sediment. Water is used in agriculture to grow grass and crops, to support livestock and for general on-farm use (such as cleaning, sanitation, crop spraying). 250 million $m^3\,y^{-1}$ of water is also used by the food and drink industry in processing (Defra, 2007)[4]. Although the UK is generally perceived to be wet, water availability varies not only from place to place but also from time to time. Water availability, from rivers, lakes and groundwater, is constrained by the physical processes of rainfall and evapotranspiration. Typically, river flows and groundwater levels are lowest towards the end of the summer and into early autumn. However, there are competing demands for water and judgements have to be made on how much water should be left in the natural environment to support wildlife, navigation and recreation.

- **Rainfall** is the largest source of water for growing grass and crops in the UK. The timing of rainfall is particularly critical to agriculture and seasonal droughts can lead to significant reductions in crop yield.

- **Abstraction** is water taken from rivers, lakes or groundwater to supplement rainfall for irrigation, for livestock and for general on-farm use. In comparison to the others, this latter category is very low. The volume of water abstraction varies across the UK but is dominated by the need for power generation and for public water supply. It has been estimated[5] that total on-farm water use in England and Wales is in excess of 300 million $m^3\,y^{-1}$, of which spray irrigation is slightly under half. This contrasts with reported abstraction for agriculture of around 120 to 150 million $m^3\,y^{-1}$[6], demonstrating how much comes directly from rainfall. This total of 300 million $m^3\,y^{-1}$ represents around 1.5 % of total fresh water withdrawals in England and Wales. Water use totals vary from year to year, but agricultural abstraction varies from less than 0.5 % of total abstraction in north-west England to around 5 % of total abstraction in the east of England.

- Most **irrigation** is for outdoor field scale crops, most notably potatoes and field vegetables. The volume of water used for irrigation varies from year to year, depending on rainfall. In the last decade total irrigation in England and Wales has varied from nearly 120 million $m^3 y^{-1}$ in 2003 and 2011 to as little as 50 million $m^3 y^{-1}$ in 2012[7]. The maximum legally allowed for spray irrigation in England and Wales is much higher, at over 300 million $m^3 y^{-1}$.

2.2 In some places, and at some times, water availability is constrained. In general, there is less water available in the south east as there is an appreciable gradient of rainfall from west to east and population density (and therefore demand for water) is highest in the south east of England. Droughts – loosely defined as an unusual shortage of water with consequences for people or the environment – occur across all parts of the UK (Marsh et al. 2007)[8]. In the impermeable catchments of the north and west short, intense droughts lasting 12 months or less can lead to shortages of water. In the permeable catchments of the south and east, it usually takes at least two consecutive dry winters before the possible consequences of drought are serious.

The impact of low rainfall for agriculture

2.3 The 2011-12 drought in England and Wales provides a good example of a drought's agricultural impact. During the dry spring of 2011, dry soils in eastern counties and the Midlands made it difficult to prepare seed beds, and not only triggered an early start to the irrigation season but affected the early growth of both cereal and root crops. Livestock farmers faced higher animal feed costs. The agricultural stress eased during the summer of 2011 but intensified through October and November resulting in difficulty in harvesting crops. Crop yields were severely affected particularly on light, sandy soils and shallow rooting crops suffered particularly badly. During the early months of 2012, with restrictions on spray irrigation expected, some cropping patterns were revised. The irrigated crop sector faced a difficult spring and summer with the likelihood that available water would be exhausted before the planned harvest and an expectation that yield and quality would be poor.

The impact of irrigation on water resources

2.4 Although the total volume of water used for agricultural irrigation is small relative to other uses, irrigation potentially has a large impact on water resources. Irrigation is concentrated into a few months and uses water in the driest years when resources are most constrained[9]. It is concentrated in the driest areas of the country (mainly in East Anglia, South East and parts of the East Midlands) and it is a consumptive use (that is, water is not returned to the environment in the short term). As a result, irrigation of food crops can be the largest abstractor in some catchments in some dry summers.

2.5 Irrigation demand is highest in hot, dry summers, where additional water makes most difference to the crop. Demand is also higher if the added value is greater, so world food availability and its prices play their part in influencing irrigation demand from year to year. Farmers normally need to decide on their planned irrigation schedule at the start of the growing season, so changes in water availability, such as irrigation restrictions, are unwelcome.

2.6 Rules about abstraction are also very important in determining water availability. Typically there may be rules that stop or restrict abstraction if river flows are below a specified level. Water allocation rules are also important in determining how much water is available for agriculture. Currently, abstraction is prioritised in the order it was requested with no consideration of how beneficial each use may be. In many parts of England and Wales, this means that no more water is available for summer abstraction[10]. Farmers can build their own reservoirs to store winter water but this is usually an expensive option that requires considerable investment and planning consent. On some farms, there is no suitable location for an on-farm reservoir.

2.7 Crops that are irrigated tend to be of higher value and grown in drier areas, where additional water makes most difference to crop yields and quality. The three most important irrigated crop categories (potatoes, field vegetables, and soft fruit) account for 85 % of the total volume of irrigation water abstracted annually. The spatial distribution of agricultural holdings involved in potato, field vegetable and soft fruit production in 2008 has been mapped and compared against water resource availability[11]. The analysis shows that on average only 10-15 % of agricultural holdings are located in catchments where additional water abstraction would be available during summer low-flow periods. About half of all holdings are located in catchments where no more water is available. Nearly a fifth of holdings are in catchments where too much water is being abstracted and measures are needed to restore environmental flows. Therefore, in water stressed catchments, where water demand for irrigation exceeds available surface or groundwater water supplies, reducing the use of abstracted water would mean that water resources could be released to sustain environmental flows or support other uses.

Using water for livestock production

2.8 Water is required by livestock farming for drinking water, for washing animals and for cleaning yards and parlours. The water used for livestock has very different impacts from water used for irrigation as it is required all year round and the prominent livestock regions tend to be in the north and west of the country where there is less stress on water resources. The amount of water required for drinking depends on the size of the animal and the diet, as a proportion of the drinking water requirement may come from moisture in the food (especially when fresh grass is grazed). The balance may come from natural sources (such as ponds and streams) or be supplied by mains water in drinking troughs.

2.9 The volume of abstracted water needed to produce meat at the farm gate is equal to 67 $l\,kg^{-1}$ for beef and 49 $l\,kg^{-1}$ for lamb[12] (see 'Water use in our food imports' report for detailed discussion of "embedded" water in food products). Dairy farms also use significant amounts of water for cooling and in total it takes about 8 litres of fresh water to produce 1 litre of milk at the farm gate[13]. Although most livestock farms use mains water, 30 % of water for livestock rearing is abstracted from surface and groundwater sources[14]. This is discussed further in the 'Water use in our food imports' report.

