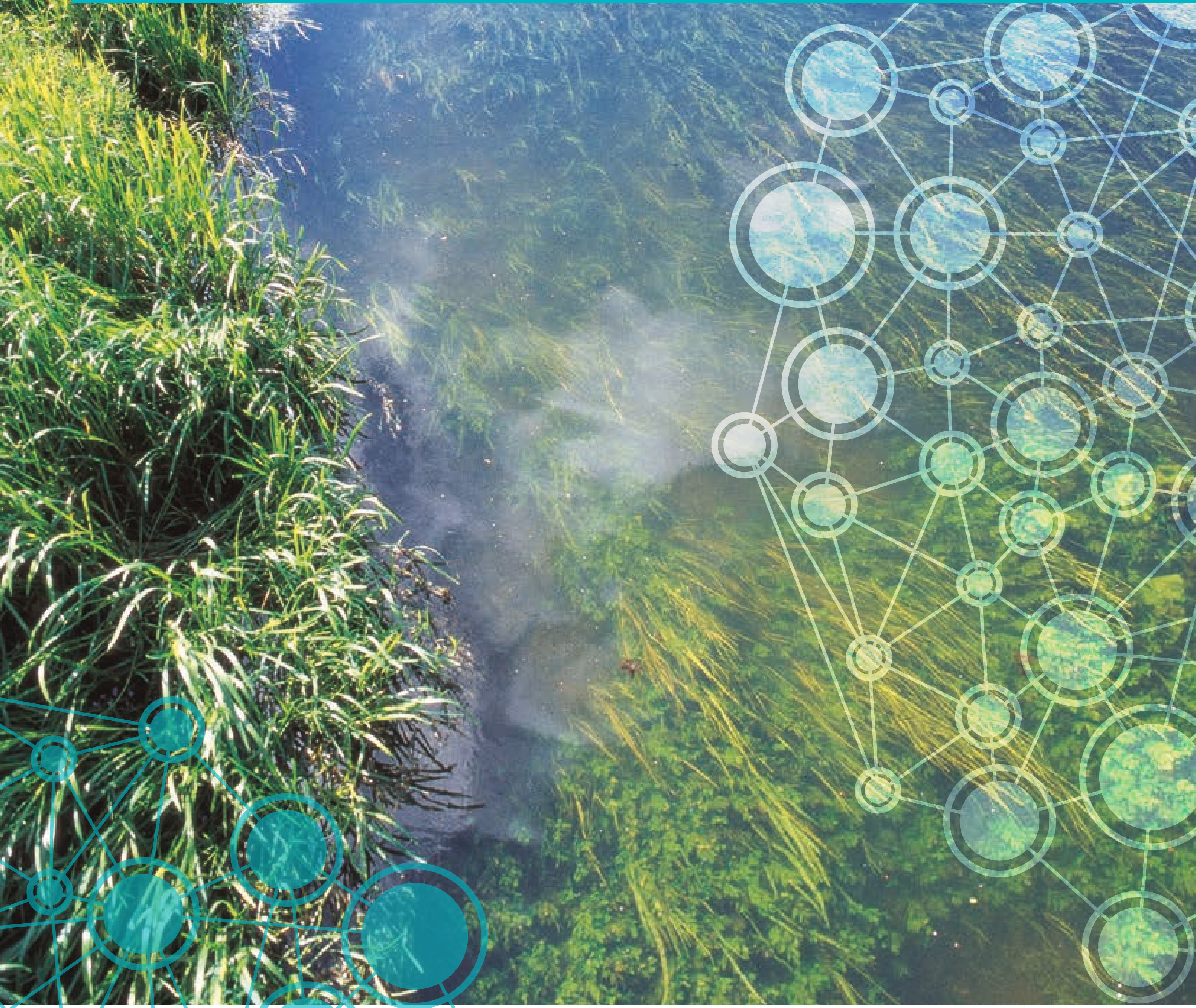
SUB REPORT

FARMING AND WATER 1

Agriculture's impacts on water quality



THE UK WATER PARTNERSHIP

Global Food Security

Sustainable, healthy food for all

Contents

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Executive summary

This report considers whether it is possible to balance high aspirations for environmental water quality, with significant growth in agricultural production to meet food security objectives and provide viable livelihoods for farmers. The quality of the UK's surface and groundwater is affected by a multitude of factors of which land management is one. The report therefore considers the existing water quality issues associated with UK agriculture, and the routes to further improvement.

The size of the water quality problem

In recent decades, a higher proportion of pollution has come from agricultural sources than the first two thirds of the twentieth century. This is a result of a reduction in the amount of effluent coming from industrial sources and human settlements into watercourses, alongside an intensification of agriculture. Agricultural intensification impacts on water quality through the release of nutrients (as a result of soil management and fertiliser application) and other chemicals (e.g. pesticides) into the water environment, through biological contamination (e.g. from microbiological organisms in manure) and via soil being eroded and washed off farmland. In the UK, around 60% of nitrates and 25% of phosphorous in water bodies are estimated to have farming origins[1,2], and it is thought that 75% of sediments polluting water bodies have derived from farming[3].

The impact of these pollutants is that currently only 24% of water bodies in England and 36% of water bodies in Wales meet 'good ecological status', as defined by the Water Framework Directive (WFD). In Scotland, 65% of water bodies are deemed good or better, but for the 35% which are failing, agriculture is deemed to be a major pressure[4]. Finally, in Northern Ireland only 22% of water bodies have achieved good status[5].

Challenges for managing farming's impact on water

Agricultural pollution can originate from either a point source (e.g. from a slurry store) or diffusely (e.g. run off from larger areas of farmland). As diffuse pollution can arise from the contributions of many smaller sources (e.g. fields on many farms), it is often difficult to attribute it to a specific sector or activity and the impacts of pollution can occur some distance from the source, for example, as nutrient levels increase downstream. One reason for the difficulty in attributing the source of pollution is that the processes by which nutrients and pollutants leave the land are complex, involving an interaction between locality (e.g. slope, rainfall, soil type), management (ploughing, input regimes, field margin management etc.) and a time lag. Fully managing farming's impacts on water quality requires more in-depth understanding of field-management-water interactions in order to inform how to adapt farming to mitigate its impacts, without impairing farm business.

Climate change may impact upon water quality by affecting the volume of water flow, pathways for water movement, and the associated transfer of pollutants from agricultural land to water bodies. Future policies need to include requirements to manage land appropriately to reduce these impacts. Climate change may also impact upon global agricultural productivity, with a likely drive towards intensification of production in the future. A challenge is to find ways for growth in the farming sector, whilst reducing its impact on water quality (and other environmental services).

Tools for incentivising better farm management

Water policy in the UK operates at different scales, such as the European and national levels, the thinking and planning scale of river basins and catchments and the 'doing' scale of sub catchments, water bodies, farms and sites. To improve communication between the different scales of water policy being undertaken across the UK, being able to develop a single message for each organisation could help develop shared actions.

At the European level, the Water Framework Directive (WFD) and Common Agricultural Policy (CAP) payments provide substantial opportunities for facilitating sustainable farm practice. However there is evidence that some regulation or stewardship measures are less effective than they could have been due to a lack of robust implementation[6] and targeting. Across the devolved administrations and England, a number of regulatory approaches are being, or have been, implemented to reduce pollution from rural sources. However better alignment for these policies is needed across scales and sectors.

What requires more work and new thinking?

Despite a number of excellent examples of good farm and management practice (such as avoiding application of manures and fertiliser before predicted heavy or prolonged rainfall events, incorporating manure into the soil as soon as possible and the use of slurry injection techniques) they are still only applied over limited areas. This means that there is scope for further water quality improvements. Many factors can contribute to rapid changes in practice, for example, fertiliser use declines as fertiliser price increases. The key will be to find positive interventions that incentivise change in increasing the efficiency of farm management. For example, improving the accuracy of weather forecasting will also assist in allowing farmers to apply nutrients at the right time, reducing losses through overland flow, leading to both economic and environmental benefits.

Change requires both innovation and uptake. A further challenge is therefore to widen the uptake of new applications on the farm and encourage acceptability of certain practices (e.g. finding alternative re-use points for lower grade water – such as using it for non-food crops like biofuels). Demonstrator projects have been successful for this and may benefit from being more joined up in the future (see 'Catchment Management' case study box). Currently there is no framework for translation of science into policy and action on the ground with regard to agriculture, the environment and water in the UK. New measures are therefore needed to address this. A free advisory hub, setup for knowledge exchange to deliver a clear set of messages that are informed by science, policy and demonstrator projects, could be a way to increase uptake of best practice.

The UK landscape is spatially variable and as such, regions differ in their capacity to contribute to production and the resulting environmental costs. 'Smart' landscape planning to make the best of the local context[7] could help to deliver both agricultural productivity and other ecosystem services, like water or biodiversity. Long-term monitoring of water quality may help to support process understanding and the impact of environmental change. New data, managed for open access to users, alongside developments in modelling capacity will provide new opportunities for understanding and mapping options and risks and the interaction between management for food and its impacts on water.

Key findings

A number of key findings have resulted from this report.

