SUB REPORT

FARMING AND WATER 3

Water use in our food imports

THE UK WATER PARTNERSHIP

Global Food Security

Sustainable, healthy food for all

Contents

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This report represents the views of the working group and not the organisations for which they work.

Executive summary

This report focuses on the issues of water use in the agricultural production of our food, especially in countries from which food is imported. From the point of view of the UK's supply chain, the report highlights what the risks are and how best to assess them alongside possible risks producers may face overseas. The report also provides some guidance on how different stakeholders in the food supply chain (producers, food manufacturers, retailers, policy-makers, research funders and academics) may respond to the challenges.

Water in food production

Water is required to produce food, whether that is for plant growth, for animals to drink or for food-processing. One UK family-of-four's diet for about 8 months requires an Olympic swimming pool's volume of water for production, mainly from rain-water underpinning crop growth, but some is abstracted from groundwater. Approximately 70% of the world's freshwater withdrawals are used for agricultural production. Globally, the relationship between water, food and trade varies significantly; for example a country with plentiful supplies of water may have a competitive production advantage over a country where water is scarce. However a country's economic strength also plays a role, with economically strong nations being able to afford to import water-rich crops and so conserve their own water resources for other purposes.

It is likely that in the future, water availability in the places where our imported food is grown may be subject to shifts in supply. These shifts may be due to the impacts of climate change or changes in demand arising from other users (e.g. an increasing population and competition for land and water for different societal needs). With only around 53-62% of food demand in the UK produced locally[1], two key questions emerge:

1. What are the supply chain risks to our food imports? And how big a problem is it?
2. What is the impact on our food choices on overseas water security? And how big a problem is it?

Quantifying the amount of water used to produce food
The concepts of 'virtual' or 'embedded' water can be a useful proxy for assessing the risks to a supply chain. During the production process, consumed resources (e.g. energy, water and fertiliser) become 'embedded' within the product and therefore become depleted at source. The embedded resources have been used and therefore do not retain their original form or function, becoming 'virtual'. So, virtual water is used to describe the sum of the different steps of the production chain. However, virtual water can be misinterpreted if no distinction between water-use in rain fed agriculture ('green water') or water use in irrigated agriculture ('blue water') is made. This is because rain falling onto soil will typically be used by plants (whether crops or natural vegetation) and so there is no choice, or opportunity cost associated with its use. However, abstracted water used for agriculture could be used for other purposes (domestic, industrial, environmental).

Virtual water can be 'traded' from one place to another in the form of food or other commodities, and this is known as 'virtual water trade'. When food is imported from water-poor areas, in effect, water stress is being exported to the location of food production and in extreme cases this has the potential to undermine local water security. For example, UK imports of tomatoes from southern Spain require the amount of blue water equivalent to the domestic consumption of 200,000 people.

Risks from obtaining food from overseas in a changing world

It is anticipated that there will be an increased global demand for fresh water in the future. This demand is driven by the increase in the global population to 9.6 billion by 2050, placing greater demand on resources, particularly in sub-Saharan Africa and parts of Asia[2]. At the same time, socio-economic development will enrich emerging economies, such as the BRIC countries (Brazil, Russia, India, China) and South Africa, and allow them to purchase more water intensive diets.

Climate and environmental change are expected to alter water availability in the future, with it becoming more variable. To adapt to these changes, farmers and growers may choose to grow options which are less vulnerable to weather. In addition, governments are examining the uses that water is put to and assessing opportunity costs via a more holistic appreciation of overall sustainability. In the future, the price of food is likely to increase, as the supply chain becomes unable to absorb extra costs.

The impact of these climate, environmental, demographic and economic changes on UK food imports is difficult to forecast. However, ensuring that the UK food supply chain remains resilient is a key concern. Resilience could be increased by choosing suppliers from locations where there are fewer sustainability issues. Retailers can also work with suppliers to ensure that food producers are enhancing their suitability in the face of increasing climate and market variations.

One of the challenges for understanding the impacts of water use in overseas supply chains is the constantly changing landscape for trade and access to water. There is an increasing need for new methods that can identify risks and rewards in water management (e.g. environmental, physical and social 'hotspots' of risk) taking into account future weather and climate variability.

Water footprinting involves quantifying the potential environmental impacts related to water[3] and offers a useful method to identify where and how risks related to water availability might arise in the chain of production and import. Water Risk Mapping is an alternative methodology for making strategic decisions about supply chains. Risk mapping involves a spatially explicit characterisation of risk, typically expressed as a map, providing nuanced information that a simple footprint fails to.

The role of retailers in the food chain

To respond to water issues, retailers are increasingly seeking to identify global water vulnerable areas. This enables them to respond within existing supply chains and also informs their strategic future sourcing decisions. Working with suppliers in high risk areas to enable better water management to mitigate these issues is increasingly important. Abandoning an area of water vulnerability should be seen as an act of last resort for the private sector due to the socio-economic impacts this would have and due to the wide range of potential mitigation options available.

Where are the knowledge gaps?

A number of gaps have been identified in our knowledge of water and our overseas supply chain for food. These knowledge gaps include the impacts of climate and environmental change on water resources, the social effects on abstraction, the risks or rewards involved in water management, tools to determine these risks or rewards, and finally how to manage the above uncertainties effectively. Retailers and manufacturers need to consider where their priorities lie since addressing water issues and brand management may have different outcomes.

Partnerships are needed at the local scale (e.g. Industry, NGOs, Government) to improve local management practices and improve data collection for a common good. Public and private policies should also be developed that integrate food production and its impacts on water, allowing the assessment from local to global scales. Finally, there is a need to promote the teaching and research of agricultural systems from a land, water and livelihoods point of view.

Key findings

A number of key findings have resulted from this report:

1. Tools to identify the risks associated with food imports and their strategic importance for the supply chain are in high demand. These need to be both spatially and temporally highly resolved. The concept of "virtual water" is insufficient.
2. More integrated understanding of the risks to food production, and of water use will arise through working in partnerships (across academia and the food chain).
3. Governance, advisory systems and structures should facilitate better management of food and its impacts on water both in the UK and abroad.
4. Catchment management systems should be encouraged (by UK actors) overseas, with the ability to monitor and collect data around water use and impacts on water quality. Farmers, extension services and advisors should work in partnership across catchments, to avoid local gains in best practice being eroded by suppliers to other countries downstream.
5. Public and private policies should be developed that integrate across food production globally and its impacts on water (and the broader environment), allowing assessment from local to global scales.
6. Teaching and research of agricultural systems from a land, water and livelihoods point of view should be further developed, promoted and embedded in stakeholder communities. In turn these should aim to better understand and quantify the complex productivities and efficiencies of rain fed and irrigated farming at the local field, basin and regional/global scales.
7. In future UK funders should facilitate greater engagement with "international agricultural water and land use" to underpin decision making for sustainable and resilient production from both a UK food chain, and exporting countries' water security perspectives.

Introduction

Overview

1.1 This report is one of three focussing on the relationship between agriculture and water. The other two address a) the relationship between UK agriculture and water availability and b) UK agriculture and its impacts on the quality of water in the environment. This report focuses on the issues of water use in the production of our food, especially in countries from which we import food. We aim to highlight how best to assess the risks, and the risks themselves; both from the point of view of the UK's food supply chain, and the risks that producers may face overseas. We also provide some guidance on how different stakeholders in the complex food supply chain (producers, food manufacturers, retailers, policy-makers, research funders and academics) may respond to the challenges.

1.2 Only 53-62% of food demand in the UK is produced locally[9] which implies that the UK's demand for food, and consequently its impact on water, overseas is significant. This report therefore looks beyond the UK and considers the impacts of the UK's food consumption on water use in the countries from which we import. Our overall aim is to examine the UK food supply in relation to overseas water use in agriculture[10], examine the vulnerabilities for our supply chain and the risks to water security in the exporting countries, and to bring clarity to a discussion that is often muddied, identifying where there are knowledge gaps. Recommendations will identify the actions that are required to help mitigate the potential impacts.

1.3 There are three important drivers affecting the global food system:

1. Increasing population and per capita demand means that global demand for food is increasing and is projected to increase by somewhere between 60 and 110% by mid-century[11,12].
2. At the same time, the climate is noticeably changing. There is likely to be increasing incidence of extreme weather (drought, heat and intense rainfall), leading to dry areas getting drier, and wet areas getting wetter[13]. If rainfall does get more intense in some areas, this may not lead to increased water availability for crops, because water might run-off more quickly.
3. Competition for land and water for different societal needs is also intensifying, due to population, consumption and economic-growth.

1.4 Thus, the increased demand for food is set against a background where the general ability to increase production is more constrained by competition for water and land, and subject to greater weather-related shocks. This general situation creates a need to focus on the length and resilience of supply chains for all countries that rely on imports for their food security[14].