Impact of agriculture on water availability

2.10 Abstraction of water for agriculture, reduces the availability of water for other users and uses (public water supply, industry, the environment). For groundwater, sustainability implies not using more each year than the annual recharge rate while leaving enough water to support connected water features (wetlands and rivers); for water in rivers and aquatic systems, environmentally sustainable water use requires not reducing flows to an ecologically detrimental level (the concept of the "minimum environmental flow") and on the social side requires sharing of water among all the stakeholders (up and down stream, industry and domestic). Concerns have been raised over the potential impacts of water abstraction on the environment, particularly in catchments where irrigation abstractions are concentrated and where water resources are under pressure.

Farming and flooding

2.11 As agriculture is the dominant land use in the UK, the management and condition of the land surface impacts on the generation of runoff and can contribute to, or mitigate downstream flood risk[15]. Although rural land management has changed markedly over the last 50 years, the impacts of these practices in terms of runoff generation at the catchment scale have been difficult to quantify. Major reviews of the scientific literature[16,17] concluded that there was substantial evidence of changes in land use and management practices affecting runoff generation at the local and small catchment scale, but very limited evidence that these local changes were propagated downstream at the larger catchment scale.

Agriculture, and the management of rural land, has important links to flood risk in three ways:

1. As only 6% of the UK land area is urban, the management and condition of the rural land surface largely determines how much, and how quickly, rainfall is translated into river flow. Creation and maintenance of land surfaces that encourage infiltration and the temporary storage of rainfall in the catchment can potentially reduce downstream flood risk by smoothing out flows.
2. Flood plains perform a critical function in providing temporary storage of flood water and riparian agricultural land, being more resilient to flooding than properties and infrastructure, can be used for flood storage.
3. 13% of the "best and most versatile" agricultural land in England and Wales is at risk of flooding from rivers or the sea, however this includes 56% of the Grade 1 agricultural land[18]. Therefore a significant proportion of agricultural production is at risk from flooding.

Agricultural land and runoff generation

2.12 When intense rain falls on agricultural land, the natural permeability of the soil allows a proportion to infiltrate into the soil, at least until the soil is saturated, whilst the "roughness" of the surface serves to retain water on the land and slow down the rate at which is reaches watercourses. This natural function will vary according to soil type and land use, with little infiltration occurring on clay soils but much more on sandy soils. Loss of infiltration capacity in the catchment, such as "surface sealing" through urbanisation, can therefore result in more water running off the land during rainfall events and water finding its way into watercourses more quickly. The result is "flashier" rivers and increased flood risk downstream. Agricultural intensification, resulting in soil compaction, removal of hedgerows and field drainage, has increased the runoff of rainfall from agricultural land and the Environment Agency[19] have estimated that about 14% of floods in England and Wales, mainly at the local level, are attributable to runoff from farmland.

2.13 Studies in S W England[20] have shown widespread structural degradation of agricultural soils that has resulted in increased surface-water runoff. This has been particularly associated with late-harvested crops (such as maize) where farm traffic on wet soil has led to soil compaction.

2.14 There are many practices that can be employed by farmers to encourage infiltration and avoid compaction, such as; lower stocking rates, grazing management, seasonal removal of livestock to avoid poaching of soils, field machinery with low ground pressure tyres, avoidance of field operations under wet conditions, soil improvement measures including conservation tillage, and field drainage[21]. Other practices can slow the rate at which water discharges from fields into watercourses including; reinstating field boundaries (hedges, walls and shelterbelts), contour ploughing, artificial bunding and retention ponds.

2.15 In the Nant Pontbren catchment (mid-Wales) shelterbelts were established in selected pastures of land used for sheep grazing. Infiltration rates were significantly higher in areas planted with young trees than in adjacent grazed pastures and runoff volumes have been reduced by 50-75 % [22]. As a result it has been suggested[23] that flood peaks in this small catchment could be reduced by up to 20 %.

2.16 Although rural land management has changed markedly over the last 50 years (driven partly by agricultural policy), the impacts of these practices in terms of runoff generation at the catchment scale have been difficult to quantify. There is a need for more evidence of the linkage between local processes that affect runoff generation at the local and small catchment scale (as in S W England, above), and the way they may be propagated downstream at the larger catchment scale[24,25], because the current absence of evidence does not necessarily imply there is no effect of land management on catchment scale processes. Of course, detection of change is very difficult and modelling suggests that “flood sensitive” rural land management could be expected to make a positive contribution to sustainable flood risk management, especially for smaller, more frequent events[26]. In addition, the changes in land management that reduce flood risk are also good for water quality (by reducing soil erosion and sediment loads) and may be beneficial where structural measures are too expensive in relation to the benefits, thus offering multiple environmental ecosystem services

Agricultural land as a flood storage area to reduce flooding in urban areas

2.17 Flood plains are usually flat, fertile land and virtually all the flood-plain land in the UK is farmed in some way. Traditionally, flood plain management was dominated by uses that were resilient to frequent flooding, such as summer grazing and grass conservation (hay and silage). Over the years, and particularly since the 1950s, flood plains with higher agricultural potential have been protected from flooding and land drainage has been improved, often with public funding, in order to enhance its agricultural potential. The separation of the flood plain from the river has resulted in a loss of flood storage and, in places, increased downstream flood risk. Across Europe, there are initiatives (e.g. along the Rhine in Germany and the Netherlands[27]) to reconnect flood plains with their rivers to restore the natural flood attenuation function.

2.18 Washlands are areas of flood-plain land that are isolated from the river by flood banks, and are allowed to flood at peak times in order to reduce flood risk downstream. These areas may support agricultural land or habitats valued for biodiversity, however, the three uses may not always be compatible and there may be trade-offs with agricultural or biodiversity uses in order to maximise flood attenuation[28].

2.19 Most plants can withstand short periods of inundation with little noticeable impact, particularly if flooding occurs in the winter, when plant growth is minimal. Periods of winter flooding of up to 21 days often have limited impact, however, prolonged waterlogging and flooding when the plants are actively growing leads to anoxic conditions in the root zone, slowed growth of crops and reduced yield and/or crop quality. The severity of the effect depends particularly on the plant type, the duration of flooding and the time of year. In the extreme, flooding can reduce yield to the point where it is uneconomic to harvest and the crop is written-off. Grassland is similarly affected and grazing-days, as well as hay and silage crops, may be lost due to flooding necessitating additional housing and purchase of supplementary feeds. Flooding also causes delays in farm operations; additional costs of inputs (e.g. fertiliser); moving and housing of animals; increased risk of animal disease (e.g. liver fluke); clean-up and reinstatement; and damage repair.

