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Water for Food Security

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This review is one of a series of Reviews Of Current Knowledge (RoCKs) produced by the FWR. They focus on topics related to the water environment and ecosystem services, water resources and quality, and sustainable wastewater management. The objective of each review is to produce concise, independent scientific and technical information on the subject to facilitate a wider understanding of the issues involved and to promote informed opinion.

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1. Introduction

Water and food are inextricably linked, as significant quantities of water are required to produce our food. Water is fundamental to agricultural production: crops require water to grow, livestock require water for drinking and hygiene, and farms need water for operations and processing. Inland fisheries and aquaculture cannot exist without freshwater. The water consumed in food production is either sourced directly from precipitation or from soil moisture (green water), or by abstracting from aquifers, streams and lakes (blue water).

Agriculture and food production are not necessarily the same thing. Large areas of the world are devoted to agriculture, growing crops such as cotton, or crops which are used to produce fuel or other non-edible products (biodiesel, palm oil). As demand for food to feed the growing world population increases, so does the emerging conflict between crops for food and crops for other purposes. This ROCK introduces and explains some of the main aspects of the water and food relationship.

Population and food

Since the 1950s the world's population has more than doubled, reaching 8.2 billion in 2024, and predicted to peak around 10.2 billion in 2084 (Ritchie, Rodés-Guirao and Roser, 2024). In response, food output also doubled, but the amount of land given over to cultivation increased by just 13 percent. This was made possible with more intensive farming and doubling the amount of land that is irrigated. This response is commonly referred to as the “Green Revolution”. New technologies, new high-yielding crop varieties, and the widespread use of inorganic fertilisers and irrigation – backed by powerful state-driven strategies to increase food gains – transformed the agricultural sector (Lundqvist *et al.*, 2008). In particular, this was the catalyst for many Asian countries to transform from agrarian to industrialising economies (FAO, 2011a).

Around the world, 1.5 billion hectares of land are dedicated to cultivated agriculture (12 percent of the total land area). That is about the same as 1.5 billion international rugby pitches all being used for cultivated farming. More than twice this amount of land is managed pastureland for livestock (FAO, 2011b).

Providing food and water for 8 billion people is already an incredibly difficult challenge, and expected population growth by 2080 may leave another 2 billion people needing food. Almost all of that growth will be in the developing world, and as standards of living rise and the trend towards people living in urban areas increases, food requirements in the developing world could double (FAO, 2011a). In particular, demand for meat is expected to rise significantly. The United Nations Food and Agricultural Organisation (FAO) estimates up to 70 percent more food will be needed: an extra 200 million tonnes of livestock products and one billion tonnes of cereals will be needed every year (much of the extra cereals will be used as animal feed). Already, about 40 percent of all cereals grown are used to feed animals to produce milk, cheese and meat (Lundqvist *et al.*, 2008).

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Food and water

Globally, agriculture is by far the biggest user of water. Around 70 percent of all water abstracted is used to irrigate crops, *in addition* to rainfed agriculture. Some of these crops directly support food supplies and others are used as animal feeds to support livestock products. The rest are non-food based – for example cotton, or crops used to produce biofuels, or other industrial ingredients (e.g. palm oil).

The demand for extra food is going to place a considerable extra stress on the world's freshwater resources. Water in sufficient quantity and of adequate quality will have to be secured, but there is very little scope to further increase the amount of cropland, and there are no 'new' sources of water (SIWI, 2012). Maximising the amount of 'crop per drop' of water will be essential (Chapter 5 has more information on strategies that could achieve this). The irony is that this growth in demand will largely be in the areas where water is often at its most scarce.

Box 1 Water Scarcity

- Every continent contains areas where water is scarce;
- If the amount of renewable water in a country is below 1,700 m³ per person per year, that country is said to be experiencing water stress; below 1,000 m³ it is said to be experiencing water scarcity; and where each person has access to less than 500 m³ of renewable water they are experiencing absolute water scarcity (Falkenmark *et al.*, 1989);
- 40 percent of the world's population (one in three people on every continent) are affected by water scarcity (WHO, online) and this could rise to over 60 percent by 2025;
- 1.6 billion people are already living in regions with absolute water scarcity, and this could rise to 1.8 billion people by 2025; and
- Over consumption of water for food production is the main factor behind water scarcity.