1.5 The relationship between water, food and trade varies significantly from place to place. Purely in terms of water, a country with plentiful supplies for agriculture may have a competitive production advantage over a country where water is scarce. However, a country's economic strength also plays a role and economically strong nations can afford to import water-rich crops and so conserve their own water-resources for other purposes. The UK occupies the middle ground; it has reasonable levels of rainfall and is capable of domestic production of most staple food products, however a large amount of food is imported because it is cheaper than domestic production, or because the UK have grown accustomed to eating exotic foods that we cannot grow locally. Water availability in the places where our imported food is grown may be subject to shifts in supply due to climate change or shifts in demand arising from other users. Any severe changes would threaten the resilience of our supply chains and may create risks to our food supply. For exporter countries, exports may generate much needed income but may create adverse incentives and environmental or social risks by undermining domestic availability of food and water.

1.6 The report is structured as follows. First we introduce the concept of virtual water as a means of visualising water-used to produce goods we consume, and we illustrate this with some examples. We then address the issues facing the UK supply chain. The next section assesses the need to go beyond the virtual water concept, and its associated water footprinting, to fully identify risks for the UK focussing on the need to assess and build resilience. We then address the actions that are needed to ensure resilience and sustainability in water use, and how the actions vary with different communities of actors. The final section identifies knowledge gaps and provides recommendations for the future.

Definitions

- **Virtual/Embedded water** is a measurement of the volume of water used to produce goods and services in the supply chain.
- **Virtual water trade** is used to describe the hidden flow of water when food or other commodities are traded from one place to another.
- **Blue water** refers to water abstracted from rivers, lakes, reservoirs and groundwater which is used in agriculture for irrigation of agricultural crops, agricultural operations and watering livestock.
- **Green water** refers to rainfall used by agricultural crops, pasture, forestry and natural vegetation.
- **Ecosystem services** are the benefits people obtain from ecosystems. These include provisioning services; regulating services; cultural services and supporting services that maintain the conditions for life on Earth.

The concept of virtual water, its trade and limitations

Virtual water

1.7 The availability of water, and its use, has considerable spatial and temporal variation which makes any attempt at quantification of water used in agriculture problematical. A useful proxy for assessing the risks to a supply chain is encompassed in the concept of "virtual" or "embedded" water[15], which is a measurement of the volume of water used to produce a good or service. All food production requires water, whether for plant growth, for animals to drink or for food-processing. For example, it takes approximately 1,600 litres of water (from rainfall or irrigation) to produce one kilogram of wheat. Globally about 70 % of the world's freshwater withdrawals are used for agricultural production.

1.8 During production, consumed resources (e.g. energy, water and fertiliser) become 'embedded' within the product and therefore become depleted at source. The embedded resources have been used and therefore do not retain their original form or function; they become 'virtual'. This establishes a powerful analogy that allows society to view food in a new 'global-yet-local' light. Thus, alongside the food that is being imported, 'virtual water' (and virtual energy, virtual fertiliser and also virtual "environmental impacts") is being imported.

1.9 A product's virtual water content, therefore, is **the volume of freshwater used to produce it, measured at the place where the product was produced.** It refers to the sum of the water consumed in the various steps of the production chain (Figure 1; Boxes 1-5).

1.10 Quantifying the virtual water requirement introduces new ways of considering water management and allows other potential uses to be considered. Agriculture, through its water consumption, can constrain the quantity of water available for other uses, e.g. power and industry, for social and domestic uses, the provision of water to the aquatic and terrestrial environments and the underpinning wider biological and ecological processes it supports (discussed in detail in the companion report 'Agriculture's impacts on the water availability'). Agriculture and food production also affects the quality of water resources through sediment generation, transport of nutrients and discharge of effluent (discussed in detail in the 'Agriculture's impacts on water quality' companion report).

Virtual water trade

1.11 The term 'virtual water trade' is used to describe the hidden flow of water when food or other commodities are traded from one place to another. When water is a limiting resource, but still available for agriculture, it implies that water-scarce countries wishing to trade agricultural products should use their water to grow high-value crops (often horticultural) for export and not use water to grow, but import low-value crops (like cereals). Such a strategic approach would preserve water for non-agricultural use. Less strategic approaches could undermine local water security through its overuse for production for the export market[16]. When food is imported, therefore, there is a risk that, in effect, water stress is being exported to the location of food production. Given the global trade in agricultural

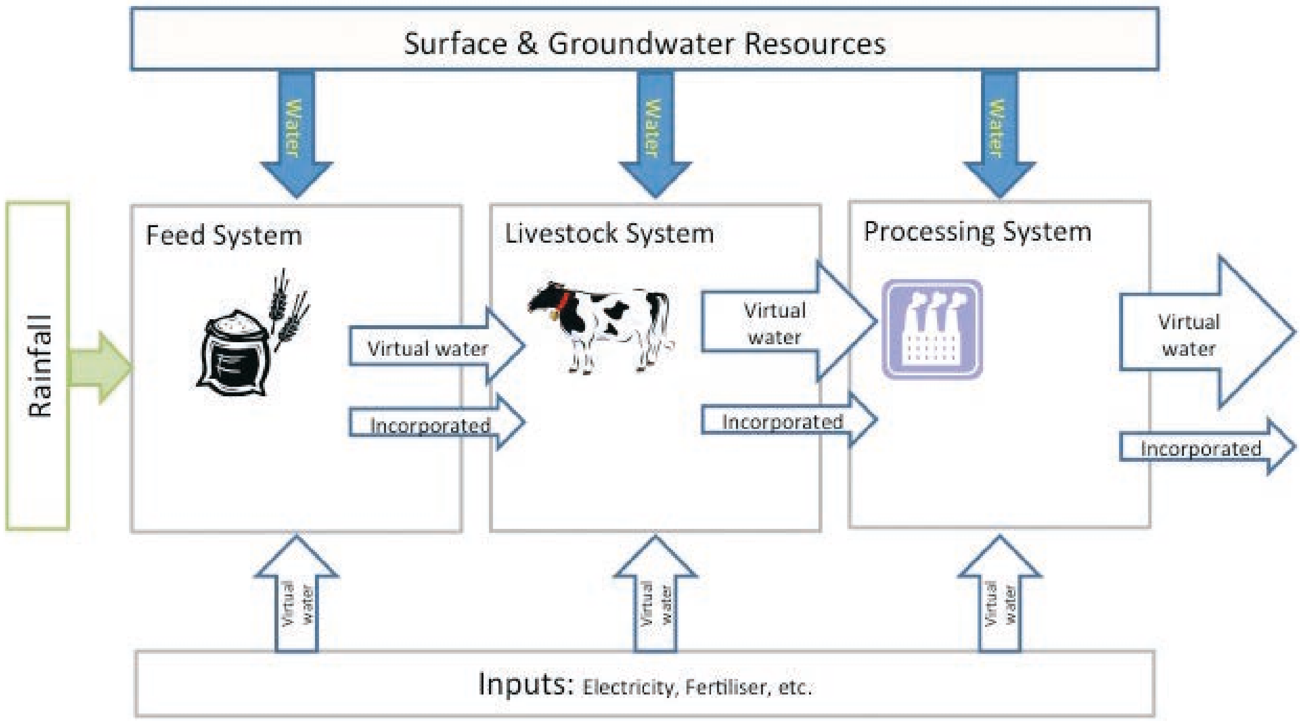

Figure 1: The diagram below illustrates various steps and virtual water inputs of a livestock production system. Incorporated water is water in the product. Virtual water is the water used to make the product but is not incorporated (e.g. transpired by the growing crop).

production[17], and changing patterns of water-availability, the use of water for production of food for export can create supply chain risk for both exporter countries (via using precious resources and undermining local water security) and importer countries (via water-shortages leading to potential interruptions to supply).

1.12 Increased demand for food necessarily means increased demand for virtual water. At the same time, especially in drier parts of the world, the changing climate will exacerbate increased demand for water for other uses. The relative increase in demand over supply constrains choices between water uses and is therefore reducing the potential for trade-offs between uses to be easily explored and achieved.

Green and blue water

1.13 A key distinction has to be made between water-use in rain-fed agriculture versus agriculture's use of water abstracted from surface and groundwater sources. This distinction is described by the following terms:

- Green water refers to rainfall used by agricultural crops, pasture, forestry and natural vegetation. The majority of agricultural production worldwide is based on consumption of green water. Green water has a low opportunity cost as it cannot be used for other purposes[18], i.e. if a crop was not grown in a certain location, the rainwater that it would have used cannot be directed to other non-agricultural uses as it will be used by some other vegetation.
- In contrast, blue water refers to water abstracted from rivers, lakes, reservoirs and groundwater which is used in agriculture for irrigation of agricultural crops, agricultural operations and watering livestock. Within, and downstream of, individual catchments, there is competing demand for blue water from different users including for domestic and industrial purposes. Blue water use has a higher opportunity cost than green water because it can be used in different ways by different people, and a certain level remaining in the environment is necessary to maintain ecosystem services. The storage, abstraction and pumping of blue water therefore represents a societal choice between different uses.