1. Decisions involving agriculture and water need to be made based on a long-term perspective; with appreciation of the time it takes for policies to have a sustained impact.
2. We need unified predictive models encompassing all key aspects of agriculture and water management that inform future policy and commercial interests.
3. Different solutions will be needed in different agri-water systems, and this requires stronger recognition from public and private policy makers.
4. Long-term support for research infrastructure is required to measure and analyse data necessary to inform decision making.
5. Farmers need better information on which to make informed management decisions regarding water management.
6. There are existing solutions to some problems and this knowledge needs to be effectively disseminated with appropriate incentives for implementation to have maximum impact.
7. We need greater collaboration between researchers, industry and policy makers with the necessary framework to deliver effective joint working.

Introduction

1.1 This report identifies the challenges, evidence gaps, progress towards and potential solutions for dealing with issues of environmental water quality associated with UK agriculture. It considers whether it is possible to balance high aspirations for environmental water quality with significant growth in agricultural production to meet food security objectives and provide viable livelihoods for farmers. Companion reports address i) the relationship between agriculture and the amount of water available and ii) the relationships between water security and our food imports and supply chain.

1.2 The quality of the UK's surface and groundwater is affected by a multitude of factors including geology, soil type, topography of the landscape, recent weather conditions, seasons, and land management. Pollution from industrial wastewater, urban runoff, forestry activity and aquaculture can all impact water quality. Here we focus on agricultural land use and water quality, but it should be recognised, that to address environmental water quality, a holistic catchment management approach is required.

1.3 To meet the challenge of managing land to produce multiple services – such as the production of food whilst ensuring the availability and cleanliness of water for humans and the environment – requires simultaneously addressing the needs of the agri-food and water industries and also the quality necessary to maintain the natural environment. Until recently, much thinking has been based on sectors and focussed either on water, food or the environment. Developing a sustainable food-and-water system requires focussing on all three together.

1.4 This report therefore considers the existing environmental water quality issues associated with UK agriculture, and measures to improve water quality. It also aims to address areas where more work and new thinking are required, and to highlight opportunities for best practice. The report concludes with a series of recommendations for research priorities, policy intervention and industry practice.

Defining water quality

1.5 Water contains dissolved and suspended organic and inorganic substances. Natural waters vary greatly in their chemical and physical characteristics and freshwater ecosystems have evolved locally in accordance with these specific conditions. Ecological networks, evolved in response to specific conditions, can therefore be remarkably sensitive to the introduction of chemicals in the environment, and may change rapidly as concentrations of substances change. Pollution is generally termed a significant deviation from the normal or 'natural' chemical conditions, usually as a consequence of human activity, so measuring the quality of water involves comparing the current condition of water to its normal/natural state. There are thousands of natural and human-made chemicals that can be measured in dissolved or particulate form within water, each of which could be used as an indicator of water quality.

1.6 However, water quality standards and what we may consider as pollution also depends not just on what's in the water but what the water is used for (e.g. drinking water, water for bathing etc.). These standards have been incorporated into the thinking behind the EU Water Framework Directive (WFD) (outlined in Box 1). We might consider a polluted water body as one where one or more substances have built up to an extent whereby they can be harmful to organisms that live in the water body or to animals and humans that may drink the water[8].

BOX 1: The European Union Water Framework Directive (WFD)

The WFD consolidates pre-existing European legislation to inform water quality standards, by using objectives based both on ecosystem status and the end-use of the water (e.g. for drinking). One of the main requirements of the WFD is that assessment of the probable causes of failures needs to be undertaken. Across the UK, this process identified agriculture (and to a lesser extent, forestry) as a key contributor to WFD failure in many catchments. The Directive requires member states to achieve objectives via the River Basin Management Plans – a single system of water management to coordinate activities regionally that includes a strong element of public participation. A second set of River Basin Management Plans are due in 2015 to inform the next cycle of water quality improvements towards 2021.

For the environmental quality standards there is an expectation that the water body should be in 'good ecological status' as determined by factors such as the geology, altitude, catchment size and so on, and is therefore diverse and different for each catchment (considering natural chemistry, climate, and ecosystems). Procedures have been developed to identify the ideal conditions for a given body of water, establish good standards and reduce the deterioration of water bodies. The approach ranks the ecological and chemical status of water bodies, with the objective that inland waters should achieve 'good ecological status' by 2015 with further improvements to 2021. Ranks are established by considering the quality of the biological community, the hydro-morphological characteristics and the chemical characteristics.

The target conditions are expected to have a minimal impact to the existing biological community comprising the ecosystem. Nutrients derived from farming play a role in establishing ecological status both directly, in that the classification depends on a series of chemical elements of a river (including nutrient concentrations), and indirectly through the role nutrient concentrations play in determining the biological quality of a river. Only one metric has to fail to meet a good status for the whole water body to be deemed below good status.

The nature and scale of the problem

2.1 During the first two thirds of the 20th century, the main cause of negative impacts on UK fresh water quality in watercourses was effluent from industrial sources and human settlements. However, over recent decades the balance of pollution sources has shifted. Industrial effluent has improved due to changes in types of production in the UK and stricter environmental standards on point source discharges (water pollution coming from a single point). At the same time, agriculture, which covers over 70% of the land area, has significantly intensified (Figure 1), leading to more productive, more efficient and larger farms. Agriculture affects water quality through the release of nutrients (as a result of soil management and fertiliser application) and other chemicals (e.g. pesticides) into the water environment, through biological contamination (e.g. from microbiological organisms in manure), and via soil being eroded and washed off farmland[9]. Alterations to the physical habitat of rivers also affect water quality.

2.2 Agriculture may affect water quality directly and indirectly. Direct impacts include soil, nutrients and pesticides being transferred from fields to watercourses during rainfall events. An example of an indirect impact might be related to upland drainage designed to improve grassland. If drainage increases the rate of loss of water from the hill slope when it rains, it may lead to flashier river flows[10] and thus more river bank erosion creating more downstream sediment problems. Management of agricultural land alongside river margins and banks, reducing vegetation cover, can increase the light exposure on river water, potentially increasing temperatures and the capacity to hold dissolved oxygen with direct and indirect impacts on in-stream ecosystems, including enhanced risk of nutrient enrichment and its negative consequences (eutrophication)[11].

2.3 Nutrients derived from farming can lead to enrichment of water courses and can be a significant contributor to poor water quality[12,13]. These are principally nitrogen and phosphorus and their various forms, which contribute to eutrophication, with associated algal blooms and undesirable aquatic organisms such as toxic algae. In the UK, around 60% of nitrates and 25% of phosphorus in water bodies are estimated to have farming origins[14,15]. The erosion and transfer of soil particles and fine silt from agricultural land into waterways can affect fish spawning and the amount of light in the water. This interrupts ecological processes and can lead to loss of flow capacity within rivers, thereby enhancing flood risk. Some chemicals (particularly pesticides and phosphorus compounds) bind readily to soil and so may be transported through this route to surface water. It is thought that 75% of sediments polluting water bodies are derived from farming[16]. The agriculture and rural land management sector has therefore been identified as the main cause of failures in water quality due to sediment and equal with the wastewater treatment sector as the main cause of failure due to nutrients across WFD River Basin Management Districts in the UK[17].

2.4 Along with nutrients, the main chemical pollutants from agriculture are organic compounds (including pesticides such as herbicides, insecticides and fungicides). The effects of these types of chemicals are complex and sometimes their degradation products can also be very harmful to aquatic life. However, highly persistent and bio-accumulative pesticides cannot be registered for sale in the EU. All pesticides must pass a rigorous risk assessment by an independent authority (the European Food Safety Authority, EFSA) to identify and exclude chemicals with these properties. There is also concern about pharmaceuticals from veterinary medicines entering watercourses and their impacts on ecological processes. There has been relatively little work to establish the nature or scale of the problem but a recent acceleration of research in this area suggests that pharmaceuticals are widespread in our watercourses[18] although the farming-derived sources are probably far smaller than sewage-effluent sources. Microbiological contaminants from agriculture that pollute water are commonly pathogens, most typically *E. coli*, *Cryptosporidium*, and *Campylobacter.*

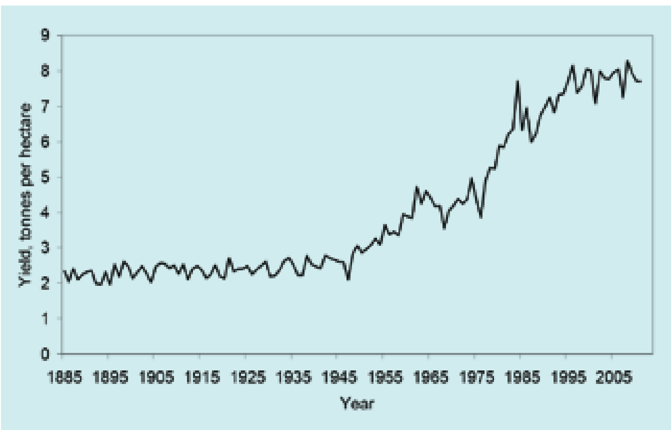

Figure 1. UK wheat yield (tonnes per ha) since 1885 (based on Defra data).