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Food waste is another important aspect in the relationship between demand for food and demand for water. Around 33% of food globally is wasted and cutting this offers a reduction in the additional global future food needs (UN Environment Programme, 2024). Food is lost due to poor storage and transport, but it is also wasted, particularly in developed countries, due to shopping and kitchen habits, both domestic and commercial. It is estimated that a 50 percent reduction in food waste at the global level would save around 1350km³ (1.3 billion litres) of water per year.

Box 2

Water Measurement Units

- 1 hectare (ha) - 10,000m² (about the same size as an international rugby pitch);
- 1m³ – cubic metre (1000 litres);
- 1Km³ – cubic kilometre: 1000m³; 1,000,000 litres (also known as a Megalitre - Ml);
- 1Mm³ - million cubic metres (1,000,000,000 litres);
- 1 Gm³ – cubic gigametre: thousand million cubic metres; a billion cubic metres (1,000,000,000,000 litres);
- The volume of Lake Windermere (north basin)¹ is about 21,500m³ (21.5 million litres); and
- Lake Victoria holds approximately 2,760.00 km³ 2,760,000,000 litres (2.7 billion litres).

¹[http://www.windermerylakes.co.uk/default.asp?textpage=Windermere South Basin and Windermere North Basin](http://www.windermerylakes.co.uk/default.asp?textpage=Windermere_South_Basin_and_Windermere_North_Basin)

2. Relationship between agriculture and water

The relationship between food and water is an ancient one. Water has been used for agricultural purposes for several millennia (Strosser *et al.*, 1999) but the relationship is changing due to pressure to produce more food with less water. Water for food is now a core environmental issue. Significant proportions of the world's land area are devoted to agriculture, making agricultural practices fundamental to environmental management, including how water is used and managed.

Figure 2.1 illustrates the main elements of the agriculture-water ('agri-water') cycle. Water inputs include rainfall, direct abstractions from surface and groundwaters (e.g. rivers, lakes, and aquifers), and municipal mains water supplies. Water that makes its way into waterbodies, e.g. rivers, lakes, and aquifers, is often referred to as 'blue water'. The portion that is retained within the soil profile, or within vegetation is 'green water'. Water that has been used is sometimes called 'grey water', e.g. used wash water. 'Grey water' is also an important term in water footprinting where it refers to pollution, and is defined as the volume of freshwater that is required to assimilate the load of pollutants given natural background concentrations and existing ambient water quality standards (Water Footprint Network, 2011).