1.14 Whilst the concept of virtual water broadly covers the amount of water used to produce our imports, it is a partial term because it doesn't assess production's impact on water quality or the wider environment. It can also be misleading if virtual water does not differentiate between blue and green water. The real impact of water use in a particular food-producing location results only from what is known as 'consumptive water use', that is, water use that reduces the availability of water in the source in the short or medium term. Water use is considered consumptive[19] when:

1. Water evaporates - this includes the water that is transpired by plants or evaporation from storage and irrigation canals;
2. Water is incorporated into the product;
3. Water does not return to the same water body from which it was withdrawn;
4. Water does not return in the same time period, or;
5. Water is degraded via pollution.

1.15 The distinction between the blue and green water is important because the hydrological, environmental and social impacts, as well as the economic opportunity costs of surface and ground water consumption, differ between them. In short, farmers, by managing soils and agriculture appropriate to local rainfall patterns, optimise their use of green water. The use of blue water for farming creates an opportunity cost in terms of reducing available water that could be used by other people, or for maintaining environmental integrity.

1.16 The volume of water used is not straightforwardly correlated to the associated environmental or social impact[20]. For example, the impact of agriculture on water quality (see the report 'Agriculture's impacts on water quality') via erosion and diffuse pollution may not be related to the volume of water required by the crop. Also, water withdrawals and use invariably change the timing and geographies of water flows which in turn alter the social relations that had developed around previously established flows and timings.

Why does water for food matter?

1.17 Despite some methodological weaknesses, the concept of virtual water helps us to recognise that the overseas production of different foods, goods and services impacts on local water resources. For us in the UK, the concern is that our food imports may be depleting water resources in arid areas, and that this is neither sustainable (putting at risk our supply chain) nor equitable for the future agriculture in those exporting countries. A strategic approach needs to consider how trade in food/feed plus the analogous virtual "trade" in embedded water can be continued in a sustainable and resilient way, and to address the social, economic and ecological issues in an equitable fashion for all the countries involved.

1.18 Somewhere around 40-50% of the UK's food is imported from 168 countries[21] (mostly fruit and vegetables, meat and beverages) so in basic terms about half of the UK's foods' environmental impacts is likely to be on land and water resources overseas. The exact nature and distribution of that impact on local water resources is less certain due to the difficulties in breaking down overlapping rain-fed (green water) and irrigated (blue water) farming systems.

Tim Hess

BOX 1: Case Study: Virtual Water in British potatoes

Water is used in potato production to support both crop growth and crop quality; as a consequence their production accounts for 43 % of the total irrigated area and 54 % of irrigation water use in England and Wales (Defra, 2011[4]). The total water consumption for potato production is shown in Table 1. Water use in a potato crop depends largely on the climate of the production area and is largest at East Anglia (82 l/kg) and smallest in North East England (65 l/kg). In some places potatoes can be grown without irrigation, however, in the drier parts of the country, supplementary irrigation is used to ensure both crop yield and quality. Taking into account the proportion of the crop that is actually irrigated, the blue water consumption of potatoes grown in Great Britain in an average year is 11 l/kg, but there is a large range from 20 l/kg for potatoes grown in the East of England to 2 l/kg in the North West. Although potatoes are grown in all regions, the main concentrations are in the areas where soil and climate conditions are most favourable, e.g. Lincolnshire and Norfolk, and it is these areas where competition for water between the public supply and agricultural use is at its fiercest. In many catchments in Great Britain (GB), water is already fully committed and abstraction cannot be increased without causing environmental harm.

Region	Blue water	Green water	Total
East of England	20	62	82
South East	17	59	76
Wales	6	68	74
East Midlands	10	62	72
West Midlands	9	62	71
Yorkshire and the Humber	7	63	70
North West	2	66	68
South West	3	65	68
North East	6	60	66
Scotland	4	61	65

Table 1: Virtual water consumption of irrigated potatoes grown in GB in an average year (l/kg potatoes)[5]

BOX 2: Case Study: Comparing potatoes, pasta and rice

Comparing the amount of water consumed whilst producing British potatoes, with those of other competing carbohydrate foods imported from elsewhere is informative. Analysis of typical portions of three alternative starchy carbohydrates, showed that 180 litres of blue water are consumed in the production of one portion of Indian basmati rice compared to 2 litres for Italian pasta and British potatoes ([6] and Table 1).

In all three cases, most of the blue water consumption was associated with the growing of the crop (mostly irrigation) and little water was used in processing. The main difference between the products is that Indian rice is fully irrigated and has a low yield per hectare, whereas a large proportion of the water requirements of British potatoes and Italian durum wheat are supplied through rainfall.

BOX 3: Case Study: Virtual Water in Irish Beef

Virtual water in livestock production includes water consumed in the production of feed (including grazing); drinking water for the animals, water for washing and cleaning; and water consumed in the slaughter and processing of meat. For Irish beef systems, the majority of feed comes from grazing or conserved hay and silage; and domestically grown or imported concentrates. These are mainly rain-fed, so supported by green water, however, blue water is consumed in the processing of the feed. The water used to support the animal is mostly the drinking water, which depends on the ambient air temperature and the animal's diet. A grazing animal gets a significant proportion of its water requirement from the grass, whereas animals fed on concentrate-rich diets require more fresh water for drinking, although this is largely offset by greater output per head.

Water consumption per kg is much lower for dairy-beef than for suckler beef because dairy-beef calves are a by-product of the dairy industry and therefore water use by the parent dairy cow is not accounted for. Whereas for suckler beef production, requirements of the suckler parent cow need to be accounted for and therefore water consumption by the suckler cow for drinking water and water in feed over the first year is included.

This case study is illustrative for two reasons. First, a kilogram of suckler beef requires 10 tonnes of water to produce. That is a lot of water. However, the impact of how much water is required is predicated on local conditions. In Ireland, blue water is essentially not needed because rainfall is plentiful and almost all food required is produced using green water, and it might be concluded that Irish beef, relative to that grown in a drier area (like California or Texas), is not associated with water issues.

The second conclusion from this case study might be that there is no issue with water based simply on its usage. Solely making assumptions as to the impact of agriculture on water based upon usage will miss other impacts, such as impacts on water quality. Pollution (or nutrient leakage) from livestock systems may create problems with water quality, and livestock feeding along river banks may cause poaching and erosion. In Eire, only 52% of rivers reach "good" ecological status under Water Framework Directive assessments.

System	Green water	Blue water		Total
	Feed & Livestock	Feed & Livestock	Meat Processing	
Intensive dairy-beef	6,710	17	6	6,733
Extensive dairy-beef	6,560	14	6	6,580
Intensive suckler beef (spring calving)	9,890	41	6	9,937
Extensive suckler beef (autumn calving)	10,700	51	6	10,757

Table 2. Blue water consumption for Irish beef, l/kg edible carcase weight (after Hess et al., 2012[7]).

BOX 4: Case Study: Virtual Water in Spanish tomatoes

Tomatoes are an important export crop for Spain and irrigated production supports the year-round demand for tomatoes in northern Europe. The blue water requirements for tomato production vary across Spain, but averages 60 litres/kg[8]. Each year, the UK imports around 180,000 tonnes of tomatoes from Spain, therefore the virtual blue water import is around 11 million m^3. This is water that is no longer available for use in Spain and is equivalent to the household consumption of 200,000 people.

BOX 5: Estimates of the virtual water consumption in different foods

The table below shows the range of water uses from the case study boxes that are outlined above. The data shows clearly that meat production and irrigated crops top the list for water use.

Food/Crop	Country	Irrigated or not	Water use (l/kg)
Pasta	Italy	Some irrigation	27
Potatoes	East England	Some irrigation	13
Tomatoes	Spain	Irrigated	60
Rice	India	Irrigated	2400
Beef	Ireland	Crops rainfed	10000

Table 3. Estimates of the virtual water consumption in different foods.

Table 4. Estimates of the UK's virtual water consumption (lcd, litres per capita per day). External=water used ex-UK.