2.20 Flooding of agricultural land may have knock-on impacts for production. Late summer or autumn flooding may prevent sowing of winter crops and compaction, due to unavoidable farm traffic on wet soils and loss of soil invertebrates (such as earthworms)[29] leads to reduced yields in subsequent years.

2.21 The summer of 2007 saw flooding of 42,000 ha of farmland across England[30] with significant effects on yields and farm incomes. The average farm level loss was estimated at £1,200/ha, but this varied according to the type of enterprise[31]. Many cereal crops recovered somewhat and average cereal yields on flooded land were only down by 40 %. Horticultural farms (e.g. in the Vale of Evesham) suffered the greatest losses, estimated at £6,900/ha, where crops were written off. The national flood damage cost for the agricultural sector was estimated at £50.7 million. Although the impact on national production was small, the losses to individual farms were significant, averaging £90,000 for each farm affected. Some farm losses (such as damage to buildings and machinery) are covered by insurance, but crop and grazing losses are not covered and many farms are not insured.

2.22 About 5,000 ha of farm land in the Somerset Levels and Moors were flooded in the spring of in 2012 at a time when stock are turned out to grass or pastures are prepared for the conservation of winter feed. Where flooding lasted for less than 2 weeks, average losses were £140/ha, but longer duration flooding resulted in farming losses between £850/ha and £1,120/ha as well as, serious damage to habitats and wildlife[32].

Current and future pressures on demand and supply

3.1 In this section, we consider how demand for water may change in the future and how water availability may change in the future. We also consider the linkages that exist between both of these factors.

- **Water demand** is defined as the additional water from rivers, aquifers, reservoirs and public water supply that farmers use to supplement rainfall. Water demand is therefore related to rainfall and other local climatic conditions (principally temperature and windspeed as these to a large extent control evapotranspiration losses) as well as crop type, farming practice and soil and site characteristics.
- **The absolute availability of water for irrigation** is a function of climate and other uses of water, including the need to leave water in rivers and aquifers, to maintain the natural environment. Farming practices and other land-uses also influence water availability - for example by changing soil infiltration characteristics or by encouraging rapid run-off. Both water availability and demand vary over time; in general, least water is available in dry summers when the irrigation demand is also highest.

How will agricultural water demand change in the future?

3.2 In the next ten to twenty years changes in agricultural water demand may be driven by regional food requirements, global food markets, new crop types and varieties as well as by water availability (which may also be influenced by demand growth in other areas, such as the increasing population size in the SE of England). The recent shift towards supermarkets accepting blemished produce may lessen the value of irrigation on some crops where water is used essentially for cosmetic reasons. Changes in the global agri-food system and concerns around reducing resilience in supply chains, may make it desirable to grow more food locally, potentially increasing irrigation demand in areas where water scarcity exists. New crops or varieties could be more water-efficient, but equally may use the same volume of water whilst delivering other benefits, perhaps an increase in yield or disease-resistance, producing more food per litre of water and becoming indirectly more water efficient.

3.3 Climate change will have an increasing impact on the demand for water for both livestock and arable crops. With higher summer temperatures, livestock will need more water and it may be necessary to make provision for permanent water supplies (cattle troughs) in places where these are not needed now. Warmer, drier summers will increase irrigation demand and may lead to irrigation in places where there is currently little, or on crops like cereals that are not normally irrigated in the UK but are irrigated in other parts of the world.

How will water availability change in the future?

3.4 At any location, average water availability for agriculture is a function of the hydrological characteristics of the catchment, other demands for water, and rules about how much water is allowed to be taken. At any one time, water availability is also determined by how much rainfall there has been.

3.5 In the future, pressures on water resources seem likely to grow, with many areas already failing environmental objectives. Demand for public water supply has been broadly stable for the last decade or more, but increased population, particularly in the south-east of England, could lead to increased demand in some places.

3.6 Climate change is expected to intensify the hydrological cycle, leading globally to more floods and droughts on average[33], though not in all regions. The pattern of changes over the 21st century is not expected to be uniform, with the contrast in precipitation between wet and dry places and wet and dry seasons expected to increase[34]. Rainfall over northern hemisphere mid-latitudes increased over the 20th century[35] but UK average annual rainfall has not changed significantly since records began in the 18th century[36]. However, within this unchanging average there has been a trend towards more winter precipitation, though with little change over the last 50 years[36]. There is also a trend towards more intense rainfall events[37]. Climate change is creating one of the main long-term pressures on water availability in the UK.

3.7 What does this mean for water availability? Reductions in average summer flows[38] would lead to more pressure on water resources and reduced water availability. All seasons are likely to become warmer and heatwaves may be hotter and more prolonged. Hotter, drier summers would be expected to lead to increased demand for public water supply[39]. At the same time, the aquatic environment may be under stress from increased river and lake water temperature, reduced dilution of pollutants and reduced flows[40]. Although we do not yet understand possible changes in drought frequency and duration, droughts will occur and we must continue to plan for a wide range of possible droughts including long droughts outside recent experience[41].

The impact of land-use on water availability

3.8 The link between land-use, farming practice and the quality of the local water environment is apparent, but upstream measures are increasingly seen as part of the UK's wider response to floods and droughts. Some farming practices increase run-off and reduce infiltration making catchments more vulnerable to both floods and droughts. Land management cannot prevent floods or protect from all droughts, but sensitive management can make catchments and society less vulnerable. For example contour ploughing can help reduce run-off and sediment transport. Bank-side roughness – hedges and trees, for example – slows the flow of flood water, hence reducing the height of flood peaks. And, in times of extreme flow, fields can be used as flood plains to protect urban areas although this may require compensation to land-owners and may reduce the UK's agricultural outputs.

3.9 The link between crops, food and water availability is often unclear to consumers and decision-makers (see 'Water use in our food imports report'). Embedded or virtual water – the water that was used to make a product or grow a crop – is always unclear to the end-user. Even where it is possible to infer something about how much water may have been used, it is not possible to tell whether this water was scarce or readily available and how else it might have been used. In a global food market, this is particularly difficult – for example, the UK consumer can choose between potatoes from the UK, Egypt and Israel and each production location has very different water availability. The other trade-offs between productivity and wider downstream impacts of water use are also often opaque. For example, more intensive farming increases food production but this may come at a cost to wildlife and flood risk.

Water management: how do we do it now?

3.10 Water resources are managed in broadly the same way across all of the countries of the UK, although the exact details depend on the administration. Throughout Europe, the Water Framework Directive sets the overall vision for protection of the water environment with the objective of making sure all water bodies support healthy ecosystems and have good water quality (see report on 'Agricultures impacts on water quality'). In achieving these objectives, water abstraction has to be managed to maintain adequate flows throughout the year, paying particular attention to low flows.