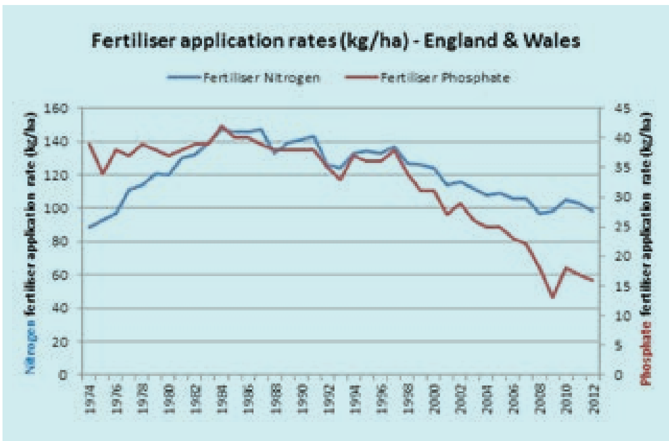

Figure 2. Nitrogen and phosphorus fertiliser application rates as an average for areas of crops and grassland on England and Wales since 1974 (data taken from gov.uk 'British Survey of Fertiliser Practice')

2.5 One of the major tools for agricultural incentivising has been the European Common Agricultural Policy (CAP), which, since the 1960s, has stimulated food production and trade. The CAP is a farm support scheme, which now accounts for approximately 40 % of the EU's budget and is linked with the management of 50 % of its land area. The majority of farmers have opted in to receive support. A decrease in relative nitrogen fertiliser costs after the 1970s oil boom also meant large increases in nitrogen input to the landscape but this declined from the 1980s, when nitrogen use started to be restricted on environmental grounds (Figure 2). In response to the 'nitrate problem', the EU Nitrates Directive stipulates the permitted amount and timeframe of nitrate applications (e.g. manure and fertiliser). In the UK, regulations apply in catchments identified to have exceeded, or are at risk of exceeding, thresholds for nitrates, termed Nitrate Vulnerable Zones (NVZs). Breaching the NVZ requirements can result in CAP entitlement penalties to farmers.

2.6 Despite restrictions on nitrogen use in many places, nitrate concentrations in groundwaters still remain elevated even in protected areas[19] as travel times of nitrogen in the water are slow and certain groundwater areas are not suitable for denitrification. Currently, only 24 % of surface water bodies in England and 36 % of surface water bodies in Wales meet 'good ecological status' as defined by the Water Framework Directive (Box 1). 22 % of water bodies achieve good status in Northern Ireland[20] and in Scotland 65 % of water bodies are deemed good or better, but for the 35 % which are failing, agriculture is deemed to be a major pressure[21]. Now and in the future, agricultural production not only needs to consider population/economic growth and development, but also its effects on water quality.

2.7 While agriculture is deemed to be a significant factor in many catchments, there is no single management practice that is the main cause of rivers and groundwater containing too many nutrients, pesticides, microbiological pollutants or silt. The natural processes by which nutrients and pollutants leave the land are complicated and may involve the interaction between locality (e.g. slope, rainfall, soil type) and management (ploughing, input regimes, field margin management and so on). There are regional differences in the source, mobilisation and delivery processes of diffuse pollution across the nation. At a smaller catchment scale, we are only now beginning to understand many of the physical processes and complexities associated with land management and water quality through advances in environmental science. These advances, however, pave the way for the development of solutions to environmental water quality while allowing sustainable farm activities. Nevertheless, quantifying the effectiveness of solutions remains a challenge.

2.8 The European Commission report on the WFD and Catchment Management[22] recommends that there should be a clear strategy that defines the basic and mandatory measures that all farmers should adhere to and the additional supplementary measures that can be financed[6]. It also recommends that this should be developed with the farming industry to ensure feasibility and acceptance. There needs to be a very clear baseline so that any farmer knows the rules and so that this can be adequately advised and enforced.

Looking into the future

2.9 Climate change will affect all forms of agricultural production via changes in temperature (e.g. livestock may require more water, soils may dry out more requiring more irrigation), rainfall (amount, intensity and pattern through the year)[23,24], river flow and groundwater recharge, and plant physiology (e.g. responses to increasing atmospheric CO_2 concentrations altering plant water-use efficiency[25], or increasing heat/drought stress). These factors may all impact on water quality by affecting farm management and the volumes of water flow, pathways for water movement, and the associated transfer of pollutants from agricultural land to water bodies.

2.10 Climate change will also lead to changes in productivity across the world. As global trade in agricultural commodities

BOX 2: How the Common Agricultural Policy can be used to support water quality

In December 2013 the European Parliament completed the latest reforms of CAP. Direct payments to farmers (known as Pillar 1) now require farmers to comply with at least one of three compulsory 'greening measures', as well as meeting statutory management requirements (SMRs) such as NVZs and plant protection product rules, and maintaining their land in good agricultural and environmental condition (GAEC). The latter includes requirements to establish buffer strips and no-spread zones near watercourses, as well as soil management to limit erosion, maintain organic matter and soil cover. Beyond the compulsory greening measures, SMRs and GAECs, additional voluntary measures are available within the Rural Development Regulation (known as 'Pillar 2'). Member States must spend at least 30% of their EU rural development allocation on environmental measures. This includes investments in agri-environment schemes, organic farming, WFD payments and forestry. WFD obligations have been confirmed one of the focus areas for support under both the Rural Development Programme for England and Rural Development Plan for Wales, as part of CAP reform from 2015. There is therefore strong potential through the modified CAP to support water quality improvements.

is growing exponentially, there will be strong economic pull to grow production in areas that can to meet the rapidly growing demand for food. The UK is an area where climate impacts may be less marked than other areas. This is likely to drive intensification of production in the future; a challenge is to find ways for growth in the farming sector whilst reducing its impact on water quality (and other environmental services). Addressing this challenge requires a greater understanding of leverage points within farming systems such as determining locations in the landscape where actions can be targeted that have the greatest benefit. A targeted approach brings significant overall cost-efficiencies supporting the future-proofing of the UK agricultural sector.

2.11 We should also be forward-thinking recognising that the world is changing, and this change may be rapid, rather than concentrating on static targets. For example, we should not assume that agricultural intensification will continue everywhere even with the current growth in demand for food. Technological innovation, permaculture and intercropping may also provide opportunities for sustainable food and water systems in specific locations. There may be a broad spectrum of agricultural activity from intensive farming through to mimicking nature. Sustainability encompasses the twin notions of sustaining supply into the future, and therefore not using resources faster than they can be replenished, and also not eroding natural capital (e.g. the amount or quality of soil, or biodiversity) in a way that reduces options for future generations. Sustaining supply into the future underpins economic sustainability so that businesses can continue to operate and support communities while minimising taxpayer subsidies.

How we approach and reduce the impact of farming operations at multiple scales

The 'transfer continuum'

3.1 The pathways by which water quality can be affected by agricultural management can be conceptualized by a simple framework known as the transfer continuum approach. This describes the sources of agricultural substances, the way they are made mobile, the route by which the substances are transferred to water and their impacts (Figure 3). It helps articulate the range of processes, and the scales at which they operate, and therefore can aid in identifying mitigation strategies

3.2 Specifically, the source of the substance may be fertilisers applied to the soil, livestock feed, or geological forms of nutrients held in the soils. Mobilisation occurs when the substance leaves the field and starts its journey; it involves subsidiary processes, solubilisation, detachment and incidental losses. Solubilisation involves geochemical and biological processes in the soil, such as desorption and enzyme hydrolysis, and is therefore closely coupled to soil nutrient cycling. Detachment involves physical processes, for example, surface soil disturbance by heavy rain. Incidental losses involves the transfer of freshly applied fertiliser or manure that is washed directly into hydrological pathways without equilibrating with soil. To reach surface waters from the point of mobilisation, substances must be delivered. Delivery is dependent on hydrologic processes and may include water flows in surface and/or subsurface pathways that vary spatially and temporally. For example, when the soil is saturated or rainfall intensity exceeds infiltration rates into the soil, pollutant-containing water may flow across the land surface. The source-mobilisation-delivery continuum approach was originally conceptualized for phosphorus, but can be applied to understand and mitigate all types of diffuse polluting substances.

3.3 By its nature, it is difficult to attribute diffuse pollution to a specific sector or activity. The continuum concept indicates that the impacts of point or diffuse pollution from agriculture can occur quite some distance from the source and with a time lag, as long as the pollutant is mobilised and transported through the catchment to accumulate downstream. Many minor issues