Source	Total virtual water (lcd)	% external	Blue water (lcd)	% external	External (lcd)	Comments
Chapagain & Orr (2008)	3,400	62 %			Virtual water 2018	All agricultural products (not just food). Includes water required to dilute polluted water emissions
Yu et al. (2010)	1,364	53 %			Virtual water 723	Agriculture, fisheries and food sectors.
Hess et al (2015)	2,400		159	68 %	Blue water 108	Food

1.19 Table 4 shows different estimates for the UKs virtual water use; the values are taken from three studies with different methodologies and assumptions. Chapagain and Orr (2008) estimated that 62 % of the water resources used to sustain UK consumption of agricultural goods were sourced externally[22]. This study also estimated the total agricultural virtual water consumption of the UK as 74.8 billion m^3 per year - equivalent to 3,400 litres per capita per day (lcd)[23]. This figure includes all agricultural products (not just food) and water required to dilute polluted water emissions. Yu et al. (2010)[24] used a regional input–output (IO) approach and estimated the virtual water consumption of agriculture, fisheries and food sectors of the UK to be lower at 1,364 lcd of which 53 % is sourced externally. An estimate of the total volume of green and blue water used to sustain UK food consumption is 2,400 lcd[25]. In this study it was also estimated that 68 % of the blue water use for food consumption was sourced overseas.

1.20 All of these estimates indicate a large dependence on importing food and by association a dependence on 'virtual water' overseas. Much of the virtual water in our food, both domestic and imported, is green water consumed in rain fed agriculture. However, the blue water required to sustain UK food consumption has been estimated as 159 lcd (which is about the same as the average per capita water use in the home in the UK). 68 % of this is associated with food imported from water-stressed countries, especially from Spain, South Africa, Egypt and India[25]. Consequently, the UK is heavily dependent on water from water-stressed locations and we are therefore at risk from the disruption of water supplies in locations far from our borders and well beyond our immediate control. In addition to any impacts on blue water availability, agricultural production overseas is also likely to have the same (or greater, if there is less regulation) impact on water quality as UK agriculture.

Food from overseas in a changing world: the need for adaptation and resilience

1.21 Water has been clearly identified as a major issue for humanity in the 21st century. In a world of global trade, a nation's requirement for food may have significant impacts on another nation's water resources. This may have implications for both importer and exporter nations depending on their development status. It may be desirable or necessary to minimise the impacts in order to build a more sustainable and resilient supply chain.

1.22 This dependence and impact on water resources overseas raises two, key inter-related questions for the UK food system. These are:

1. What are the supply chain risks to our food imports? And how big a problem do they present?
2. What is the impact on our food choices on overseas water security? And how big a problem is it?

1.23 The first question addresses the risk to the UK food supply system that may emerge from the impacts of our food demand on water overseas. How much of a risk does our virtual water use place on us? What might the risks be to security of supply and its impacts on the prices we may pay?

The second question addresses the same issues from the point of view of the regions from which we may import. What impacts might our demand have upon them at the producer, environmental and societal levels? Where (and when) may this be a particular issue and how may we identify it, and work to mitigate it, to allow the impacts to be sustainably managed? In the extreme, demands for food (and drink) that place unsustainable demands on local water availability may not only lead to local collapse in the production, but also destabilise local economies and societies.

1.24 **With respect to food production, the range of stakeholders includes water companies, growers, processors, retailers, consumers, governments, NGOs, extension services and policy-makers.**

Although the particular impacts that virtual water have in the food chain are both hidden and distant from the end consumer, these issues will more directly impact farmers, retailers and water companies both now and in the future. No single stakeholder in the food chain sees the totality of the connections between local food and water issues and their global and regional dimensions. Consequently part of the issue is to ensure all stakeholders are aware of the links between water and food, and bring new ideas into our individual and national food choices, in terms of consumption, abstraction and waste.

Supply chains are facing growing pressures

2.1 The supply and availability of food, especially in developed economies, is reliant on plentiful and relatively low direct-cost production. Historically, impacts from fluctuations in water supply on cost have been absorbed by the supply chains, resulting in little if any impact on prices and therefore on the consumer. Seasonal or daily effects of changing water availability are compensated by excess production ("insurance production") and by global logistics to source from different places.

2.2 The increasing demand for food is changing this situation. Farmers and growers have freedom to choose what they grow and some options are less vulnerable to weather - but this is widely acknowledged to be changing. In addition, governments are examining the uses that water is put to and assessing opportunity costs via a more holistic appreciation of overall sustainability. This is likely to create pricing issues of such a magnitude that they can no longer be absorbed into the supply chain, so the consumers' immunity from water related effects will struggle to be maintained. There is a need for UK food supplies to reflect the changing circumstances to ensure domestic and overseas sourcing is resilient to the ebb and flow of water supply and policy. In this section, different aspects of the risks and impacts of virtual water on food supply will be explored.

2.3 The growing global population is placing significantly greater pressure on the earth's freshwater resources. This growth will be concentrated in sub-Saharan Africa and parts of Asia[26]. At the same time, socio-economic development will enrich the BRICS countries (Brazil, Russia, India, China and South Africa), and allow them to purchase more water-intensive diets, such as more livestock products. Taken together, the outcome is likely to be a massively increased demand for fresh water in the BRICS and developing nations.

2.4 Climate and environmental change will alter water availability through both a gradual change in the average properties of weather and through its variability. Many studies of climate impacts assess the average change between two periods, and sometimes it is not clear to what extent variability around the mean may matter. Such assessments can therefore be misleading and omit important information, particularly with regard to extreme events and how they may be changing[27]. Climate variability interacts with other drivers of supply and demand for food in complex ways that can exacerbate its impact[28]. The Russian heatwave of 2010[29] and the subsequent rise in wheat prices, are one example of this. Coupled with the spatial variability of weather's impacts on yields, and the associated uncertainty in projecting impacts, this implies less stable and less predictable agricultural production[30]. Input costs (for land, water, fuel, labour etc.) are also likely to change over time, and vary spatially, with production system and with product.

2.5 The challenge for agriculture is therefore not just to adapt to the average change in crop growing conditions but also the vulnerability of crops to the increasing incidence of extreme weather events (such as very high temperatures, drought and extreme rainfall). Climate and technological change is also leading to shifts in the most productive locations for crops and livestock[31] and assessments of impacts on, and usage of, water need to take into account these continually evolving conditions.

2.6 The impact of these drivers on UK food imports is difficult to forecast. There are two key issues; firstly, climate and other environmental demographic and economic changes may impact on the average conditions in different places, making some areas less likely to be future sources of food; secondly, climate change may increasingly cause extreme weather events that affect the stability of supply and therefore the resilience of supply chains.

2.7 Considering first the evolution of the global market in the face of change, one (plausible) scenario is that the UK will become less attractive as a market to major global exporters. This will be the result of a combination of price pressure (to deliver food as cheaply as possible to the UK) and the strict EU market/product regulatory requirements (whether quality, safety or sustainability). There is the potential, as the buying power of other developed and the BRICS nations increases relative to the UK's, for exporters' profit margins to become less dependent on trade to the UK. This will potentially lead to those nations with fewer regulations becoming favoured. This is 'the ease of doing business with the EU' dilemma: if the UK (and EU) food chain requires more regulations from producers, and producers have other markets available, they will choose to supply elsewhere. Maintaining access to markets may require paying more. Given its economic status, the UK may still be able to import water-intensive products on the open market. But the competition to do so will increase and future water shortages on the farms producing these crops are likely to be reflected in the higher price that the UK will have to pay for those products. The impacts may be felt most by the poorer members of UK society whose ability to purchase fresh fruits and vegetables will diminish.

2.8 An alternative scenario sees environmental change causing decreasing water availability throughout many Asian and sub-Saharan countries and these countries subsequently reducing exports of food products to allow them to feed their own populations. The consequence for the UK market would be similar to the first scenario above. Therefore, in future the UK should expect either higher prices or restricted supplies of some products, or indeed both.

2.9 Secondly, considering resilience under shocks, the food sector today uses global supply chains to supply food to consumers and maintain access to a wide range of foods year-round. The impact of volatile water resources, be it through high-impact rain events, flooding, drought or over-abstraction, on companies

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in the food industry can be very significant. Widespread droughts, for example, can feed through very quickly into price increases even for globally produced and traded commodities such as soya. Where cultivation is geographically concentrated in one region there is, in worst case scenarios, the potential for supply chain disruption and also reduced on-shelf product availability.

2.10 The global reliance on international trade is exemplified by an analysis of data from a single fresh-produce importer with about £200m turnover; it sources over 150 lines from over 30,000 farms worldwide[32]. In a competitive market, subject to increasing supply-side shocks, ensuring a sustainable and resilient supply chain is of paramount importance for UK retailers. Supply chain resilience is typically managed via contingency planning and sourcing from a variety of geographical areas to ensure that there are substitute suppliers if spatially-localised shocks occur. This strategy, however, isn't directed towards supporting agriculture to adapt to climate change nor is it effective against the predicted widespread and global threats of extreme events and increased competition for water which will affect every country and region to some extent.