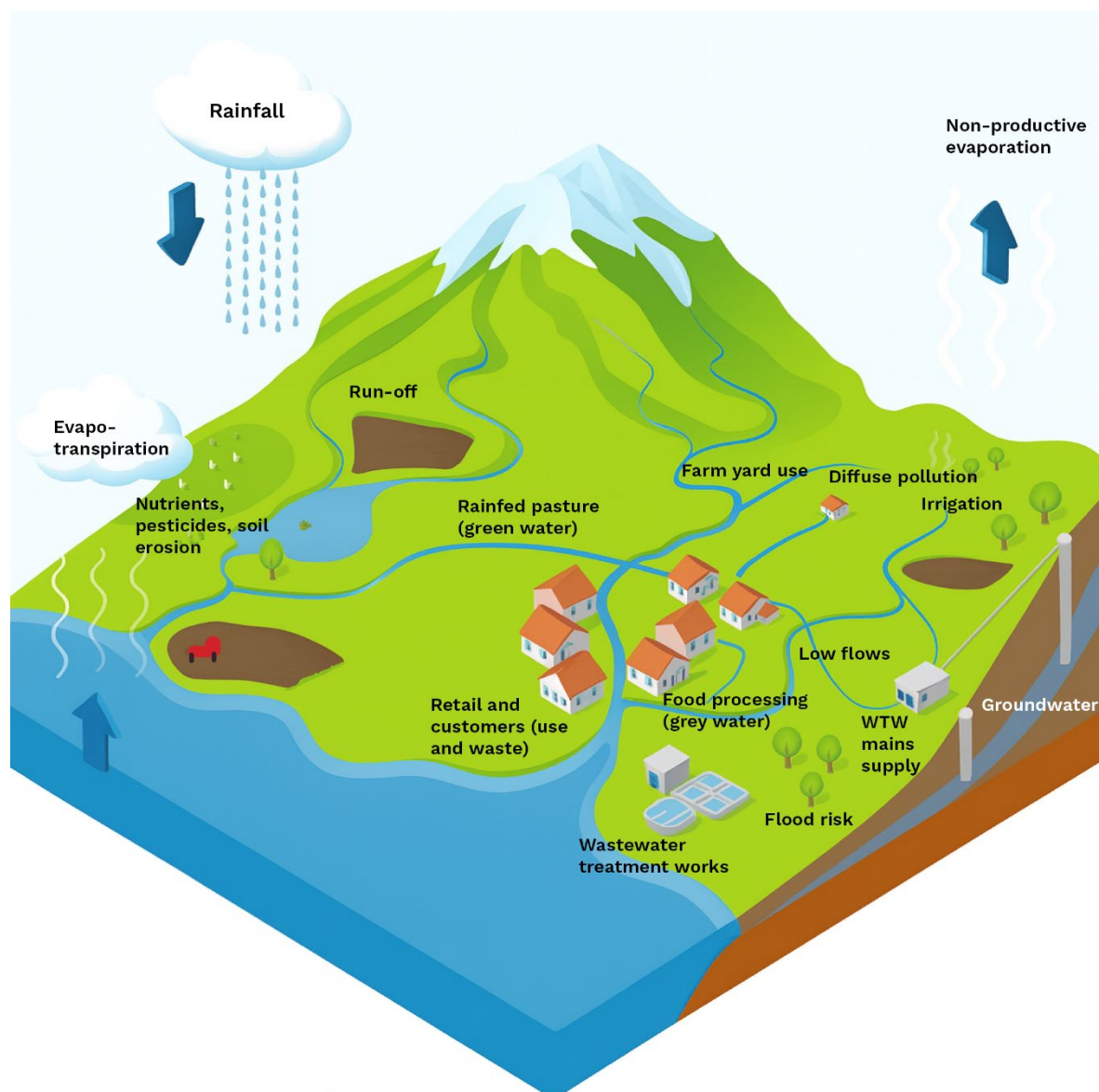


Figure 2.1. The agri-water cycle

Land use affects how water moves and flows across and through land. As it passes through cultivated and pastureland, water also transfers sediments, nutrients, and other agricultural elements (e.g. pesticides) along with other pollutants from the land into the water environment. Water is used by agriculture when producing food, mostly through the process of evapo-transpiration which enables plants to convert water and other elements into plant material. Plants need water to photosynthesise, help regulate temperature, and maintain turgor pressure which supports the shape and rigidity of their cells. It is also used by livestock as drinking water and used on farms for cooling and cleaning purposes. Further down the food supply chain, significant volumes of water are used in food manufacturing.

Not all of the water that enters the agri-water cycle is productive. Some of it is lost without contributing to crop growth (e.g.: non-productive evaporation or run-off from poorly managed irrigation). Only about 30 percent of the incoming precipitation is available for productive transpiration, but this varies around the

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world (higher proportions of productive transpiration occur in temperate regions).

Food production is limited by water availability and there are two main ways to access water. The vast majority of agricultural land (80 percent) is rainfed; most of this is pastureland or in humid regions. Unsurprisingly 90 percent of all the water used by agriculture comes directly from rainfall. Despite this only 60 percent of the annual food stocks comes from rainfed agriculture (FAO, 2011a). Rainfed agriculture is highly vulnerable to weather patterns (and climate change) and tends to be less productive than irrigated land. The rest of our food is sourced from farms that abstract water to irrigate crops (the remaining 10 percent of water used in agriculture). Only 20 percent of agricultural land is cultivated but produces 40 percent of food output. Around 80% of global rainfall falls straight into the sea; the remaining 20% falls on land. Of this, 16% is used by agriculture. 90% of water used by agriculture is ‘green water’ – rainfed. A further 10% is ‘blue water’ – irrigation.