3.11 In the UK, all but the smallest abstractions need official permission, usually with an abstraction licence that almost always specifies the use or uses to which the water may be put. The licence will normally include conditions that identify the maximum volume of water that can be taken, often with hourly, daily and annual limits. Abstraction may be limited to particular months or may be allowed through the entire year. Particularly for abstraction from surface waters, there is usually a condition that limits or stops abstraction when flows or levels fall below a specified point. Similar conditions may also be applied to groundwater abstractions.

3.12 If someone wants to abstract water, they have to apply for a licence. At present, all UK abstraction licensing authorities operate on a "first come, first served" basis; in other words, a licence will be granted based on the availability of water at that location now, and without considering future uses of water or whether the proposed use of water is in some way better than existing uses. If no water is available, the licence will be refused. Once a licence is granted, the holder has a protected right to water that means further licences cannot be granted if they would reduce water availability to the licence holder.

3.13 In England, agricultural spray irrigation abstraction can be restricted or stopped by the Environment Agency during droughts; in practice, the Environment Agency seeks voluntary reductions in water use wherever possible. Natural Resources Wales has the same powers in Wales. The Scottish Environmental Protection Agency, SEPA, also has the power to alter licences to protect the environment.

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BOX 1: Case Study: Environmental impact of abstraction: Anglian Water

Since privatisation and as a result of the outcome of extensive environmental assessments, Anglian Water has made significant investment to help understand and minimise the impacts of their abstractions. As a result, Anglian Water have reduced output from, relocated or closed a number of abstraction sources. Anglian Water currently operate 15 river support schemes, of which 12 are directly associated with one of their abstraction licences. The river support schemes comprise boreholes that are pumped to enhance flows and river ecology at times of environmental stress, or as advised by the EA.

In addition to these existing mitigation measures, a significant proportion of abstraction licences include conditions requiring them to monitor environmental impact which they report on annually. If the results of this monitoring indicate any deterioration, then they remain committed to addressing the issue.

BOX 2: Case Study: Balancing water supply demands for agriculture and domestic and environment needs on the Wye River

The river Wye is one of the largest rivers in Britain, rising in the Pumlumon mountains of mid-Wales and flowing down through the Wales – England border before meeting the Severn estuary at Chepstow. The total catchment area is 4136km^2 and the river's mean annual discharge is 80 m^3 per second. Although the river has a large catchment, the geology means that there is little or no groundwater storage and as a result the river is very responsive to rainfall and drought.

It is designated as a European Special Area of Conservation (SAC) (underpinned by Site of special scientific interest (SSSI) designation) for 6 species of fish, including Atlantic salmon, white clawed crayfish and Eurasian otter. One of the most striking features is the series of dams in the Elan valley catchment that allows the transfer of water via a gravity fed aqueduct to Birmingham and the regulation of flows in the river Wye. Regulation of the river Wye is undertaken through a management agreement between Dŵr Cymru Welsh water (DCWW) and Natural Resources Wales (NRW).

The environmental vision for the river system is that 'all of its special fish and other animal features are able to sustain themselves in the long-term as part of a naturally functioning ecosystem. Allowing the natural processes of erosion and deposition to operate without undue interference and maintaining or restoring connectivity maintains the physical river habitat, which forms the foundation for this ecosystem.' Abstract from the Wye River / Afon Gwy SAC site management plan 2007.

The water flow from the Elan valley dam system has a number of impacts on the environmental functionality of the river. Compensation water released from the reservoir can often be colder than normal river temperature and have lower oxygen levels and this can detrimentally affect fish. This amount of control also restricts the number of high flow events, which in turn impacts on the renewal of sediment and gravel which fish species use for spawning, although the impoundment of the water does allow for water to continue entering the river system even at low flow. However, the degree of river control is necessary to smooth out the river flow and secure reliability of public drinking water.

In addition to the water companies there are a number of private and industrial license holders who abstract water to meet their needs. Many of the private license holders are agricultural, using the water for spray irrigation of crops such as potatoes and fruit growing. These licences only tend to be activated in average and dry years impacting the river at the time of lowest flow. In the Wye, these licenses have a clause which means that abstraction for irrigation purposes must stop if river levels fall below a certain level to protect public drinking water supplies.

NRW are responsible for the protection of the SAC and are responsible for operating the water abstraction licencing system. They are tasked with balancing the aims of SAC designation to 'restore the river to high ecological status' and the Water Framework Directive (WFD) targets to maintain the river system in 'good ecological status' with the demands of all the abstractors from the river system. This balancing act requires negotiation with Dwr Cymru who manages the dam system to ensure the discharges support the river system and the demands of the abstraction sites further downstream. This is achieved by modelling the demand on the reservoirs along with the range of weather conditions that impact on how quickly the reservoirs refill to ensure that the reservoirs always have sufficient supplies to meet the demands placed upon them. Agricultural needs are not included in the water demand calculations for dam releases, which means that NRW need to notify irrigation licence holders if there is a risk that they may have to cease abstracting. The unpredictable rainfall in the catchment and the responsiveness of the river mean that some overnight rainfall may change the situation. NRW have developed a 'spray line' hotline that notifies farmers and other users quickly and immediately of any changes in water availability.

Dŵr Cymru Welsh Water

Modelling and balancing the demands of water supply on such a responsive river system will become more challenging as climate change makes weather events more extreme and uncertain.

Innovation in on-farm water storage and use

On-farm water management

Storing water supplies

4.1 Reservoirs are increasingly viewed as the best way to secure reliable water supplies for agricultural irrigation and are the preferred adaptation for coping with increasing water scarcity. Storage is one of three key themes which make up agriculture's strategy for ensuring a fair share of water for food production. These include working together to improve dialogue between farmers, the agri-food industry and regulators developing a knowledge base to improve water management and making best use of available water resources[42].

4.2 Reservoirs are a secure water storage mechanism; once water is in the reservoir the farmer can plan the following year's cropping and their supply contracts with supermarkets and processors with much greater certainty. Reservoirs can also enhance ecosystem services. They can secure agricultural production and improve water supply for domestic and environmental uses by reducing abstraction during summer months. Larger reservoirs may help to attenuate peak flows when flows are high and maintain low flows during dry spells, so long as they are not full or at a low level. They also provide informal recreation, nature conservation, and indirectly support rural employment along the agricultural value chain[43].

4.3 Most reservoirs are either constructed in clay or clay lined, but some have a synthetic membrane lining to control seepage and are usually much smaller capacity. Costs vary by size and type (clay and membrane lined) and also include ancillary works such as inlets, pump stations, and pipework. A recent reservoir review showed that the unit cost (in £/m^3) of membrane lined reservoirs is almost three times the cost of clay reservoirs[44]. Storage capacity provides a good indicator of capital costs provided a distinction is made between the linings.