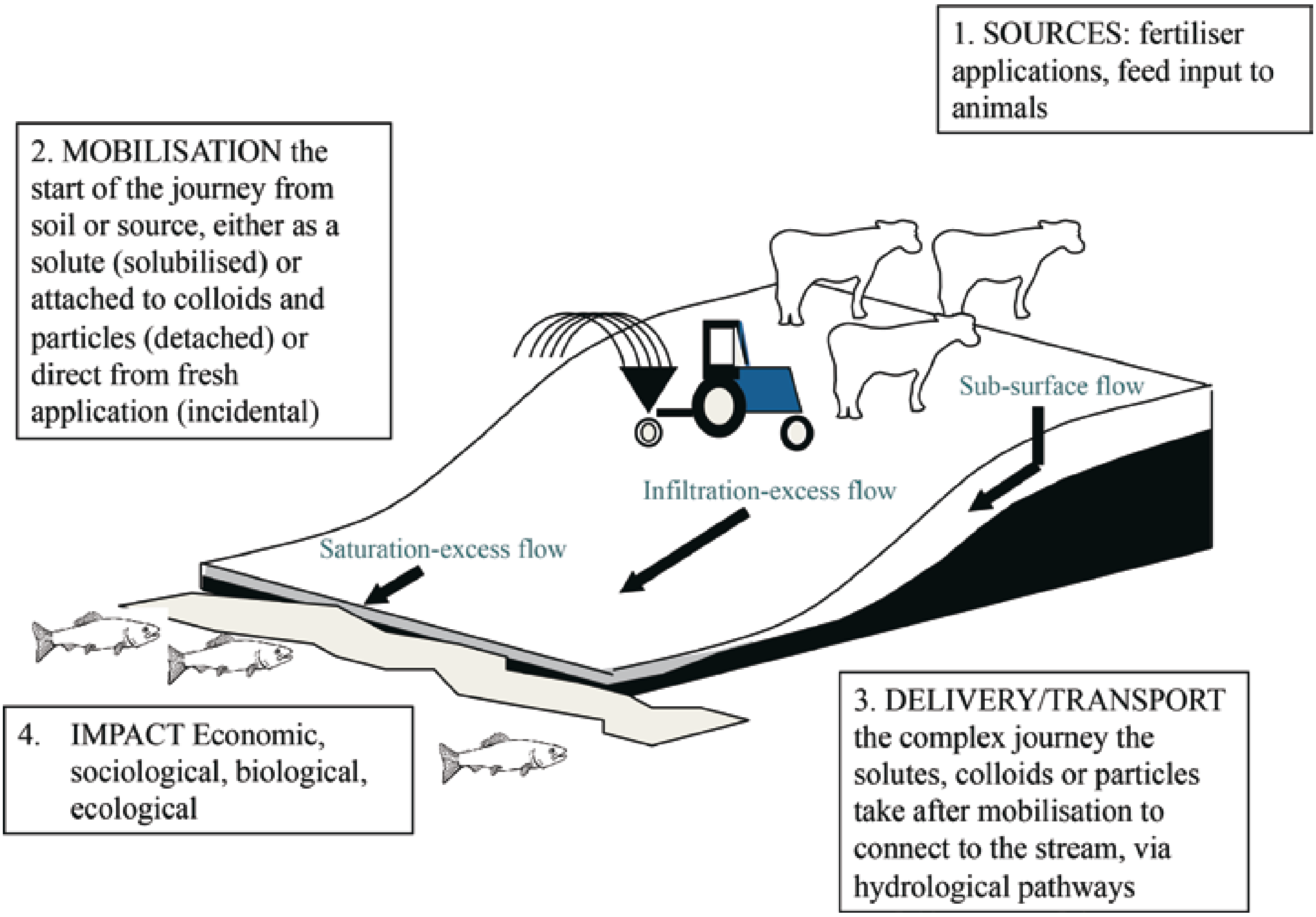

Figure 3. The transfer continuum for nutrients (redrawn after Haygarth et al.[26]).

upstream, which would have little impact if isolated, can sum to large impacts a long distance downstream at some point in the future. However, these can be hard to detect so that historically it is likely that low input farming upstream has contributed to downstream nutrient loads.

3.4 Managing diffuse pollution therefore most appropriately lies in prevention rather than cure, utilising best practices at the farm level to avoid the small-scale, field-level impacts that sum up to significant impacts on water quality downstream. Linking the upstream with the downstream together in a holistic and systems-based framework is required to manage the food-land-water system and this is increasingly being tackled in catchment scale approaches by a range of organisations. Addressing the scales and linkages of land management to water quality can be achieved using the source-mobilisation-delivery-impact approach[27].

3.5 Source control considers the overall inputs and works towards better nutrient-use efficiency, and therefore less loss of nutrients to the environment. For example, source control means applying just the right amount of fertiliser at the right time for the crop to use. It also involves balancing the farm's use of nutrients, considering all source inputs to the farm, including bagged fertiliser, concentrate feeds, atmospheric inputs and weathered sources from soil.

3.6 Mobilisation control focuses on the means of prevention of soil or nutrient loss from the field itself, and may, for example, include ploughing practices to increase the infiltration capacity and lessen soil erosion, or manure management practices to reduce opportunities for leakage. Good soil and manure management, in turn, has a positive effect on water quality and soil and manure held on land means that the land will be more profitable to the farmer.

3.7 Good agricultural practices, such as avoiding application of manures and fertiliser before predicted heavy or prolonged rainfall events ('incidental losses'[28]), using slurry injection techniques or incorporating manure into the soil as soon as possible after application can all reduce the risk of nutrients reaching water bodies. This can also result in a win-win situation as efficient nutrient use will save the farmer money as well as improve water quality downstream. Indirect benefits may also accrue in the form of fewer journeys across the land thereby protecting soil structure, which in turn means a better growing medium for crops resulting in better yields. At the site or field scale, small but identifiable point sources such as chemical leaks, septic tank drainage or poorly maintained farmyard infrastructure are identifiable and manageable. Enhanced farm technologies are required to detect such problems and to reduce the risks.

3.8 Delivery, essentially water flow, from fields to water bodies can occur via a number of pathways, namely overland flow, throughflow (within the soil) or via deeper groundwater flow. Overland flow provides considerable energy for the detachment (mobilisation) of particles and colloids, but can also contribute to the delivery via the flow pathway. However, in temperate regions such as those of the UK, most flow in watercourses is actually derived from throughflow; water that has percolated through the soil and drained into watercourses through shallow subsurface routes or via longer pathways through deeper groundwater. Overland flow is more likely to occur during heavy rainfall events (infiltration-excess overland flow), or after sustained periods of rainfall when the soil is saturated. It is also more likely in certain areas such as the foot of hillslopes, along tractor wheel-ruts or animal tracks where the soil surface has been compacted, or on shallow, poorly drained soils, which are more easily saturated [29,30].

3.9 Climate change models are predicting higher rainfall intensity in the UK and this may contribute to more overland flow in the future. Delivery control involves ways to slow and stop substances once entrained in the flowing water, for example through the use of ponds to catch sediment or buffer strips to catch nitrates and encourage denitrification of the soil water through biological activity, or trap sediment and pollutants[31]. It should be noted that deliberate channel changes, land and under-field drainage have also improved productivity and

BOX 3: First Milk Ltd: Nutrient management and off-set scheme

First Milk is the UK's only major dairy company that is 100% owned by British farmers. Their creamery in Haverfordwest processes 250 million litres of milk to produce over 25,000 tonnes of cheese per annum. The milk is sourced from 300 local farms.

First Milk is investing £5.6 million in a new effluent plant at their Haverfordwest Creamery. This is being built to industry-leading standards and the discharge levels will be some of the best in Wales. The treated effluent will discharge, via a dedicated pipeline, into the Western Cleddau which flows into the Cleddau Rivers Special Area of Conservation. The features of the Special Area are dependent on good water quality and the biggest threat to good water quality is excess nutrients.

Natural Resources Wales have assisted First Milk to develop an innovative approach in collaboration with its local dairy farmers to reduce nutrients leaving their farms and utilise an ecosystem approach, in order to offset any additional nutrient loadings to the Cleddau catchment. The farmers who have been involved in this partnership, have had bespoke nutrient management plans created for them. The project group's forecasted reduction in nitrate, phosphate and sediment losses are on target to offset the entire outflow of the new effluent plant. Other companies also wishing to discharge into the Cleddau Special Area of Conservation or the Pembrokeshire Marine Special Area of Conservation are expressing interest in using the dairy as a farm intermediary as part of potential mitigation measures under the habitat regulations.

increased the duration of time when land is workable, but there is some ambiguity as to whether drainage is of benefit or detriment to diffuse pollution control.

3.10 While there can be point source pollution from agriculture (e.g. from a slurry store), much agricultural pollution is considered to occur from diffuse sources and is therefore more difficult to monitor and attribute to particular activities or areas of land. It is therefore important to consider the pathway for pollutants and whether the transfer continuum can be cut off through appropriate land management to stop pollutants from reaching water bodies.

Balancing regulation and encouraging voluntary action

3.11 The UK currently uses regulation to protect water quality. The WFD and CAP payments provide substantial opportunities for facilitating sustainable farm practice as described in Box 2. However, there is evidence that some regulation or stewardship measures are less effective than they could have been through a lack of robust implementation[32] and targeting. There are also excellent examples of innovative approaches to using regulation to best effect such as the practices adopted by First Milk described in Box 3. For pesticide use and regulation there is a broadly positive story in the UK as outlined in Box 4, yet significant challenges still remain. The UK's National Action Plan for pesticides, required as part of the EU Directive for the Sustainable Use of Pesticides[33], advocates non-regulatory approaches as much as possible via an initiative called the Voluntary Initiative[34]. The initiative began in 2001, introducing a voluntary programme of measures for promoting responsible pesticide use and has been deemed a success story in both reducing pesticide impacts and educating farmers in conservation measures. That said, pesticides are still a major issue for water companies because pesticides tend to be strictly regulated in drinking water to very low concentrations (Box 4).

BOX 4: Pesticide management

In terms of environmental quality standards no surface or groundwater in Scotland fails good status due to pesticides. Three water bodies in Northern Ireland were affected by surface water failures to WFD pesticide standards in the period 2007–2011 while none of Northern Ireland's groundwater bodies are at poor status as a result of pesticide usage. Only 0.8 % of surface waters in England and Wales fail 'good status' because of pesticides and just over 5% of groundwater fail because of substances, which have been or are still being used as pesticides. In many cases, authorisations to use products containing these active substances have expired and this demonstrates, in line with the nitrates groundwater issue discussed above, that there can be a long lag time for recovery of groundwater systems from some types of pollution.