Irrigation is clearly a highly significant, albeit smaller, proportion of total water used in agriculture. However, it is easier to understand the significance of irrigation on water resources by comparing how abstraction for agriculture compares to abstraction for all other purposes. **On a global scale, agricultural irrigation accounts for 70 percent of freshwater withdrawals** (UNESCO, 2003).

Use versus consumption

Referring to the volume of water ‘used’ by agriculture can be misleading. Some water used is ‘consumed’ i.e. it is effectively removed from the local water environment and is no longer available for re-use or re-circulation. Consumptive uses include evapo-transpiration and water embedded within agricultural products, e.g. milk and crops. In the UK, most water that is abstracted for irrigation is considered to be ‘consumptive’ although elsewhere this is not always the case. Irrigation is not always planned and used efficiently; more water may be supplied than is needed by the crops and can end up as run-off rather than evapo-transpiring. Water is also said to be consumed if it is lost (as far as the environment is concerned) due to pollution (i.e. ‘grey water’), for example when contaminated by pesticides or degraded during crop washing. Generally, water resources in areas downstream of consumptive use are negatively impacted, especially where water is scarce (Lundqvist *et al.*, 2008).

Non-consumptive uses are defined as a use of abstracted water which is returned to the immediate environment from where it came, with the water requiring little or no wastewater treatment, e.g. fish farms, cress ponds (aquaculture). Aquaculture is the fastest growing food-producing sector. Inland fisheries and aquaculture are often considered not to consume water, but do require a certain quantity and quality of water in rivers, wetlands, lakes, and estuaries (FAO, 2012). However, there is increasing concern about nutrient and parasite contamination of water by industrial-scale aquaculture, most notably in the Scottish farmed salmon industry. The volume of water that is required to produce food varies depending on the type of food, farming practices and location. These are covered in the following chapters.

Land-use and water

Modern agriculture impacts on the natural water cycle in several ways. Since the onset of agriculture 8000 years ago the global landscape has changed dramatically; primarily extensive areas of forest and woodlands have been replaced by managed pastureland and large-scale intensively farmed cultivated land. These types of land use have very different properties when it comes to how water moves through the water cycle. The main issues for the agri-water cycle relate to how the existing agricultural land is managed. Considering the vast areas of land that are managed by the agricultural sector, agricultural management practices can exert a significant influence on the water environment.

Effective land and soil management can capture much of the rainwater and avoid surface run-off that causes erosion and the loss of soil nutrients. It can also support groundwater recharge by slowing down run-off rates whilst performing a water purification role. Good management includes effective crop rotation, installation of hedgerows to protect soils from wind (aeolian) erosion, installation of 'buffer strips' for the capture of sediment and nutrients in run-off – to prevent them from entering rivers and streams – and managing livestock to protect riverbanks from erosion and animal waste. From a crop production perspective, managing water is about maintaining soil conditions that are optimal for crop growth via irrigation, drainage and water conservation.

Conversely, poor agricultural practices can create problems for farming and the water environment:

- **Excessive abstraction** can divert water from supporting ecosystems (OECD, 2010);
- **Irrigation infrastructure** along riverbanks can affect fragile ecosystems, including wetlands;
- **Tilling cultivation** disturbs the soil surface exposing more soil to evaporation and erosion. It can also create compaction leading to highly impermeable layers, exacerbating water loss;
- **Poor drainage** and run-off, often caused by compaction from machinery transit or livestock poaching, can cause valuable soil material and nutrients to be lost; and
- **Pollution:** Excessive application of pesticides and organic and inorganic fertilisers can have a direct impact on water quality and affect people's health. There is also some evidence that nitrogen salt fertilisers may negatively impact beneficial exchanges between crop plants and the active soil biology, leading to declining soil structure which further restricts soil water availability and drainage.
- **Overstocking of livestock**

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Pesticides, herbicides, nitrates and phosphates are often spread over wide areas. They are highly soluble so it can be very difficult to isolate, measure, and control their transfer into the water environment where they have a major impact on the water environment.

Phosphates are a soluble form of phosphorus and come from livestock effluents and mineral fertilisers. On the land these are important for plant growth, but in water they continue to stimulate algae and other plant growth and can lead to eutrophication within rivers, lakes and coastal waters. Ultimately this depletes oxygen levels and significantly reduces water quality. Water quality problems arising from pesticides (e.g. weedkillers such as Atrazine) are generally seasonal, reflecting the seasonal use of the products.