2.11 An increasing element of supply chain resilience involves ensuring its sustainability in a changing world. This involves both picking suppliers from locations where there are likely to be fewer resilience or sustainability issues (e.g. not sourcing water-rich products from areas that are increasingly water-scarce and where the supply-side risks are increasing) and working with suppliers to ensure that food producers are enhancing their sustainability in the face of increasing climate and market variations (e.g. by ensuring investment in resource-use efficiency, including water and managing soil carbon better to maintain functionality). Of course, part of the sustainability agenda also involves the social aspects of sustainability. This may include both welfare and wages, and increasingly, ensuring good nutrition for the workforce (e.g. the Global Nutrition for Growth Compact[33]); but also ensuring that a supplier's agricultural practice does not reduce the local environment for the resident population, by creating conflict over water quality or quantity.

2.12 One of the challenges for understanding the impacts of water use in overseas supply chains is the constantly changing landscape for trade and for access to water: changes in the weather will affect different locations in different ways at different times. These changes will have downstream effects, for example importing food produced in a drought is likely to have a greater impact on environmental and social sustainability than producing it in non-drought conditions.

2.13 As supply chains evolve in response to climate change and other pressures, current approaches to tracing and managing the risks associated with our demands for water overseas may fail. Methodologies that can be applied under variable and changing climates are needed, as opposed to methodologies that produce static maps and risk assessments.

2.14 Security of access to water, and competition for it amongst different stakeholder groups, is not the only issue about water that is affected by our agricultural imports. Diffuse pollution is pollution arising from land-use activities (urban and rural) that are dispersed across a catchment or sub-catchment[34] (see the report 'Agriculture's impacts on water quality') and includes nitrates and phosphates from the use of fertilisers and various inorganic chemical compounds from the use of pesticides. Symptoms include euthrophication of surface waters and toxicity of soils and water courses. The local impacts of diffuse pollution can be severe and include a reduction in the quality of drinking water, to the point of rendering it unsuitable for human consumption, and causing considerable land degradation to the degree where land cannot support crop production. However, evidence to support any direct impact on the supply of goods to the UK is very limited. The main risk would seem to be reputational damage to the brands as a result of NGOs raising awareness of the issue and any subsequent problems. The exception to this is where diffuse pollution has contaminated irrigation water with potentially lethal pathogens, e.g. *E. coli* which may affect food safety (see the report 'Agriculture's impacts on water quality').

Going beyond 'virtual water' to assess water use in supply chains

3.1 Having set the scene of why water embedded in food is important, and introduced the basic definitional and conceptual issues, in this, largely methodological section, we now address how to assess the risks that can come from water in the food chain. We ask whether the concept of virtual water, and the associated assessment of products' "water footprints", can identify the appropriate issues and guide us in addressing the key questions outlined in the introduction. We identify a need for more sophisticated assessment of production and supply-chain risks and then end this section by concluding that when risks are identified, an analysis of the technological needs is required. We illustrate this with reference to the fact that many see drip irrigation as the prime solution to increasing the efficiency of irrigated agriculture, despite it often being an inappropriate technology.

3.2 The term "water footprint" has been used to describe the virtual water used throughout the life-cycle of a product, process or population. The term was originally intended to account for the appropriation of natural resources (the "natural capital") used, in terms of the volume of water required to satisfy human consumption. Therefore, the water footprint of a consumer, business or nation was the sum of the water used in the products the person, business or nation consumed.

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3.3 Water footprinting involves quantifying the potential environmental impacts related to water[35] and it offers society a useful method to identify where and how risks related to water availability might arise in the chain of production and import. Since many people (wrongly) consider the UK to be self-sufficient in food and geographically well-placed in the wet and cool North Atlantic, it comes as a surprise to realise that we consume large amounts of water at home and overseas. Therefore in managing this and similar risks, two key and interrelated dimensions arise. One is measurement – how good or 'fit for purpose' are the virtual water and footprinting methods and how accurate are the results? The second is management – can we use footprinting to manage water consumption and therefore possible virtual water risks?

3.4 At an appropriate high level global and annual time-scale, virtual water offers a satisfactory method to quantify the UK's water consumption both within and external to its borders, and therefore a route to answer both questions posed in 3.3. However, it does not encompass the totality of the agriculture-water linkages beyond volumetric use. At a finer grained scale (micro and meso scale, and also at the seasonal, monthly and weekly time periods), assumptions made by the virtual water methodology become questionable. At any small scale, and at particular points in time, a favourable water footprint analysis on average may not relate at all to conditions related to consumption. For example, a product may have the same water consumption but can be produced by different farming systems (see Case study box 3). One may favour the use of rainfall (green water) in an area rich in water resources, the other blue water for irrigation abstracted from a water-stressed area. Water can also be used both consumptively and non-consumptively. In the case of the former, these also divide into other types such as beneficial and non-beneficial consumption. In the case of non-consumption, the act of withdrawal of water in productive systems can degrade water via pollutants or slow water down and attenuate water flows to neighbouring systems dependent on that recycled water. While these neighbourly effects are intricate and meaningful at the local scale they might not be detectable at the basin scale.

3.5 Water availability and quality is location and context dependent which lends itself well to the development of risk mapping, and provides an alternative methodology to virtual water for making strategic decisions about supply chains. Risk mapping involves a spatially explicit characterisation of risk, typically expressed as a map. The definition of risk, which in this context is a bit fuzzy, includes uncertainty in profits, danger of loss and also the chance of events in future that may threaten production. Thus, rather than the concept of a product having a fixed virtual water of X, wherever it is sourced from; the risk map concept implies a family of maps ("layers"), typically colour coded, highlighting issues across a range of potential

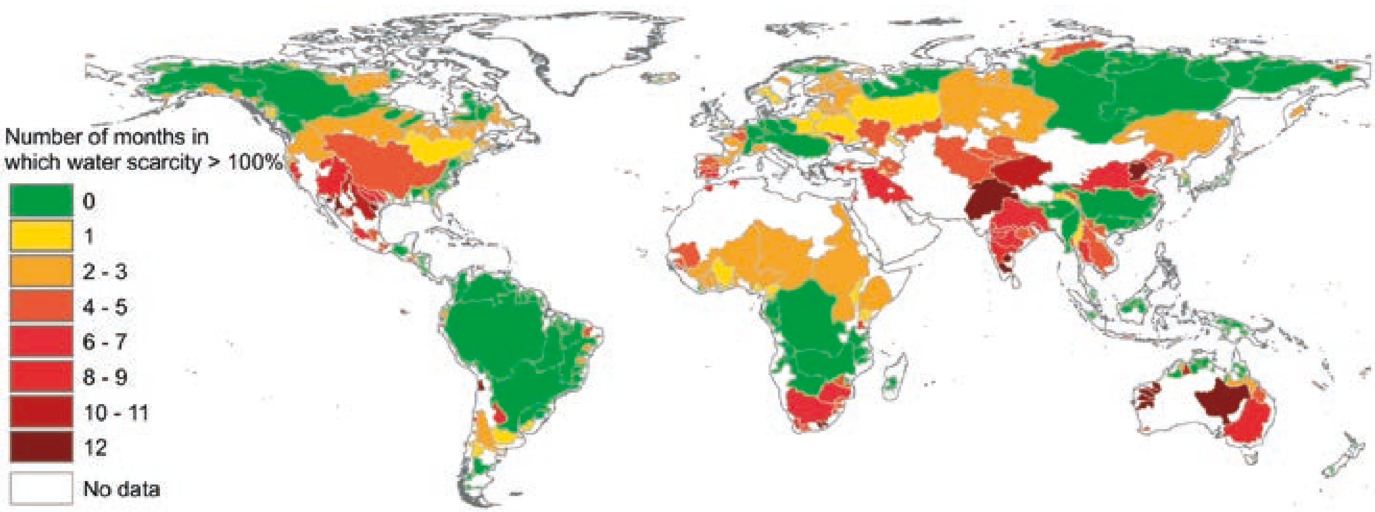

Figure 2. An example of a water risk map. The number of months during the year in which the blue water usage exceeds blue water availability for the world's major river basins, based on the period 1996-2005.[36]

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threats to production. These layers may include, *inter alia*, the requirement for water, the ability to access that water, the potential for environmental impact, climate risk (e.g. chance of drought), and elements of social risk such as workforce size or stability. This approach has the potential to provide spatially nuanced information that an estimate of virtual water fails to.

3.6 Maps typically illustrate a static estimate; whereas in reality the requirements for, access to, and risks associated with, water consumption are dynamically variable. The same water requirement in different years may have quite different impacts and therefore risks. The challenge is not to ignore the variability from year to year, or the fact that it may be dynamically changing (due to climate change or change in another environmental variable). Such variability can itself be portrayed as a risk that varies with space and therefore produced as a map.

Assessing technological potentials for reducing risks

3.7 Given that our demand for food has significant impacts on water resources overseas, it is desirable to reduce the impacts in order to build a more sustainable and resilient supply chain. The policies and technologies required to achieve this are many (see section "Addressing the issues" below) and it is important to ensure that the right ones are chosen. Poor choices can arise from incorrect theorising and reading of the underlying context and trajectory of technological change; limited finances; a lack of monitoring of the evidence of change; and the question of how to ascribe ownership to stakeholders of different types.