However, in terms of water bodies that provide drinking water, the situation is worse, primarily because the drinking water standards are far more stringent. Five out of 346 Drinking Water Protected Areas in Scotland have been identified at risk of deterioration from pesticides. Data reported in the UK Pesticides Forum report[35] suggest for England and Wales that 15% of Drinking Water Protected Areas are at risk of failing to meet the WFD protection objectives due to pesticides. The risk is more prevalent in eastern, southern, and south western areas, but less so in the north and west. Of those areas at risk, a number are affected by a single active substance, while others are affected by several active substances, or by combinations of pollutants – for example, pesticides and nitrate. Metaldehyde is the most significant active substance, causing risk at 80% of sites.

This means there is still considerable work to be undertaken on pesticide reduction in drinking water protected areas and there is a considerable cost being borne by water companies. Since privatisation, water companies have invested about £1.6 billion to reduce the levels of pesticides and nitrates in untreated water. They expect to spend a further £125 million to the end of the 2014/15 financial year.[36]

The implementation of the EU Directive for the Sustainable Use of Pesticides[37] requires a National Action Plan (NAP)[38] to be developed by each Member State. The NAP provides a framework for reducing the risks and impacts of pesticide use on human health and the environment, promoting the use of integrated pest management and of alternative approaches or techniques such as non-chemical alternatives to pesticides. Specific measures in the UK NAP are proposed to further reduce the number of water bodies at risk from pesticides and include mandatory training for operators and distributors, inspection of application equipment and regular calibration checks, aerial applications are to be limited to permitted uses only.

Tim Hess

Catchment-based approaches: raising awareness and learning from doing

3.12 The Scottish Environmental Protection Agency (SEPA), the Scottish Government and partner organisations are currently implementing a coordinated approach across Scotland to reduce diffuse pollution from rural sources, as described in the Rural Diffuse Pollution Plan for Scotland[39]. Fourteen priority catchments have been identified that contain some of Scotland's most important waters for conservation, drinking water, bathing and fishing, using a risk-based approach, where water bodies or protected areas are significantly failing standards due to rural diffuse pollution. High priority has been given to those areas affecting human health (i.e. drinking water protected areas and catchments draining to bathing waters)[40]. Specifically for agriculture, the objectives of the WFD are implemented via a diffuse pollution plan which includes one to one visits to all farmers in priority catchments to advise them on their regulatory responsibilities and to encourage them to apply for funding for measures to improve water quality and the wider environment. Measures include regulations (General Binding Rules) based on widely accepted standards of good practice, which provide a level playing field for all farmers and a clear baseline above which funding is used via the Rural Development programme. Measures are implemented via a two-tier approach of national awareness-raising and targeted action in priority catchments.

3.13 The most recent figures from SEPA[41] show that just under 90% of farmers are making changes to their management after follow-up SEPA visits. The key lessons from the approach in Scotland are:

- Having a sound evidence base suitable for the audience (e.g. pictorial/infographic for farmers and scientific for those designing and targeting measures).
- Having a clear regulatory baseline of good practice provides a level playing field for all farmers and ensures catchment coverage.
- Having a partnership approach ensuring all organisations involved in water quality and farming have one clear and consistent message: engagement with the National Farmers Union of Scotland and Scottish Tenant Farmers Association has been invaluable.
- Having one to one visits by well-trained agency staff who understand agriculture and farmers with a focus on advice on compliance.

3.14 Monitoring the water quality success of the above approach is obviously important but the complexities of diffuse pollution, and the time taken for impacts, mean that it is very difficult to disentangle and identify a response in water quality to changes in land management on individual farms. However, SEPA is developing an indicator approach (e.g. changes in land use) to show the direction of travel until changes in water quality are detected by monitoring.

3.15 In England, Catchment Sensitive Farming (CSF) has been developed to address agricultural diffuse pollution issues through a voluntary, incentivised approach. CSF offers free, practical advice and training to farmers and land managers on how to reduce diffuse water pollution from agriculture, across

80 Priority Catchments in England. Priority Catchments have been targeted to help meet the requirements of the Water Framework Directive (WFD) and improve freshwater Sites of Special Scientific Interest (SSSIs), where evidence suggests that pollution from farming practices impacts significantly on water quality and aquatic habitats. CSF has a number of officers who engage with local farmers through a practical, advice-led approach and with the support of an annual Capital Grant Scheme (funded through the Rural Development Payments). The officers are responsible for individual catchments, coordinated at River Basin District level. The officers:

- encourage changes in behaviours and practices by engaging with farmers through workshops, seminars, farm demonstrations, self-help groups and undertaking 1:1 farm visits;
- co-ordinate Catchment Steering Group activity;
- undertake communications and publicity;
- signpost agri-environment schemes and other incentives; and
- assist farmers with CSF Capital Grant applications.

3.16 Free advice and capital grants are also available to farmers through local partners in nine catchment partnerships. The CSF Phase 1 and 2 Evaluation Report in 2011 showed that farmer engagement in the first five years of the project was highly effective and that the initiative had brought about significant improvements to soil and land management practices. The uptake rate for recommendations was over 50 %. Modelling indicated that improvements implemented as a result of the first four years of CSF were predicted to reduce pollutant losses between 5 and 10 % in 'Target Areas' but it could be up to 36 %. Longer-term datasets would be needed to assess the impact on ecology in rivers within Priority Catchments.

3.17 In England, the Catchment Based Approach[42] was launched in 2013 to form catchment partnerships at sub-River Basin planning level (catchment, sub-catchment or watercourse) to focus on tackling issues in a collaborative way. This seeks to draw on existing catchment scale and community partnerships and initiatives and allow new ones to develop allowing a more targeted and holistic approach to be taken to delivery of objectives at a local level. It should therefore lead, in time, to more resilient communities and landscapes while co-ordinating with existing initiatives such as CSF[43], the Campaign for the Farmed Environment (CFE)[44], Local Nature Partnerships, Nature Improvement Areas, Local Enterprise Zones etc. However, there is a funding gap because very little money has been allocated to the Catchment Based Approach lead bodies.

3.18 The links between water supply for urban conurbations and upstream land management are often not fully appreciated by society, although there are some good examples in different parts of the world. The New York watershed project in the Catskills Mountains aims to protect water supplies for the City of New York. The project was set up in the 1990s with a combination of the city authorities buying land or entering into long term covenants. In return the City provides support and funding in the Catskills communities for land management to protect the water quality but also business opportunities within the communities[45]. In the UK, more needs to be done to raise awareness of the connectedness of land and water systems, the true value of water and the potential role of different parts of the community in protecting land and water services (see section 4).

3.19 Wales is adopting a Natural Resource Management approach to all policy thinking to achieve a holistic catchment approach to policy and development plans[6]. Natural Resources Wales are developing priority catchments, building a similar model to the Catchment Based Approach outlined above, where the drive is from government (top down). The Welsh Government is also supporting a number of self-assembled groups who have put themselves forward presenting proposals for landscape scale co-operative projects to test the holistic approach from the bottom up.

3.20 In Northern Ireland (NI)[46], diffuse pollution from agricultural sources is managed via direct regulation through good agricultural practice under the EU Nitrates Directive and Phosphorus Use (in Agriculture) Regulations 2006. Together they limit the magnitude and timing of artificial fertiliser use and organic N loading; however, no restrictions have yet been placed directly on the magnitude of manure P applications. This regulatory framework is subject to periodic review. Similar to the Republic of Ireland, regulations are based on a whole-territory approach rather than in specific zones or catchments. The Northern Ireland Environment Agency (NIEA) is responsible for conducting farm inspections, which, in the

BOX 5: The National Defra Demonstration Test Catchments project

The Demonstration Test Catchments project (DTC) is an innovative exemplar of cross community working, bringing together land and catchment managers, researchers and policy makers around focused, long-term demonstration platforms, showcasing problems and potential solutions. The DTCs were set up in England in 2010 and use four contrasting catchments: The River Eden in the North West, chosen for its representation of livestock and upland farming; the River Wensum in the East of England, chosen for its representative large intensive arable farming systems; the Hampshire Avon in the South of England, representative of mixed lowland farming; and the Tamar in Devon/Cornwall, representative of lowland dairy farming. The DTCs are viewed as a successful model, helping deliver:

1. At the strategic level (evidence in a wide range of agricultural environments; support for an ecosystem services approach to catchment management; close links to stakeholder communities to check/test);
2. At the planning level (focused technical advice; mitigation plan advice) and at the operational level (policy approaches; supporting data and information);
3. Local understanding (local/general advice).

BOX 6: Reducing dissolved organic carbon loss from upland catchments through long-term, large-scale, land-cover change

A number of large scale partnership initiatives in the UK have been established to improve the condition and services delivered in the uplands particularly on upland peatland blanket bogs. Some are focussed on practical conservation others on demonstrating multiple benefits of peatland restoration. For example, Yorkshire Water and water@leeds at the University of Leeds have undertaken comprehensive monitoring since 2007 that demonstrates:

1. The reduction of costly water colour and dissolved organic carbon in stream waters and reservoirs.
2. Improved saturation of the peat which both reduces the loss of carbon from the land and encourages more carbon to be drawn out of the atmosphere to form the peat
3. Less erosion entering streams
4. Improvements in upland stream ecology benefiting biodiversity
5. The value of long-term monitoring, assessment and research.