Water Footprinting

Water Footprinting is a concept that was introduced in 2003 by Professor Arjen Hoekstra of the University of Twente (Netherlands) to help measure our total demand for water (direct and indirect) in the products we use and consume (FAO, 2012).

Traditionally, water use to produce food has been measured purely as direct water abstraction. This approach underestimates total water use and makes no assessment of the impacts. A water footprint (WWF, 2008) measures all the direct and indirect water ('virtual water') used to produce a product. It is usually true to say that the direct water use of a product is small compared to the indirect water use of the supply chain. There is currently no standard accredited approach to calculating a water footprint. The concept and methodology is evolving and research is being advanced, promoted and coordinated by the Water Footprint Network (<http://www.waterfootprint.org>) and also by ISO project 14046.

A water footprint (m^3/ton) considers the total freshwater volume required across all stages in the production chain, direct (e.g. water taken from the tap) and indirect (e.g. the water use required to produce all inputs into the production process, measured where these inputs were produced). Water use is measured in terms of water volumes consumed (e.g. evapo-transpired) or polluted (e.g. effluent requiring treatment, or pesticides in water courses) and as such a water footprint can be broken down into three components: the blue, green, and grey water footprint:

- The blue water footprint is defined as the volume of freshwater evaporated from global water resources e.g. rivers, lakes, and groundwater used to produce a product;
- The green water footprint is defined as the volume of water stored in the soil from rainfall that is evaporated to produce a product; and,
- The grey water footprint is the volume of water that is required to dilute pollutants to an extent that the quality of the discharged water is above the agreed water quality standards.

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A water footprint on its own quantifies use, taking into account temporal considerations of water use and spatial variability, but it does not measure impact, and it does not enable comparisons of environmental, social, or economic impacts to be made between different locations. Work is ongoing to continue to improve the method and its application. Ridoutt and Pfister (2009) present a revised water footprint approach to incorporate a water stress characterisation factor.

Understanding footprints may enable business to target water use hotspots within the food supply chain, mitigate against water risks, and enable customers to make informed decisions about the sustainability of their food choices. However, some argue that current water footprinting methodology is compromised by ignoring the counterfactual that converting land from forest to crop production generally reduces evaporative loss significantly (Mulligan, 2022).

3. Water and food production: a UK perspective

The UK is only 38% self-sufficient in water given a total water footprint of 102 Gm³/year, and 73 percent of this (75 Gm³/year) is driven by demand for agricultural products (61% of which are imported including non-food products such as cotton) (WWF, 2008).

Of the water resources available within England and Wales, they are becoming increasingly stressed in many areas, with a recurrent imbalance arising from an overuse of water resources caused by consumption being significantly higher than water availability. As such, there is not always enough water available for the environmental requirements and of all other users. Similarly, water quality in many water bodies is failing, or is at risk of failing, the standards set by the UK Water Framework Directive. Also, the costs of water quality treatment at the treatment works are high; some water quality issues cannot feasibly be treated, resulting in further loss of water available.

Agricultural water users are increasingly concerned about the quantity of water that is or is forecast to be available to them, as demands for water become increasingly more competitive whilst climate change creates uncertainty and unpredictable water availability.

3.1 Agricultural activity in the UK

According to Defra (Defra, 2023) agriculture occupies over 70 percent of land in the UK, approximately 17 million hectares. The majority of this (64 percent of agricultural land) 10.9 million hectares, is pastureland for grazing livestock. 6.1 million hectares (36 percent of agricultural land) is given over to arable farming. In terms of output, arable farming is dominated by 20.9 million tonnes per year of cereal crops (two-thirds of which is wheat and one third barley). Oilseeds, potatoes, peas and beans, sugar beet, and horticultural crops combined generate the remaining arable output. The most valuable crops are those within the horticultural sector that occupy the smallest areas of land. 6 percent of agricultural land consists of other types of land holding, e.g. woodland (Figure 3.1).