3.8 To illustrate this problem we use the example of drip irrigation technology. Drip irrigation is efficient at the field scale, but it is best utilised for perennial horticultural row crops such as citrus and vines; it is not appropriate for arable cropping and the production of annual crops such as cereals and soya. Drip irrigation attracts considerable policy attention as a means to make water use efficient. However, canal (gravity) irrigation is used on about 90% of global area of 320 million hectares of irrigated crops and its modernisation and technological development receives very little attention despite it being vital for billions of smallholders in Africa and Asia and for crops such as rice, sugarcane cotton, vegetables and fruit. Furthermore, the research science effort and funding on irrigation efficiency and productivity is almost negligible with the consequence that the current status of irrigation performance is very poorly quantified, nor is there an understanding of the potential for innovation in water use to improve efficiency in gravity irrigation systems, cropping systems and the knowledge transfer of this learning to growers via the extension services.

Addressing the issues

4.1 In the previous sections we have highlighted that in a world of increasing demand for water and food, attention must be paid to the need for resilience in supply chains based on their requirements for, and impact on, water availability in the production areas. Perhaps more thinking has been invested in understanding the land used for agricultural production for supply chains, whereas, especially with changing patterns of weather, water availability is perhaps of equal, or even greater, importance. In this section, we address what different actors can do to enhance the resilience of our supply chains, and the sustainability of food production systems.

Water in food policy

4.2 In this case, the term "policy" needs to encompass public policy, institutional policy and voluntary regulation. Institutional policy, such as the strategy developed by industry using non-regulated mechanisms is clearly a force for change. In between public and individual corporate policies is "voluntary regulation" which may be government encouraged, sector-level, policy that aims to bring change across a sector. Public policy is often seen as a last resort developed when markets are not properly working; there is reluctance, therefore, to regulate if there are other courses of action to avoid a "red tape burden".

4.3 The original focus of academic papers on virtual water was to understand the role of crops and water in the absolute advantage of countries producing and exporting water-intensive products[37]. It was based on the notion that water-scarce nations could ease pressure on their limited internal freshwater resources and achieve greater water security, by importing water-intensive products (rather than producing them using limited domestic supplies) whilst water-rich countries could stand to benefit from their natural resource endowments by exporting water intensive products. As such, trade in crops and its embedded virtual water is beneficial for importers and exporters[38]. Whether or not these factor endowment theories are realistic, they underline the point that food-exporting countries may take decisions to exploit their water resources for their own reasons and their current advantage.

4.4 As described above, water footprinting has been used to describe the virtual water used throughout the life-cycle of a product, process or population; and it has become a common proxy for the issues associated with water in food production. Proponents of water footprinting have suggested the need to regulate virtual water flows through global governance and the use of mechanisms such as allowable water footprints[39] or tradable water footprint permits[40]. However, there has been significant criticism of the suggestion that virtual water can contribute to water management at a sub-basin scale, or to trade policy, largely because volumetric virtual water estimates only consider the volume of water consumed and do not provide information about the details of water management, or the true economic and environmental costs of water use; and it largely ignores social relations and impacts on livelihoods[41,42,43].

4.5 Whilst virtual water approaches can be used to support national policy in a number of areas, there are only a few examples where it has led to improvements in water resource management or influencing public policy[44]. Below are some examples where this has taken place:

- **Water resources:** Virtual water has been used to inform water resource management plans. For example, analyses in Spain[45] have resulted in an economic assessment of water footprints that has been captured as part of government policy making. The Ministry for the Environment now requires the water footprint as a tool for the implementation of the River Basin Management Plans prescribed by the EU Water Framework Directive (WFD)[46]. In South Africa, virtual water has been used to support national policy objectives for the water sector in the Breede Catchment[47]. In India, the 2012 National Water Policy refers to water footprints in relation to demand management and water use efficiency[48].
- **Sustainable consumption and production:** Virtual water has been used to contribute to sustainable food consumption and production policies. When placed in context (green/blue, local scarcity) estimates of virtual water can help identify unsustainable "hotspots" and exposes how consumers in one country may be dependent on water exploitation and pollution in another. For this reason, the Dutch Government passed a resolution that aims for Dutch companies to present their water footprint and reduce this footprint in water scarce countries[49]. It also demonstrates a nation's vulnerability to global water scarcity risks. Both the European Commission[50] and UNEP[51] recognise that use of the water footprint can contribute to sustainable development.
- **Communication:** Virtual water can be useful to communicate sustainability to consumers. For example, The Waste and Resources Action Programme (WRAP) and the WWF have used virtual water (together with carbon footprinting) as a tool for raising awareness of the environmental impacts of food waste (WRAP & WWF UK, 2011).

4.6 Despite the criticisms of the way that water footprints can be mis-used, they are providing a tool that can be used to support policy decisions. More nuanced 'decision' or 'discussion support' is available from water risk maps, which can identify spatially specific issues associated with food production. Food importers and food retailers have already adopted these tools. Looking to the future, there could be a role for these tools in public policy, to regulate good stewardship and environmental compliance of the food which we import.

The role of the food chain

4.7 Retailers in the food chain are seeking to identify global water vulnerable areas to enable them to a) respond appropriately to current water issues within its existing supply chains and b) to inform their long-term planning for strategic future sourcing decisions.

4.8 In the absence of appropriate local governance, the private sector food-supply chain has the ability to promote water stewardship above and beyond any public requirements. The unique circumstances of each locality should determine the specific response. A variety of measures can be supported by the private sector from improved on-farm water management (e.g. storage/irrigation), to using more drought resilient crops, to projects supporting water management across the entire watershed. Abandoning an area of water vulnerability should be seen as an act of absolute last resort for the private sector due to the socio-economic impacts this would have and due to the wide range of potential mitigation options available. Furthermore, a genuine and holistic approach to sustainable sourcing requires long-term relationships within the private sector. Simple risk aversion and abandoning areas of supply is not suitable.

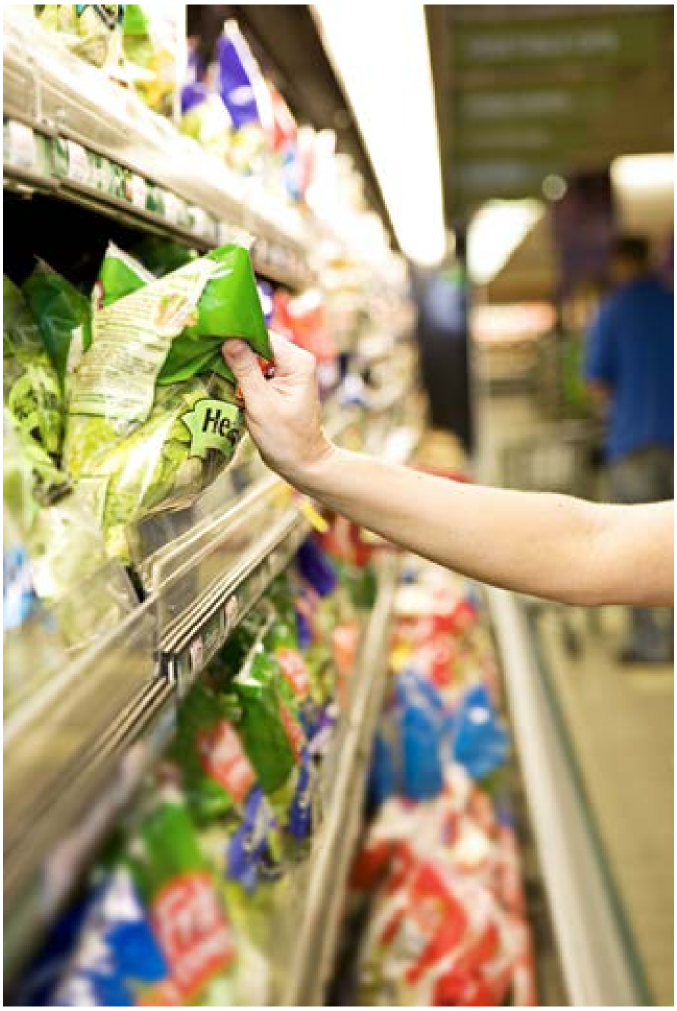
4.9 If the food chain actors work together, however, they can promote water stewardship with suppliers and also collaborate across entire catchments where solutions are required at this scale.

Food retailers

4.10 It is important first to consider the scale of the challenge that retailers face in addressing the water risks related to their products. A typical retailer will sell over 30,000 products with the raw materials originating from tens of thousands of farmers from across the globe. While some of the supply chains for these products will be short and transparent, others will be long and complex. Information relating to the exact water impact of a product and its local context, which will vary from farm to farm, is rarely collected. Water issues and specific impacts are generally unknown to the retailer. This information gap quite often inhibits direct action.