Responses can vary from place to place and because initial responses to management interventions can be quite different to those that unfold several years after the interventions once the system starts to change. Some responses to restoration activity in the uplands can be quick such as a reduction of erosion and sediment entering streams in some catchments. However, for other benefits to be realised we may have to be more patient and wait many years after our initial investment for the benefits to be realised.

This may be the case for flood risk where research has shown that moving from an eroding, degraded peatland towards one that is rich in moss cover can slow the flow of water[49,50]. It takes many years for mosses to re-establish in a thick mat over the peat surface and yet this small plant may create a rough surface to slow down the flow of water. Published field measurements have confirmed this slower flow across moss and modelling work has demonstrated that at larger scales the delay of water movement means that, if we carefully focus our efforts in particular parts of upland catchments, river flow peaks following heavy rain can be decreased by a few percent even though the same total amount of water will flow down our rivers. This is good news for downstream residents and businesses, and water companies alike who need to maintain water yields for times when water is scarcer (see also discussion in the 'Agriculture's impacts on the water availability' report).

case of the EU Nitrates Directive, are carried out under cross compliance.

3.21 Awareness raising of water quality issues and support is provided by NIEA Catchment Officers through nine catchment stakeholder groups, and reporting of WFD progress is also made at this catchment scale. Unlike other parts of the UK, there has been limited implementation of catchment-based initiatives; however, there are several emerging exemplars of bottom-up approaches to water quality management and action in catchments. One of the most sustained is the Ballinderry Rivers Trust, which focuses on the sustainability of the river system, for dollaghan (endemic trout) and freshwater pearl mussel habitats, through a combination of habitat restoration, stakeholder support and implementation of targeted agricultural mitigation measures. The recent emergence of the catchments' based Rivers Trusts as a movement in Northern Ireland (and the Republic of Ireland) is likely to provide a strong bottom-up complement to the highly regulated (top-down) approach to diffuse pollution management.

3.22 There are examples of bottom-up approaches that have had some success. However, often these projects are somewhat *ad hoc* and rely on dedicated individuals with vision and an entrepreneurial approach. Adaptive and iterative approaches are needed but as yet we do not have robust systems to achieve them. There remains a lack of shared understanding and shared language between the thinkers and planners at river basin scale and above, and the doers at the field scale (e.g. the Nant Pontbren catchment farmers in the Welsh borders[47] who had to invent their own incentive schemes to deal with their particular circumstances, and commoners on Bodmin Moor who developed their own method of awarding support funds from UK Government sources). The ESRC has recently launched a three year food-water-environment Nexus project, to foster debate, innovative research and practical collaborations across the Nexus.[48]

3.23 Catchment partnership approaches are now central to UK and devolved Government approaches to water quality. There are a number of projects such as Defra's Demonstration Test Catchments (DTC) projects (see Box 5) which showcase cross-community working and encourage others to take up some of the farm and catchment-wide practices. There is also scope for building upon some of the existing long-term water company monitoring in upland areas which investigates how large scale land management investment yields benefits for water quality, treatment and energy costs and wider ecosystem services (see Box 6).

What requires more work and new thinking?

Supporting innovation and uptake of practical measures

4.1 A range of excellent practical measures for reducing diffuse pollution from agriculture has been researched and assessed by governments and academia[51]. The Defra 'Diffuse Pollution Mitigation User Guide'[52] provides summarised information on a range of farm-level mitigation options to reduce diffuse water pollution, air pollution and greenhouse gas (GHGs) emissions. The document assesses the impact of each method on nitrogen losses (nitrate, nitrite, ammonium), phosphorus (total and soluble), sediment, biological oxygen demand (BOD) and faecal indicator organism (FIO) losses to water, and gaseous emissions (e.g. ammonia, nitrous oxide, methane and carbon dioxide) to air. In addition to the above guidance we need further innovation in the development of on farm methods for reducing diffuse pollution. There is scope for industry and research councils to join forces to support funding for trials and development of innovative approaches. We should not solely rely on methods of the past, but need to use our science-base and encourage innovation to provide globally leading solutions to diffuse pollution.

4.2 We also note that it has been assumed that many of the risk-management techniques tested in lowland settings for reducing diffuse pollution can be applied in upland environments (e.g. sheep dip practices, livestock management, herbicide and fertiliser application methods, and the use of buffer zones and biobeds). However, there has been little testing of these techniques for the range of soils in upland settings. The outcomes may be different as upland soils often tend to be organo-mineral soils which behave in different ways physically, hydrologically and chemically to mineral soils. They are also more vulnerable to degradation under environmental stressors than mineral soils[53]. While the overall loading for pollutants from upland environments tends to be low on a national scale, this does not negate the need for further action and research given the importance of these environments for water supply and downstream ecosystem services.

4.3 Overall, many excellent examples of good farm and catchment management practice exist. However, despite recent increases in uptake, such measures are still only applied over limited areas, so that there is a greater capacity for water quality improvements. At the farm scale, good interventions are being designed and incentivised. For example, supported by an agreed farm plan and with agreement for infrastructure changes on the property for periods of up to 20 years, sustainable and profitable food production is being achieved in many locations with environmentally safe management of adjacent water resources. Such practices have been in place in the Netherlands for decades to ensure water security, but have only started to be introduced in the UK, pioneered by South West Water[54] with their 'Upstream thinking' initiatives.

4.4 In the agricultural sector, economic drivers can cause rapid changes in practices. Fertiliser use in the UK has declined as prices have increased. Livestock numbers have declined since the 2000 outbreak of foot and mouth disease. Farmers have become more aware of the need to manage farm efficiencies and their impact on the environment. In parallel, precision farming techniques have also increased to enable less fertiliser to be applied in a more targeted way. This will have an impact on water quality as fewer nutrients will be lost through leaching from the soil. The greater uptake of nutrient planning, again driven by economics as well as industry-focused advice and guidance (e.g. Tried & Tested[55]), should lead to a change in attitudes to slurry and manures helping farmers to view them as a resource and not a waste. Increasing the value of these resources will ultimately benefit water quality as slurries and manures are applied more accurately and more effectively to soils to maximise the availability of nutrients to the crop and reducing the losses to environment. In addition, improving the accuracy of weather forecasting will also assist in allowing farmers to apply nutrients at the right time to reduce losses through overland flow. These innovations are driven by economics and the farmers' eagerness to 'do the right thing' and to minimise environmental impacts.

4.5 Greater use of demonstrator projects could help widen the uptake of applications and encourage acceptability of certain practices (e.g. finding alternative re-use points for lower grade water applied to other areas of agriculture, such as for non-food crops like biofuels). The UK could use a network of well-instrumented farm demonstrator projects (in addition to the Demonstration Test Catchments) to export cutting edge innovation to the rest of the world. This would require capital investment to support long-term operational costs of the research and development activity at these sites. Several leading universities in the UK have research farms, or farms that are run as commercial enterprises in different physical settings. Joining some of these farms together in different regions of the UK to create farm innovation platforms or a set of demonstration sites would enable greater practical and economic leverage to be borne from the intellectual capital that exists within UK universities. Some provisional work is underway in this regard via the Sustainable Intensification Platform, but we recommend enhancement and broadening of the farm innovation demonstrators. Water quality innovation could be one of many components in the food-water-energy nexus that would be tackled by these demonstrators.

4.6 There is no framework for translation of science into policy and action on the ground with regard to agriculture, the environment and water in the UK and we need to seek new means to address this[56]. A free advisory hub for knowledge exchange to deliver a clear set of messages that are informed by science, policy and demonstrator projects, could be a way to increase uptake of best practice. There is a Catchment Data User Group that is part of the Catchment Based Approach in England, but such activities around knowledge exchange are under-funded by the public purse in the UK.

4.7 We need to ensure that more work is undertaken to find and demonstrate win-win situations (while recognising that win-win is not always possible) that build farm resilience and efficiency and contribute to more sustainable environmental management. This may require policy and economic incentives, knowledge exchange, advice, guidance and a wider appreciation of how to ensure wide uptake of good practice. Such a service, similar to that provided by SEPA's River Basin Management Plans[57], would ensure that there is one clear and consistent message for all rural land users. It would also offer a more useful route to policy development noting that policy workers often have short windows for influence and need to be able to draw on clear guidance, built upon findings from synthesis and long-term strategic projects, at short notice[58].

4.8 Water policy in the UK operates at different scales; the European and national levels, the thinking and planning scale of river basins and catchments, and the 'doing' scale of sub-catchments, water bodies, farms and sites. Both the actors and the issues vary at the different levels of governance. However, we often try to bypass this layered system and try to communicate across several layers at once (e.g. government trying to talk to all farmers) with limited success. In addition, the sections of business or society that governments are trying to communicate with often respond to very different messages or methods of communication. Being able to develop a single message for a wider citizenship of organisations could help develop shared actions.