4.4 Investing in storage is always a more expensive option than direct summer abstraction, even though summer water charges are ten times higher than in winter. The additional reservoir costs can be seen as insurance against unreliable, insecure summer water. High costs will no doubt serve to focus future irrigation development on high-value, water responsive crops such as potatoes, soft fruit, vegetables, and salad crops, which can carry the additional costs of water storage[45].

4.5 There are few reliable data on the number or total volume of on-farm irrigation reservoirs. Estimates suggest that current storage capacity is more than 20 million m^3, based on the highest recorded winter abstraction volume[46]. But winter abstraction has increased in recent years. Also winter abstraction licence numbers are increasing annually as is the total licenced volume for storage. This reflects a trend towards larger licences and larger reservoirs. The size of lined reservoirs has not increased but costs have risen by 50% reflecting the rising costs of oil-based lining materials[47].

4.6 Farmers face many problems in building reservoirs. By far the most important is the high initial cost of construction which varies depending on size, water source, construction method, local geology, topography, and proximity to environmentally sensitive areas. Most farmers find it difficult to justify costs in relation to returns they expect from the investment. Reservoirs continue to be built, but most are supported by government grants in order to be financially viable, or they are financed as part of an aggregate extraction package. Farmers also face considerable obstacles and long delays with local authority planning and demanding environmental and archaeological surveys which are required by different organisations.

Managing the demand for water

Livestock

4.7 Dairy, beef and sheep farmers can improve their water use efficiency directly by better use of water, and indirectly by improving performance efficiency. For grazing livestock, improving grass sward management improves utilisation of rain-onto-soil water flows – with good conditions for grass growth (e.g. soil nutrition, soil structure, grazing management), the grass has evolved to utilise water efficiently, so less is lost through evapotranspiration or runoff. Soil management to improve sward resilience with organic matter and compaction remediation improves soil water storage[48,49], while minimising runoff and waterlogging. The efficiency of using abstracted water can be improved with leak repair and rainwater harvesting in high rainfall areas. With dairy, continuing efficiencies are being implemented for washing down and milk cooling, high pressure low volume hoses, and recycling milk cooling water.

4.8 Enhancing genetics, health, nutrition and breeding can all indirectly help to produce more litres of milk or kilograms of meat per livestock unit or hectare, thereby reducing the water requirement. Feed budgeting and reducing feed wastage optimises feed usage to achieve target performance gains while reducing the water embedded in livestock feed.

4.9 Deep rooting grass varieties and other forage crops (e.g. lucerne and chicory) have been developed to enhance drought tolerance[50] while, in some cases, simultaneously improving soil structure for water infiltration and storage. Using co-products, such as distillers' grains, spreads the water cost over multiple products thereby reducing the water footprint to the livestock producer. Livestock genetics and breeds from drier climates offer potential to improve drought tolerance in the UK beef and sheep industry as the climate changes.

4.10 For non-ruminant systems, particularly pigs, the industry consists predominately of housed production systems[51], and all production relies on sufficient, good quality piped water. Using potable standard water is the norm, because the main uses are for drinking and hygiene purposes[52]. The quality of water is important, because animal health and performance are interlinked[53], as bacteria and disease can be passed very quickly around herds. In recent years the emphasis on hygiene, especially cleaning and the disinfection of houses and equipment, has made the sector heavily dependent upon adequate and reliable supplies of water, but at the same productivity has risen[54].There is a balance between increased water use and better performance in relation to the amount of feed used (embedded water), generally it is preferable to use water than to let health deteriorate.

4.11 The cost of water is a significant driver for optimising use. Genetic and other on-farm performance improvements are leading to increasing numbers of pigs reared per sow and these additional pigs increase the demand for water of the national herd but, overall water use may decline on a unit output (mass) basis. New housing and production techniques can contribute to reducing the volume of water consumed. Better ventilation and insulation optimise the housed environment, feed consumption is focused on production, minimising heat weather feed intake dips, and enabling the pigs natural differentiated lying and dunging behaviour results in cleaner, healthier pigs and pens. Modern building materials with their impervious easy to clean surfaces reduce water required for washing[55]. The health and cleanliness benefits follow the pig through to the abattoir and water required there and for subsequent processing.

Cereals and Oilseeds

4.12 Cereals and oilseeds production in the UK is among the most efficient in the world, with a water footprint per tonne of wheat of less than a third of the global averag[56]. However this reflects the fact that they are largely rain-fed crops, and typically less than 0.3 % of the cereal area receives irrigation. In future, the expected increase in rainfall variability may increase the demand for irrigation[57]. Potentially, average yields of 15 t ha^{-1} are possible if the crops are grown under optimal conditions in the UK[58]. Better water use can be achieved by breeding varieties with improved water stress resilience and higher nutrient/water use efficiency. Increasing the genetic diversity can be achieved through conventional cross-breeding and early trials have also shown that synthetic crosses can increase yield potential while also introducing new genetic diversity which can be used to increase drought tolerance, disease resistance and input use efficiency

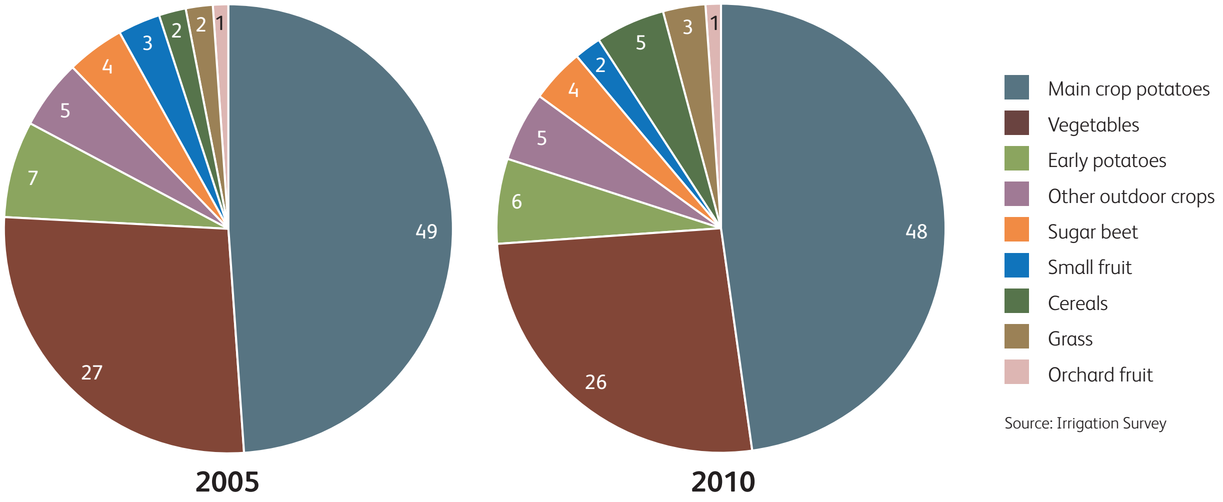
Increasing efficiencies in horticulture and crop production

4.13 Potatoes and other vegetables use the majority of water abstracted for irrigation in England & Wales, accounting for 54 % and 26 % respectively in 2010 (Figure 1)[59]. Horticulture can achieve efficiencies in water use in a number of ways. There is already a move toward deficit irrigation using sensitive and accurate sensors to determine the irrigation needs of covered crops such as substrate grown strawberries. This has potential to be used in other crops, such as tree fruit, and over much wider areas but is currently constrained by cost. However, if water becomes more expensive the investment may become worthwhile. Additional efficiency can be achieved by the selection of drought and/or waterlogging tolerant varieties through genomics, marker assisted breeding and other techniques; recent work in Israel has produced lettuce that is significantly more tolerant of drought and has longer shelf life.