4.11 In order for a retailer to address water issues associated with their products they need to be able to identify water risks in their global supply chains and then prioritise action accordingly. The utility of using virtual water as a guide is limited as actual water risk is determined by the farm's individual agricultural practices and its specific local environmental and social circumstances. By contrast, risk mapping, which looks at the spatial and temporal distribution of water scarcity, water quality and other factors has greater potential to identify risks in global supply chains and guiding further work to investigate and address this.

4.12 Once areas of water vulnerability have been predicted, and these predictions validated on the ground, then a number of mitigation options are available and a tailored approach, appropriate to the specific local circumstances, can then be pursued by the retailer through their customer relationship with the farmer. It should be noted that the influence of one individual retailer will be determined by the relative size and importance of its commercial relationship to the farmer. Clearly, if a retailer is of marginal importance to a farmer then its influence will be limited impacting its ability to support improved stewardship. In addition, supporting on-farm water stewardship will not tackle systemic issues at the watershed level.



Food manufacturers

4.13 Food manufacturers are significant users of water in their own right during their production processes (e.g. sterilisation and cooling) and also indirectly through the materials that they source. Manufacturers, therefore, can tackle their immediate water impact (through efficiency improvements and water treatment) and support stewardship in their supply chains.

4.14 Food manufacturers have smaller product portfolios compared to retailers although they are often produced on a larger scale. They are also likely to have shorter supply chains although they will also source materials from complex supply chains; however, in general their product specialism and scale supports greater focus on key ingredients and sourcing areas.

4.15 Manufacturers, like retailers, use tools to identify specific water risks in their supply chain and to decide what appropriate mitigation options can be supported. Food manufacturers will also experience circumstances in which their influence is limited and where action is required at a greater scale across, e.g. river or basin catchment.

Farmers and growers

4.16 Farmers have similar issues to retailers and manufacturers, but at a different scale. Production and use of water is undertaken at farm or even field scale and risks tend to be assessed at these scales. While farmers are aware of, and are often receptive to, many water-use issues, their ability to manage water more efficiently is often constrained by their locality and therefore choice of crop or livestock system. In some places, where catchments or basins are known to be water stressed, farmers work in partnership across catchments using Water Abstraction Groups to make best use of the limited resource.

4.17 Governance and advisory systems are needed overseas to facilitate understanding of local issues. This should include the collection and interpretation of data on water quantity and quality at all appropriate scales (from farm to catchment) as all too often there is a lack of understanding between farmers, environmentalists and regulators on the appropriate uses of water to support societal requirements.

Encouraging a strategic basin approach

4.18 The governance of water resources involves multiple stakeholders so strategies for improvement need to be identified that are both holistic and yet focussed. One such approach can be found when water is managed via the river basin employing integrated and adaptive principles and actions. Following the 1992 Dublin Conference on water management, integrated water resources management (IWRM) developed basin level tools to manage the constraints and opportunities in water and land. Although IWRM receives criticism for various failings such as adopting formal regulatory procedures while ignoring local and informal legal frameworks, the river catchment (basin) remains a sensible unit of management. Recognising that the majority of consumed water is accounted for by agriculture, basin managers resolve allocation issues through a number of supply and demand interventions including dialogue and discussion with the many stakeholders engaged in food production. Following on, one pragmatic way that the impact of Britain's food imports could be managed is via policies that support the river basin approach.

Where are the knowledge gaps?

4.19 In order to identify the risks that water poses in our overseas supply chain (both in terms of managing our supply chain risk and the producers' local risks), the following key issues have been identified. Some are fundamental gaps in our knowledge, others concern how best to use our knowledge.

- Our understanding of water resources, water availability and risks to food production in exporter countries at a fine spatial scale (i.e. sub catchment) is poor. More information is required on the impacts of climate and environmental change and extreme events on water resources, that is spatially resolved enough to be useful for local water management decisions. Currently there is a gap in the fundamental and strategic research surrounding suitable/ sustainable abstraction levels.
- There is a lack of understanding regarding the direct and indirect social effects of abstraction, and that, coupled with the biophysical issues, means it is difficult to rigorously yet easily identify environmental/ physical and social "hotspots" of risk. This prevents retailers and manufacturers from taking strategic sourcing decisions.
- Currently few tools exist to determine the risks/ rewards involved in water management and to link these back to the producers. There is a need to identify and develop risk

tools (i.e. risk mapping, hot spotting, multi-dimensional risk analysis).

- When the risk has been identified, there is still uncertainty of how best it should be managed. To ensure long-term resilience and sustainability, a problem-led, action orientated, multi-partnership approach to local water management is needed in addition to actions by retailer/manufacturers. Greater understanding of local governance is required to ensure that risk mapping is translated into solutions for sustainable management of water resources. As part of this translation of knowledge into use, careful consideration should be given to dissemination and implementation.
- Retailers and manufacturers need to weight their priorities as addressing water issues and brand management may have different outcomes. Consideration also needs to be given as to how water management aligns with other aspects of sustainability in the broad sense (such as carbon management, biodiversity management).
- Partnerships are needed at the local scale (i.e. farmers, retailers, water companies, extension services, advisors, crop input suppliers, livestock businesses, NGOs, Governments etc.), to improve local management practices and improve data collection for the common good (e.g. local farms working together, via sharing data and water access). Furthermore, if some supply chains are at risk due to water issues, how can manufacturers and retailers engage consumers to manage demand realistically, without it affecting business (in other words, turn water stewardship overseas into a positive attribute of what is available in store)?

4.20 The UK's role in partnering with overseas nations and growers in the science and production of agricultural goods has reduced over the last fifty years, and this knowledge/ research platform needs to be rebuilt. In previous decades, the UK often provided funds for UK agriculturalists and engineers to work abroad, particularly in the developing world, to help develop systems of crop production creating much co-learning between stakeholders. However, alongside the decline in donor funding for irrigation and agriculture programmes in the last 25 years, opportunities to work alongside such national scientists have diminished greatly. In this regard, the UK's Agri-Tech strategies' international dimension is welcomed. There is perhaps a role for UK funders to re-energise its engagement with the "international agricultural water and land use" science and make a greater contribution to the research and science agenda now facing food producers and extension services at the global and local scales.

Conclusions and key findings

5.1 In this report, the issues of water use in the production of our food imports are reviewed. To summarise:

- The UK is not self-sufficient in food, over 40% of the UK's demand for food is imported, and consequently the impact on water use is overseas. The overall aim is of this report is to highlight the vulnerability of UK food supply in relation to overseas water use in agriculture and to bring clarity to this discussion, especially through a discussion of the suitability of "virtual water" assessments to guide the management of water demands for food production in the overseas food chain. In particular, this report encourages the UK to understand, and account for, the impact of food imports/exports on the water security of drought prone countries.
- Whilst the virtual water concept has utility to provide an overview, particularly at large scales, it is a problematic approach to guide strategic decisions about supply chain resilience decisions. Mapping a variety of risks explicitly appropriate to location is seen as a more fruitful approach.
- Retailers (as food importers) need to be able to make supply-chain decisions for a multitude of different foods and therefore need more sophisticated risk mapping data for foods where there is a high water usage (e.g. fresh fruits and salads).
- Catchment management systems with the ability to monitor and collect data around water use and impacts on quality should be encouraged. Farmers should work in partnership across catchments to adopt best management practices.

Key findings

5.2 Key findings from this report are outlined below:

1. The concept of "virtual water" is insufficient. There is high demand for tools to identify the risks associated with food imports and their strategic importance for the supply chain, which need to be both spatially and temporally highly resolved.
2. A more integrated understanding of water use and the risks to food production will arise through working in partnerships (across academia and the food chain).
3. Governance and advisory systems and structures should facilitate better management of food and its impacts on water both in the UK and abroad.
4. Catchment management systems with the ability to monitor and collect data around water use and impacts on water quality should be encouraged overseas by UK actors. Farmers, extension services and advisors should work in partnership across catchments to avoid local gains in best practice being eroded by other suppliers exploiting resources unsustainably.
5. Public and private policies should be developed that integrate across global food production and its impacts on water (and the broader environment) allowing assessment from local to global scales.
6. Teaching and research of agricultural systems and extension services from a land, water and livelihoods point of view should be further developed, promoted and embedded in stakeholder communities. In turn these should aim to better understand and quantify the complex productivities and efficiencies of rain fed and irrigated farming at the local field, basin, regional and global scales.
7. In future UK funders should facilitate greater engagement with "international agricultural water and land use" to underpin decision making for sustainable and resilient production both from the UK food chain and the exporting countries' water security perspectives.