Using spatial variability for best outcomes

4.9 Delivering both agricultural productivity and other ecosystem services, like water or biodiversity, can be enhanced by "smart" landscape planning making the best of the local context[59]. It may not be necessary to take productive land out of cultivation to provide land to improve wildlife and water services. Making areas such as grassy margins available to prevent soil erosion and trap nitrates and to provide for natural pest control agents, or flower-rich margins available for pollinators, is also beneficial for crop production. In some places the optimal strategy will be to farm intensively, whilst also managing areas of land for water or other services. In other places, farming extensively and not specifically managing land for wildlife or water may be more advantageous. We need to accept that different regions in the UK will vary in their capacity to contribute to production requirements and in the environmental cost of doing so, whilst recognising that every landscape needs to produce a range of goods and services. Hence farming more intensively in one region allows other regions to specialise more in the production of other ecosystem services. At the same time, within both catchments and farms we may be able to identify best locations for activities (intensive, extensive, new cultivation methods and water protection measures) by using novel spatial environmental science and modelling.

4.10 There are two key needs for determining the right configurations of such spatial optimisation strategies for agricultural management: i) scientifically-derived information and understanding of how the water quality and agriculture system operates at different scales; ii) good governance to ensure landscape-scale and farm-scale activity supports agricultural productivity, economic viability and water and wildlife services at the same time. We need a sound scientific basis to understand the impact of different measures in different locations; farm-advisers with a good understanding of how different measures can be used in different farming scenarios; and an approach that tailors measures for different farms so that farmers can relate to what is being asked of them. The solutions are not "one size fits all".

4.11 In many instances our ability to map water quality issues is somewhat more advanced than our ability to understand the scale of intervention needed to maintain and improve water quality and to prevent future deterioration. Applying the ecosystem services or landscape scale approach to consider the wider value of different types of land use in different locations has been hampered to date by a lack of knowledge about the complexity of the interactions that influence the relationship between management actions, location and outcomes. While work is rapidly helping to fill this gap we remain uncertain about how many complex interactions operate. Developments in modelling capacity and the production and management of complex algorithms are providing new opportunities for understanding and mapping options and risks, including the potential to model for the UK as a whole the interaction between management for food and its impact on water.

4.12 There is potential to pull together the complexities of the environment and to understand how spatially-targeted measures for land management might best impact water quality while allowing agricultural productivity to grow. This should be done in the context of building upon concepts such as ecosystem services[60] but not being restrained by such concepts. It is possible to ensure that large-scale modelling of larger, regional scales is combined with smaller-scale farm and field-scale applications, subject to appropriate funding being available. Such modelling could be converted into usable and accessible decision-support tools for use within catchments and on-farm.

4.13 It may be that through technological innovation in agricultural practices combined with mechanisms for promoting behaviour change and good practice and spatial optimisation approaches, we may be able to achieve enhanced production without a water quality trade off. That has to remain a mission for the UK agricultural sector supported by government and through investment in research, innovation and monitoring. It should also be a mission for environmentalists to achieve a balance between both rather than trading agriculture for environmental objectives.

Better understanding of fast and slow responses of the system to change and support for long-term, slow-recovery deliverables

4.14 Some management interventions may lead to rapid improvements in water quality such as the recent restoration of the Culm grasslands in Devon undertaken by Devon Wildlife Trust. Other interventions may take many decades before positive effects on water quality can be detected. As illustrated by the groundwater nitrate example described earlier in this report (see paragraph 2.6), there are legacy effects with some parts of the water quality system very slow to recover to earlier pollutant inputs. In many high-profile cases internationally, intended reductions in catchment phosphorus fluxes have not occurred as quickly as expected or desired by catchment managers. Increasingly, this has been recognized to result from legacy effects associated with the build-up of phosphorus in the topsoil, and the complex release patterns in catchments and their rivers[61]. It has recently been suggested[45] that there is a need to try to achieve an equilibrium state, balancing inputs and outputs, for phosphorus within a catchment supporting agricultural productivity and population growth while moving toward closing the phosphorus cycle. Achieving phosphorus equilibrium will ensure efficient use, thus minimizing downstream losses and water quality impairment. For example, some catchments tend to accumulate phosphorus and in these cases phosphorus imports to the catchment should be reduced while creating internal phosphorus sources for agriculture within the catchment.

4.15 The UK uplands, dominated by organo-mineral soils, contribute significantly to the 70% of surface water that supplies drinking water and provide the source of many of our major rivers. Water quality benefits derived from re-vegetating eroded peat in the uplands or changing pesticide usage patterns may be seen in one or two years. There are also parts of the soil-water system in UK uplands that are slow to change in response to management interventions. It may take 10 to 20 years to see full benefits accrue from blocking peatland drainage ditches or reducing the areas that undergo moorland burning in terms of dissolved organic carbon and water discolouration in stream waters[62,63,64].

4.16 Because some interventions may take considerable time to have a water quality impact, incentives for promoting pro-water interventions ought not be based on evidence of immediate outcomes. There needs to be a recognition that the processes and consequent solutions need to operate over both the short and long term. Mitigation measures need to address current practices and the legacy of past pollution or disturbance. There is also a clear role in supporting long-term monitoring. For many stewardship measures there are limited data to describe their impact at the catchment scale[65]. In the main, our water quality monitoring networks have been short term, are often risk-based and where long-term records exist there are often major gaps in the monitoring network which means that we are often not able to link historic land management interventions to water quality changes. A consistent network of long-term monitoring sites is critical to supporting process understanding and environmental change and provides a vital starting point for determining cause-effect and short versus long-term responses of the water system to environmental change.

Choosing the optimum intervention

4.17 The challenge of selecting the optimal mix of strategies is complicated by the limited availability of public resources on evidence-based interventions. In practice, practitioners seeking to reduce water pollution problems will need to put together their own mix of interventions. An optimal mix of interventions will fit the particular needs of the locality– its type of agriculture and landscape factors, including community readiness. As far as possible interventions should be "evidence-based" through inclusion in research reports or reported findings in the peer-reviewed literature. An optimal mix of strategies will combine complementary and synergistic interventions.

Improving understanding of the real value of water

4.18 Catchment management refers to the concept of managing the land by intervening at appropriate places upstream to ensure that downstream impacts are mitigated. This is both a scientific challenge and a joint social and economic one given that different actors may be unaware, economically unable or disinterested in changing behaviour to reduce issues elsewhere. The complexities of water use and the social value of water and water bodies are little understood beyond experts. Recent high-level reports have noted that there is a challenge we need to tackle to raise public awareness of the wider value of water (e.g. [66,67]).

4.19 Figure 4 illustrates that it is important to recognise that there is a linked chain of actors who all have an individual part to play in influencing food production, therefore land management and in turn the impact of farming on water and the environment in general. For example, today's public and political expectation of cheap food is reflected in the competition between supermarkets who consequently put pressure on their suppliers, be they added value suppliers or farm businesses directly, to cut costs. This leads to farming necessarily focussing on maximising volumes of production at low costs, and as a result, enhancing environmental conditions on-farm may be seen as a luxury. Each actor/stakeholder has a responsibility in environmental protection but because they are removed from the immediate impact of the farmer's activities they often do not recognise their role, or responsibility. This includes consumers who generally want more for less cost at the supermarket but do not necessarily recognise that there may be a trade-off between water costs and food costs, such that more intensive production may impact upon water quality, leading to greater costs for water treatment.

4.20 Greater public debate could be encouraged about whether we should either adopt approaches to ensure the cost of food fully reflects the related costs to water and the environment or whether we find an alternative way of paying for ecosystem services provided.

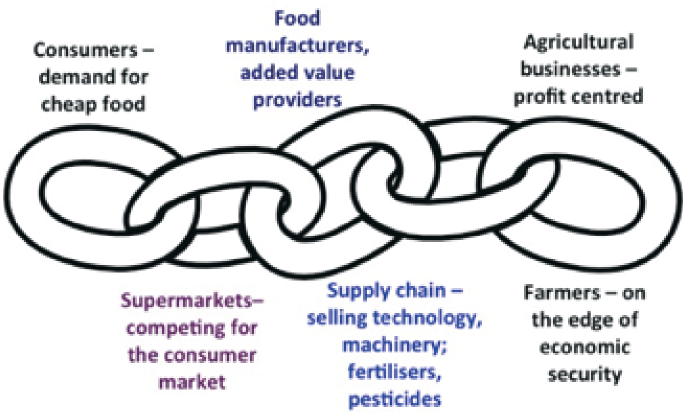

Figure 4. Showing the responsibility of all stakeholders including the public within the food production chain.

4.21 With the apparent relative abundance of water in the UK, few businesses or individuals understand or appreciate the broad spectrum of other businesses and communities in a water catchment that rely on a steady supply of clean water. In fact, water scarcity is a significant issue in the south and east of the UK and climate change presents considerable challenges to sustainability. Although all of these users value the water they use, in that they want a continuous supply of clean water, there is little monetary value actually placed on the water itself. This lack of monetary valuing of water may have contributed to a lack of integration around how water is managed or used. Regulatory frameworks protect catchments from over abstraction but may not have fully acknowledged the need for protection of the pathways in which low-level endemic pollution can enter watercourses.