4.14 For orchards, cropping plans can cover 25 to 30 year periods so the selection of appropriate varieties or perhaps species is something that may need to be considered very soon where orchards are due to be replaced

4.15 The cost of water to producers and competing demands of other users are significant drivers to improve efficiency of water use and irrigation in potato production. In the UK, production is from both rain-fed and irrigated systems and the national crop uses water effectively for food production in comparison to other dietary carbohydrates (pasta and rice) (see 'Water use in our food imports' report). Approximately 50 % of the production area currently has the potential to be irrigated, but improvements in the efficiency of water use and irrigation management will be necessary to maintain production at current levels in the future given likely limits on abstraction (see Box 3).

Figure 1: Irrigation volumes in England and Wales (%) in 2005 and 2010.



Source: Irrigation Survey

BOX 3: Case Study: Increasing efficiencies in potato production

Models[60] suggest that in the future, land availability suited for rain-fed potato production will decline between 74-95 % under median UK Climate Projections 2009 (UKCP09) projections for low – high emission scenarios due to increased drought likeliness (Figure 2). In contrast, on land where irrigated potato production is presently situated, this would remain suitable if irrigation water can continue to be made available. However, without adaptation existing irrigation schemes could have insufficient capacity to meet future irrigation needs, with serious consequences for national yield, quality and food supply. The uncertainty in weather patterns and likelihood of damaging drought is driving adaptive change in crop and soil management.

Some potato varieties are very sensitive to drought but there are also opportunities to manage variety selection to match crop development to water availability. As with cereals and horticultural crops, efficient breeding of varieties with improved water use efficiency can be aided by a better understanding of the crop's physiology, canopy development and rooting, and exploiting knowledge from genomics, with the identification of markers. Crop performance has to go hand in hand with annual soil cultivations and improving soil structure over a number of years so that the crop being grown can most effectively exploit the available soil water and deliver 'more crop per drop'. To deliver this there needs to be a better understanding of the heterogeneity of soils and the ability to match the crop needs with irrigation[61].

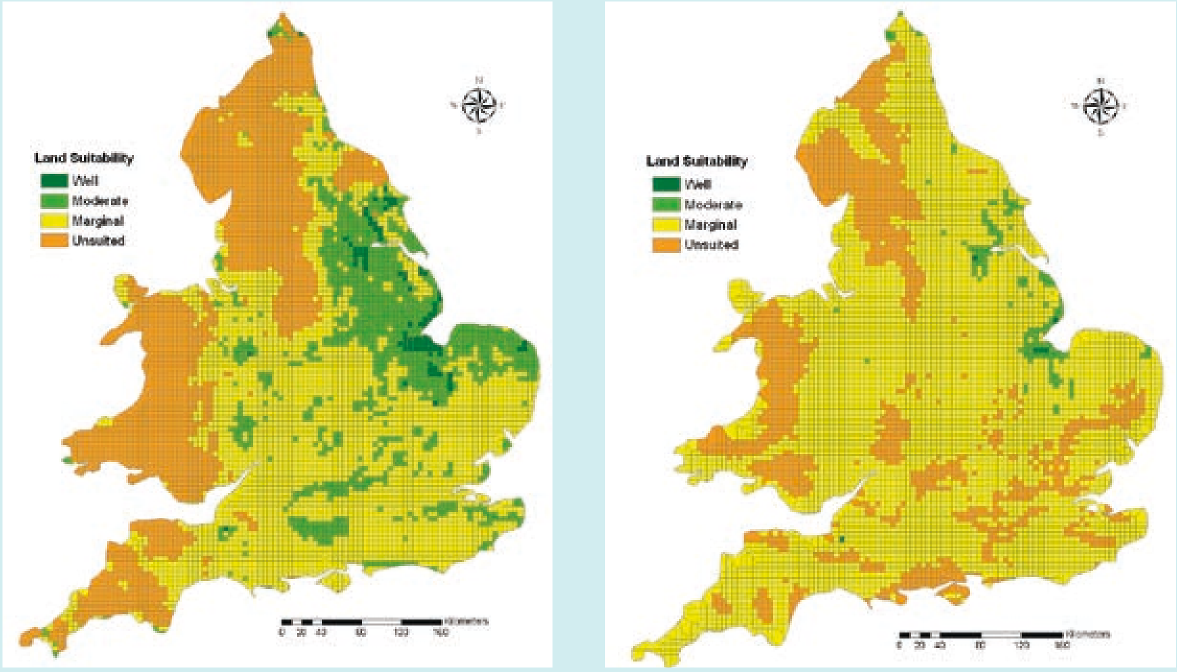


Figure 2: Projected Changes in land suitability for potato production[62].

Recycling Water

4.16 As most of the water for livestock is required for their drinking, there is little opportunity to reduce water consumption. However, there is scope to reduce water losses through maintenance (e.g. fixing leaks in water troughs) and good management (e.g. trigger sprayers when washing down); or reuse of cooling water.

4.17 Rain water collection may be a viable alternative water source for livestock farms as many farms are located in the wetter parts of the country; have large areas of hard surfaces and roofs; and can use the lower quality water for washing-down and cleaning. However, whilst this may reduce farm water costs it does not create "new" water and the water captured may otherwise have contributed to streams or aquifers. In addition, livestock farms will still require an adequate mains supply to meet their water requirements during periods of low rainfall and drought.

Large-scale water management

Water transfers: are they a solution to local scarcity?

5.1 A water transfer can be defined as an artificial movement of water from one water body to another. Considered like this, a transfer has three basic components: a source, a vector, and a receptor. The source may be a river or stream, a lake, a reservoir or groundwater. The vector may be one or more of: a canal (an artificially constructed channel), a pipeline, an aqueduct, an existing river channel, or road or rail tankers. The receptor may be a water supply system, a reservoir, or direct use from the vector – for example, direct abstraction for irrigation.