References

1. Defra. (2013). Food statistics pocketbook.
2. UN. (2012). World Population Prospects.
3. ISO 14046. (2014). Environmental management — Water footprint — Principles, requirements and guidelines.
4. Defra. (2011). Water Usage in Agriculture and Horticulture. Results from the Farm Business Survey 2009/10 and the Irrigation Survey 2010. http://webarchive.nationalarchives.gov.uk/20130123162956/www.defra.gov.uk/statistics/files/defra-stats-foodfarm-farmmanage-fbs-waterusage20110609.pdf.
5. Hess, T.M., Andersson, U., Mena, C. and Williams, A. (2014). The impact of healthier dietary scenarios on the global blue water scarcity footprint of food consumption in the UK. *Food Policy*.
6. Williams, A., Hess, T.M., Chatterton, J. and Daccache, A. (2013). Are potatoes a low-impact food for GB consumers compared with rice and pasta? *Potato Council Limited*.
7. Hess, T.M., Chatterton, J. and Williams, A. (2012). The Water Footprint of Irish Meat and Dairy Products. *Bord Bia*.
8 Chapagain, A.K., Orr, S. (2009). An improved water footprint methodology linking global consumption to local water resources: A case of Spanish tomatoes. *Journal of Environmental Management*, 90, (2), 1219-1228.
9. Defra. (2013). Food statistics pocketbook.
10. The focus of the report is agriculture's use of water. Clearly, processing food (including washing) has significant water requirements, but these are out of our scope.
11. FAO. (2003). World agriculture: towards 2015/2030 an FAO perspective.
12. Tilman, D., Balzer, C., Hill, J., Befort, B. (2012). Global food demand and the sustainable intensification of agriculture.
13. Challinor, A., Watson, J., Lobell, D., Howden, S., Smith, D., Chhetri, N. (2014). A meta-analysis of crop yield under climate change and adaptation. *Nature Climate Change* 4, 287-291.
14. Environment, Food and Rural Affairs Committee. (2014). Food Security. Second Report of Session 2014–15
15. Allan, J.A. (1998). Virtual water. A strategic resource global solutions to regional deficits. *Ground Water*, 36: 4, 545-546.
16. Zeitoun, M., Allan, J.A., Mohieldeen, Y. (2010). Virtual water 'flows' of the Nile Basin, 1998–2004: A first approximation and implications for water security. *Global Environtal Change* 20, 229-242.
17. M Erksay-Ravasz et al. (2012). Complexity of the international agri-food chain and its effects on food safety. *Plos One* 7:e37810.
18 Ridoutt, B.G. and Pfister, S. (2009). A revised approach to water footprinting to make transparent the impacts of consumption and production on freshwater scarcity, *Global Environmental Change*, 20: 113–120.
19. Hoekstra, A.Y., Chapagain, A.K., Aldaya, M.M. and Mekonnen, M.M. (2011). The water footprint assessment manual, setting the global standard. www.waterfootprint.org/downloads/TheWaterFootprintAssessmentManual.pdf .
20. Ridoutt, B.G. and Pfister, S. (2009). A revised approach to water footprinting to make transparent the impacts of consumption and production on freshwater scarcity, *Global Environmental Change*, 20: 113–120.
21. Defra. (2012). Food Statistics Pocketbook.
22. Chapagain, A. K and S. Orr. (2008). UK Water Footprint: The impact of the UKs food and fibre consumption on global water resources. Volume one, *WWF UK, Godalming, UK*.
23. To put 3400 litres per capita per day of water in context: an Olympic swimming pool would be used up in 2 years and 5 days if it were supplying a single person.
24. Yu, Y., Hubacek, K., Feng, K. and Guan, D. (2010). Assessing regional and global water footprints for the UK, *Ecological Economics*, 69, 5, 1140-1147.
25. Hess, T.M., Andersson, U., Mena, C. and Williams, A. (2015). The impact of healthier dietary scenarios on the global blue water scarcity footprint of food consumption in the UK. *Food Policy*. 666-674.
26. UN (2012). UN World Population Prospects.
27. IPCC (2012). Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. *A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change* [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L.Ebi, M.D. Mastrandrea, K.J.Mach, G.K. Plattner, S.K.Allen, M. Tignor, and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, UK and New York NY, USA, 582 pp.
28. Benton, T. and Food Research Partnership. (2014). Severe weather and UK food chain resilience.
29. Otto, F., Massey, N., Oldenborgh, G., Jones, R., Allen, M. (2012). Reconciling two approaches to attribution of the 2010 Russian heat wave. *Geophysical Research Letters* 39, 4.

30. Challinor, A., Watson, J., Lobell, D., Howden, S., Smith, D., Chhetri, N. (2014). A meta-analysis of crop yield under climate change and adaptation. *Nature Climate Change* 4, 287-291.
31. www.card.iastate.edu/books/shifting_patterns/pdfs/shifting_patterns_book.pdf
32. Business confidential personal communication.
33. www.gov.uk/government/uploads/system/uploads/attachment_data/file/248760/Endorserscompact_update7_10_2013.pdf
34. The current definition in international standard use is based on the CIWEM definition (2000), and refined by Novotny (2003).
35. ISO 14046. (2014). Environmental management – Water footprint – Principles, requirements and guidelines.
36. Hoekstra, A.Y, Mekonnen, M.M., Chapagain, A.K., Mathews, R.E., Richter, B.D. (2012). Global Monthly Water Scarcity: Blue Water Footprints versus Blue Water Availability. *PLOS One*.
37. Allan, J.A. (1998). Virtual water. A strategic resource global solutions to regional deficits. *Ground Water*, 36, 4, 545–546.
38. Gawel, E. and Bernsen, K. (2011). Do we really need a water footprint? GAIA 20/3 (2011): 162-167.
39. A number of the examples quoted refer to 'water footprint', but as these are volumetric (and are not related to impact) they are analogous to virtual water.
40. Hoekstra, A.Y. (2006). The global dimension of water governance: Nine reasons for global arrangements in order to cope with local water problems, *Value of Water Research Report* Series No.20, UNESCO-IHE.
41. Gawel, E. and Bernsen, K. (2011). Do we really need a water footprint? GAIA 20/3 (2011): 162-167.
42. Wichelns, D. (2010). Virtual water and water footprints offer limited insight regarding important policy questions. *International Journal of Water Resources Development*, 26, 4, 639-651.
43. Witmer, M.C.H. and Cleij, P. (2012). Water footprint: Useful for sustainability policies? PBL Note 500007001. PBL Netherlands Environmental Assessment Agency.
44. Chapagain, A.K. and Tickner, D. (2012). Water footprint: Help or hindrance? *Water Alternatives* 5, 3, 563-581.
45. Aldaya, M.M., and Llamas, M.R. (2009). Water Footprint Analysis for the Guadiana River Basin. *Value of Water Research Report Series No. 35*. Netherlands: UNESCO-IHE.
46. Aldaya, M.M., Martínez-Santos, P., Llamas, M.R. (2010). Incorporating the water footprint and virtual water into policy: Reflections from the Mancha Occidental region, Spain. *Water Resources Management*, 24, 5, 941-958.
47. Pegasys. (2010). Water Footprint Analysis for the Breede Catchment, South Africa. Report prepared by Pegasys for the Catchment Management Agency, Breede Overberg, South Africa.
http://bocma.co.za/docs/2010/BreedeWMA_Water FootprintReport_Aug10.pdf.
48. Government of India. Ministry of Water Resources. National Water Policy. (2012).
http://mowr.gov.in/writereaddata/linkimages/NWP2012Eng6495132651.pdf.
49. Motion by Members of the Dutch House of Representatives Hachchi and Ferrier. 5th April 2012.
50. European Resource Efficiency Platform. (2012). Manifesto and Policy Recommendations.
51. IISD. (2014). Sustainable Consumption and Production (SCP): Targets and Indicators and the SDGs.

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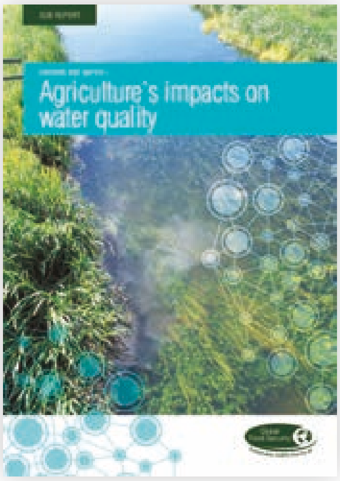

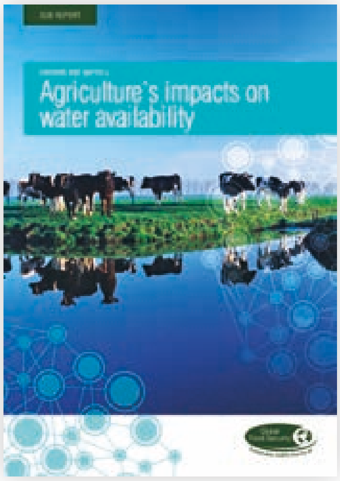

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