4.22 To improve public engagement with water quality, further steps could be taken to connect land managers with other catchment users of raw water, most notably water companies. The costs that water companies incur removing farm inputs from the water are not widely raised or discussed for various reasons, primarily to prevent public concerns about water quality. Where this connection has been made the willingness to work in partnership has been strong from both parties. These connections are growing with water companies given the flexibility by OFWAT to engage with landowners upstream of their facilities.[68] The engagement to date has taken a number of different forms such as close working with the farmer, often using trusted intermediaries (e.g. Wessex Water paying farmers to work in particular ways[69] and South West Water's 'Upstream Thinking' programme'[70] with its third sector delivery partners, Westcountry Rivers Trust, Devon Wildlife Trust and Cornwall Wildlife Trust or the Tweed Forum). The water industry has realised that this simultaneously localised and catchment-wide approach has great significance to it for water security and is developing or implanting wide-scale programmes to support the techniques developed by Rivers Trusts and Catchment Sensitive Farming. Strong evidence of 'willingness to pay' by water customers for better river flow, quality and enhanced biodiversity has enabled South West Water to propose further work to improve water systems downstream of moorland and farmed land, based on its Upstream Thinking principles.

4.23 These approaches present real opportunities to not only develop an understanding of the relationships between securing clean water and growing food, but to also change the way those in a catchment interact. However, there are two water industry difficulties: i) the water industry typically operates on a five year timescale, because of the OFWAT price reviews cycle, which makes it difficult to commit to long-term catchment management schemes: ii) water companies tend to be risk averse as there are strict standards in place for the sector but there are large risks associated with a catchment management approach for water companies in that water companies do not typically own all of the land within their catchments and they are therefore relying on others to deliver water quality improvements.

4.24 There needs to be a more complete evaluation of the costs, benefits and effectiveness of a range of water quality risk mitigation measures. A key issue is where, when and if measures will allow us to reach water quality objectives and at what cost. It may be that some WFD requirements are simply too costly to deliver in some places without completely compromising food production – for example in the East Anglian arable areas where the land is very fertile, farming is both intensive and productive and many of the watercourses are effectively industrial (agricultural) drains. In these cases, appropriate use of WFD derogations should be possible, although this would be a political decision based on cost benefit assessment of the impact on the industry. However, the costing approach (ecosystem service evaluations or otherwise) will need to be done in tandem with the sort of spatial environmental science described earlier.

4.25 Optimal solutions may also require thinking beyond the needs of a single catchment. For example, as farming systems have become less mixed, manure-related pollution issues are pressured around those livestock systems that generate the manure generally in the west of Britain. However, there is a nutrient (and organic substrate) need for the arable sector in the east of Britain, generating the potential for manure to be recycled[71]. This is also the case for human sewage sludge cake – yet utilities are struggling to find places for disposal in the west due to saturation with nitrates and phosphorus, but have no economically feasible means of sending it eastwards where nutrients and organic matter are required. So finding a solution to the prohibitive economic cost of transporting nutrients in the form of manure or slurry from an area of excess to an area of need would be beneficial[72].

Grasping the climate change challenge

4.26 Projected increases in rainfall intensity and warmer, wetter winters will undoubtedly affect hydrological pathways and will therefore impact on diffuse pollution[73]. Warmer, drier summers, may lead to changes in soil structure such as crusting or cracking, which means that when high intensity rainfall follows, it will be more likely to follow faster routes to the river channel. Research results from the National Demonstration Test Catchment Project (Box 5), show that a very high proportion of both phosphate and sediment load to the river is transported in a very few storm events. Changes in river flow regime will also impact water quality and if there is less volume available for dilution then point sources of agricultural pollution will yield higher concentrations in water bodies. Confident projections of warmer temperatures in water bodies would mean that there could be accelerated biological and chemical processing with more algal blooms. Thus, on the ground solutions that may have been appropriate in the past for delivering to water quality standards in agricultural areas may no longer be robust under climate change. Therefore, we need to ensure approaches for water quality management are future-proofed as the climate changes. Modelling work has, to date, revealed rather complex outcomes from climate change on water quality, which are dependent on catchment characteristics, and location within the catchment[74] and this also means that there may be no silver bullet with regard to climate resilience. However, it is fair to say that in the UK (and internationally, given the relatively short sections on water quality in IPCC reports) there has been very little research into how climate change may affect water quality, and in particular within the agricultural sector, and there is therefore a major research gap that needs to be addressed.

Key findings

5.1 We believe it will be possible to balance high aspirations for environmental water quality while ensuring UK food security and viable livelihoods for farmers at the national scale. This will be achievable in general, but may not be achievable everywhere. There could be areas where we may decide to make a political decision to trade-off water quality for agricultural production and vice versa, although these sorts of decisions need to be built upon improved science of spatial processes and optimisation modelling, in order to keep such areas to a minimum.

5.2 There are significant challenges in finding and targeting cost-effective solutions, however the UK should be able to deliver world-leading solutions for agricultural growth, without putting environmental water quality at further risk. This could be achieved through developing our process understanding, supporting data collection, supporting innovation and farm and catchment demonstration, clever implementation of policy and communication and governance mechanisms and by developing new spatial models of interlinked agricultural production and water quality that can support policy planning at different scales That will also mean tackling other sources of water pollution in parallel, as part of an integrated landscape-scale approach.

The key findings from this report are outlined below:

1. **Decisions involving agriculture and water need to be made based on a long-term perspective; with appreciation of the time it takes for policies to have sustained impact.** There is a need to recognise that the relationship between agriculture and water operates on a long-term timescale of tens of years and therefore any policies or improvements for the UK may need this time frame to elicit a response. So, this cross-cutting recommendation unites research and policy makers, industry and regulators in recognition of the need for novel and innovative perspective on long-term decision making and funding.

2. **We need unified predictive models encompassing all key aspects of agriculture and water management that inform future policy and commercial interests.** It is essential to recognise that balancing water quality management, food production and other ecosystem services in any given area is not easy, providing a grand challenge for scientists and policy makers alike. Scientifically and socially, the big target is to work towards 'more unified models' for the UK for water quality and food production, where we can predict the long-term costs of food production against the real cost of the environmental trade-offs (e.g. benefits of land sharing versus land sparing).

3. **There needs to be recognition from policy makers and industry that different solutions will be needed in different agri-water systems.** There is a strong requirement to embrace the challenges of scale and heterogeneity in agriculture and water quality. These present both an on-going research challenge yet also an opportunity for providing new and diverse solutions and mitigation. For example, it will be important to acknowledge that there are many types of land/water systems, and overlying communities, and that "one size does not fit all".

4. **Long-term support for research infrastructure is required to measure and analyse data necessary to inform decision making.** There is a need to maintain appropriate depth and resilience in the supporting UK research and innovation infrastructure. This infrastructure is required to allow research into the highly complex and only partially understood agricultural production-water system. The emphasis needs to be on research infrastructure equipped to manage long term, large scale, integrated and multidisciplinary data that can be used to inform and influence a range of industry and policy makers. The Defra Demonstration Test Catchments and the North Wyke farm platform are good exemplars of this, but the UK needs novel approaches to support more of these infrastructures, as well as improved coordination across the UK. We also need to acknowledge the need for better exploitation of existing data and novel approaches to data analysis. Soil and systems orientated research can also be of tremendous value in maintaining and underpinning this resilience, and are cost beneficial to the nation in maximising the long-term economic potential of the managed landscape.

5. **Farmers need better information on which to make informed management decisions regarding water management.** Farmers are the focus of numerous policies, environmental and economic factors that affect their businesses. Advice given to farmers from different sources is often perceived to be in conflict. There is a need for better coordination of the range of policy information and scientific research data available - targeted at a farming audience - and framed in a way that takes account of trade-offs between different environmental, economic and agronomic objectives. There is an urgent need to identify novel mechanisms to translate this existing knowledge to a wider UK audience.

6. **There are existing solutions to some problems and this knowledge needs to be effectively disseminated with appropriate incentives for implementation to have maximum impact.** Mechanisms need to be explored to encourage wider uptake of the growing number of solutions that support food production whilst reducing or minimising negative impacts on water quality. These solutions cover, legal, incentive-based (both government and industry led), market-based (e.g. payment for ecosystem service schemes, reverse auctions, pollution trading schemes etc.) and cooperative actions involving a wide range of industries with local interests. These local solutions have potential to deliver large-scale improvements in water quality and financial and sustainable outcomes for a range of businesses.

7. **We need greater collaboration between researchers, industry and policy makers with the necessary framework to deliver effective joint working.** Only by working in a more collaborative way will we be able to rapidly address the challenges around the need for food security in a changing climate. There is a need for building a more coordinated UK community around agriculture and water quality that more closely aligns researchers, industry and policy makers to help meet some of the grand challenges in science and innovation (e.g. building on the existing activities under the UK Water Research Innovation Partnership, the Global Food Security programme and the Government's Agri-technology strategy).

   The key principles of this community should include:
   - Coordinating activities across industry, government, agencies and research communities;
   - Developing a more strategic, long term approach to address joint working between all actors in sector, including academia, industry, policy and advisory workers;
   - Pooling resources data and knowledge;
   - A closer working between researchers and the end users;
   - Working across a multidisciplinary environment and across different industries; and
   - Improved communication and uptake of findings.

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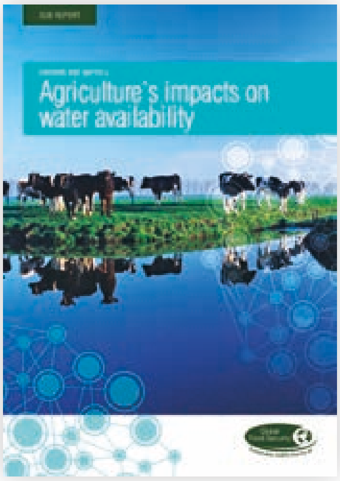

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