5.2 Water transfers can be an effective way of providing water for agriculture and public water supply, with the particular benefit of moving water from an area of surplus to an area where water is scarcer. This scarcity may be permanent – moving water from wetter to drier areas – or temporary, where the receiving area may be in a more intense drought than the water source. Transfers themselves can be temporary or permanent, solving short-term shortages or contributing to a long-term plan to manage water resources.

5.3 There are many existing water transfers in the UK, including:

- Trent-Witham-Ancholme: using canals and river channels to move water from the Trent to two rivers in Lincolnshire, for public water supply and agricultural use.
- Ely Ouse-Essex Transfer Scheme: using rivers, channels, tunnels and pipes to transfer water from the Ely Ouse in Norfolk to Essex rivers and reservoirs, for public water supply and agricultural use.
- Elan Valley-Birmingham: using pipes to take water from Wales to Birmingham for public water supply.
- River Severn-Gloucester and Sharpness Canal-Bristol: used for public water supply in Bristol.
- Wimbleball- River Exe: using the River Exe to transfer water to Exeter for public water supply.
- Road or rail tankers have been used as an emergency supply during brief periods of drought (e.g. in 1995 tankers were used so deliver water to reservoirs in West Yorkshire) or infrastructure failure (e.g. when the floods in the summer of 2007 disabled the Mythe Water Treatment works in Tewkesbury).

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5.4 Water transfers are not without problems. They can be controversial, because the impacts tend to fall on people who do not benefit directly from the scheme. Removing water from the source will deplete flows in some way, often with some environmental impact. Putting water into a natural or semi-natural channel leads to a risk of transferring invasive or non-native plants and animals, as well as diseases that affect not only the aquatic ecosystem but also crops or livestock. Differences in water quality and water temperature can be important, with potential for altering the characteristics of the receiving water body.

5.5 Building a new transfer is expensive, usually requiring extensive engineering works over a large area. In most transfers there will be some need for pumping, and as water is heavy, the energy use can be large. Whether transfers are worthwhile depends on the costs and benefits of alternative sources of water, the value of the use of the transferred water and the reliability of the transfer itself.

Allocating water to agriculture whilst preserving other ecosystem services: the need for catchment management

5.6 Water catchments provide a range of important ecosystem services to society as a whole: not just water to grow food and potentially mitigate flood risks, but also services such as providing fresh water for drinking, raw water for use in industry including food processing, energy production, amenity in urban environments, leisure activity destinations, tourist attractions and habitat for biodiversity.

5.7 Any management aimed at addressing water quantity in agriculture, either by managing run-off or by water storage, needs to take into account other requirements of the water system. This will have to be considered on a catchment by catchment basis as demands on the water resources are location specific.

5.8 With complex systems, any change in the behaviour of one part can work through a variety of routes to affect outcomes. When thinking about change it is best to think about the system as a whole to avoid the potential for negative, indirect impacts: this is “systems thinking”. Thus, it is perhaps necessary to think about the demand for water by farmers, industry, domestic use and environmental needs in the round and recognise that demand, requirement and availability are all time-varying. Understanding how the availability of water supply is likely to change in future (through changing patterns of rainfall), the resilience of aquatic systems to minimum flow and how to negotiate human use, from the different stakeholder communities in an equitable and transparent way, will be increasingly challenging. To what extent should a farmer be able to abstract water to prevent significant financial losses, if it reduces water availability for domestic users, which may be inconvenient for domestic users but no more? Likewise, is a short-term unsustainable use of water (causing rivers to run dry) considered a high impact event for a short time period (in terms of wildlife loss) even if, in the long-run, it may be low-impact if the ecological system recovers quickly? In the other extreme, it may be desirable to use agricultural land (with its impact on food production) for flood water storage, upstream of large settlements. Where balances need to be struck, the impacts on all users in the catchment should be considered.

5.9 Finding ways to allocate water resources, taking into account all stakeholders’ interests, and environmental concerns, is likely to be a growing challenge. Catchment management approaches where stakeholder representatives negotiate amongst themselves for access to resources and for payment for ecosystem services (or for water use foregone) is an emerging approach. These types of trade-offs need to be managed impartially or through regulation, as there is a real potential for societal inequalities to be exacerbated. Big industry, with large amounts of money may be able buy a larger share of the resources at the expense of others. For instance, if water charging was used as a tool to reduce domestic use, this has the potential to impact the lowest income families the hardest. Furthermore, other ecosystem services provided by river catchments do not necessarily have the ‘buying’ power of other users, such as biodiversity.

5.10 A balance must be struck with often competing demands on water resources and the extremes of availability. Plans need to consider all aspects of the system to ensure solutions are sustainable for all members of society in the long term. Furthermore, with multiple interests in water also come greater opportunities to develop multidimensional solutions. For instance, greater water storage requirements could be coupled with leisure or tourist activities to benefit society in a broader way.

BOX 4: Case Study: The Pont Bren Farmer Group, Powys

River catchment partnerships are springing up across the UK and these groups have been very diverse, reflecting the diverse nature of water users. These partnerships have primarily been looking at water quality, however, flood and drought issues are being addressed in some catchments where water quantity has been an issue. The Pont Bren farmer group in Powys is a high profile example of a river catchment partnership. The group undertook tree planting in strategic parts of their farms to increase interception rates of rainfall and to lower the peak flow from their catchment[63]. This group are aiming to expand their approach throughout the Wye and Usk catchments.

Looking to the future

6.1 Patterns of water use and legislative controls have developed over the last two centuries in response to needs to improve public health, produce food and protect the environment. With a growing population, changing world food markets and a changing climate, pressures on UK water resources are increasing. Here we look at the challenges of managing water for food production and ways that this could be improved over the coming decades.

6.2 Demand and availability change from day to day with the weather. Demand follows a seasonal pattern with most water needed in summer and least in winter. Availability also follows seasonal patterns with most water available in winter and spring and least in summer and autumn, particularly in groundwater-fed catchments. River flows and groundwater levels are usually lowest in late summer and early autumn. Demand changes from year to year, as farmers grow different crops or varieties or take different decisions about how much irrigation to use in different years. Over longer timescales, climate change will alter catchment hydrological response and the crops that can be grown. Superimposed on all of these are changes in regional and global food needs changing the profitability of different crops and therefore demand for water, particularly if more irrigated crops are grown in the UK. Other uses of water will also change, and changes in the rules about the total volume of water available for abstraction in different places can also be expected.

6.3 **Improved forecasting** of water availability offers the prospect of a more dynamic allocation of water, as well as allowing farmers to plan cropping patterns and water application. Hydrological forecasting in the UK has changed dramatically in recent years, with improved short-term flood forecasting and the development of a monthly hydrological outlook that looks up to two years ahead[64]. The UK Climate Projections 2009 (UKCP09[65]) provide a risk-based assessment of how climate may change over the 21st century. Further improvements in forecasting are expected to come from improved monthly to decadal weather forecasts, where skill is increasing as high resolution weather models start to capture the main drivers of seasonal variability in European weather. The UK's position on the edge of the European continent means that medium range weather forecasts will always be uncertain, but improvements should be beneficial to all water users.

6.4 Alternative approaches to **water allocation** may also present opportunities for improvement. Options include:

- Centralised planning of water allocation and use
- Local co-operative planning of water use
- Market-based solutions to water allocation, including water trading

6.5 **Centralised planning**, usually at the catchment or river-basin scale, can be a very effective way of managing water allocation. It allows for a direct link between water policy and allocation,

which can include complex allocation rules that take into account social and economic needs. The stability of centralised planning can be very welcome, particularly for small businesses with little resilience. However, this very stability means that centralised planning is not very flexible, and it can be hard for new water users to access water this way.

6.6 **Local, co-operative planning** can help to move away from the conservatism of centralised planning towards more dynamic planning based on local needs. Carried out well, local groups can negotiate complex water needs in ways that centralised rule-based planning could never achieve. However, local planning is not always co-operative, and sometimes a few groups or individuals achieve disproportionate influence in the decision-making process. Co-operative planning of water use has worked well where there are obviously shared resources, such as shared aquifer units or where there are small internal drainage boards. In these cases, water used by one farmer directly affects the amount available for others. Such groups have often proved very successful at negotiating more equable water allocation, offering a powerful but considered voice for abstractors.

6.7 An alternative approach lets the **market allocate water,** most simply to whoever will pay most for it. The market can be used to decide on long-term water allocation, on day-to-day or season-to-season water use, or even both. For example, in the Murray-Darling basin in Australia it is possible for farmers to sell their share of the resource permanently to another farmer, or to sell water for all or part of a season. Market-based solutions can be very flexible but this means that it can also be very difficult to enforce agreements. In any market there is a risk of abuse, where dominant players can exclude others from the market or control prices in a way that makes it hard for new or smaller users. Most markets require some sort of central management, for example to set the basic rules for total water availability. In the case of agricultural water use, it may be necessary to limit trade between sectors so that water is not gradually moved away from agriculture to public water supply.

6.8 Perhaps the most promising way of managing water availability is through improved catchment management, sometimes called "**water cycle management**". Managing the water cycle involves finding ways to move water from places or times where it is not scarce to places or times when it is scarce. Reservoirs store winter water for use in summer; in many countries, large reservoirs are important sources of water for agriculture, but in the UK most farm reservoirs are small. Building more farm reservoirs can also make more summer flows available for other summer demands and so benefit others and not just farmers. Transfers from wetter catchments and groundwater storage schemes can also benefit agriculture. The way the catchment is managed also affects water availability; impermeable surfaces create rapid runoff, but well managed soils retain moisture and increase water availability during drier periods.

6.9 Along with all of these measures we can expect drives towards more **efficient use of water** in both arable and livestock farming. New technology can help with precision irrigation, where exactly the right volume of water is applied. Different crop types can use less water. Rainwater harvesting, recycling and attention to supply system maintenance can reduce water use in livestock farming. Away from the farm itself, **supply chain management** can also reduce crop water use. For example, supermarkets could decide to accept potatoes with skin blemishes which would in turn reduce water use or allow existing irrigation volumes to water more crops.

Conclusions

7.1 Water and food are inextricably linked: almost all of our water flows from agricultural land, and farmers need water to produce food. Across the UK, water resources are under pressure from current and future demand for water as well as climate change. At the same time, world demand for food is increasing and this makes efficient home production more and more important. In this report, we set out to establish the challenges, evidence gaps and potential solutions for the linked areas of water and food. Here we bring this together and draw our conclusions.

There are many **challenges**, but these can perhaps be summarised into three main areas:

- Allocating water to farming, public water supply and the environment in a way that meets the wider needs of society
- Using water efficiently, especially in times of scarcity
- Looking to the future to make sure that expectations for food production, other water use and the environment continue to be met over the rest of the century.

7.2 Much is known about the links between farming and water, but evidence gaps remain. Key evidence gaps highlighted in this report are:

- An increased understanding of the link between farming practices and run-off both at high and low flows in order to develop appropriate mitigation actions for water management - this requires new research.
- Identification of opportunities for saving water on the farm and innovations created to make them viable.
- Better management of water demand in the food supply chain both in the UK and globally (for food imported into the UK), in order to improve water use efficiency and reduce environmental and social issues.
- Better forecasting of short and medium term water availability that is of benefit to agricultural users is needed.
- Better understanding of the wider impacts of climate change on future water availability, including a better understanding of changing catchment hydrology.
- Improvement of mechanisms to allow the reallocation of water between different uses to the wider benefit of society.

7.3 Many of the components of potential solutions are understood. We know that further water efficiency can deliver many benefits, and that soil and landscape management could deliver wider benefits as well as improving crop yield. Dynamic approaches to negotiating and managing water use, particularly in dry periods, could allow a better focus on achieving the results that society wants. Is further intervention needed, or will all of these factors come together autonomously as pressures on water increase?

7.4 One way of looking at this question is to consider whether there has or could be a market failure. Market failures can occur for a number of reasons[66]:

- Lack of information - where participants do not have enough information to make appropriate choices.
- Moral hazard - loosely, the idea that someone else will manage the risk if something goes wrong.
- Policy failures - where policies have unexpected knock-on effects.
- Governance failure - where those in charge of decisions may not think at the right scale.

7.5 It seems clear that all of these could apply in some part to water and agriculture. Farmers often lack information on current and future water availability and their possible options to manage these better. In such a complex area, people may not fully understand or manage the risks they face, and policies set in one area can have unexpected impacts in other places. Finally, managing water and food production needs a long-term view, but many of the decision-makers inevitably have to take short term decisions about cropping patterns and varieties. All of this suggests that more work is needed to understand the risks and potential solutions to this important problem, and that these must translate into practical action that protects both food and water security.

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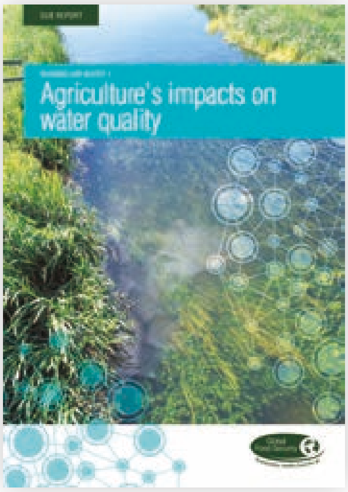
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