Livestock produce around 14.9 billion litres of milk per year, over 1.9 million tonnes of poultry meat, 904 thousand tonnes of cattle, 887 thousand tonnes of swine, and 296 thousand tonnes of sheep and lamb. As a whole, over 20 million tonnes of cereals are harvested per year. At over 13 million tonnes, wheat is the single most voluminous foodstuff produced in the UK. In monetary terms, £24.4Bn worth – around 16% – of the food and drink produced in this country is exported overseas, but 42 percent of the total food consumed in the UK is imported (Defra, 2023).

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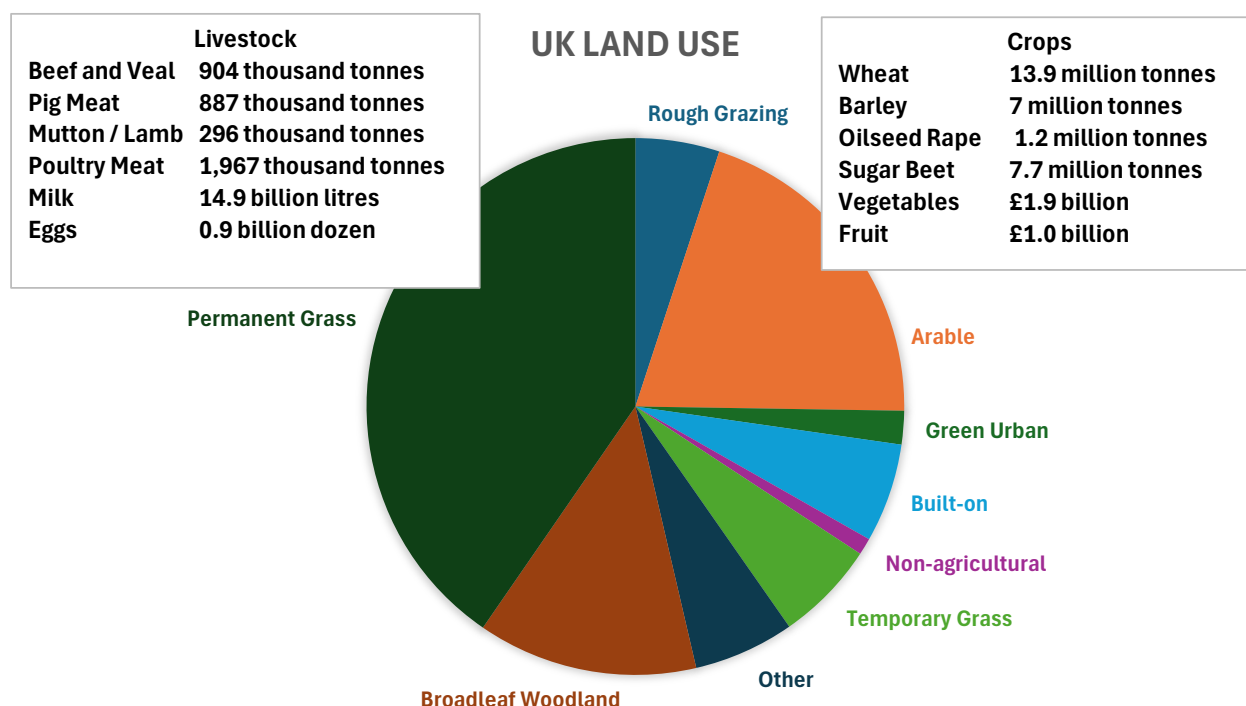


Figure 3.1 Land use in the UK. Source: SAVILLS 2019, Defra 2023

3.2 Agricultural water demand

Each person in the UK requires, depending on dietary choices and measurement used, between 2000 and 5000 litres (SIWI, 2012) of water per day to support their eating habits and demand for agriculturally based products. This is vast compared to the average daily consumption of 'drinking water' of 142 litres/person/day.

Almost three quarters of land in the UK is agricultural so it is not surprising that the associated demand for 'green' water is very high. Volumes of 'blue' water, abstracted for irrigation, are a small proportion of the total and estimates of irrigated water use vary significantly:

- According to the Environment Agency an estimated 129 million m³ of water was used to irrigate crops in 2018;
- In the same year they record a total of 150 million m³ of water was applied to land and used on farms during;
- The total licensed volume of water for agriculture that could have been abstracted was 384 million m³.

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The volume of water used may vary significantly from year to year depending on the weather conditions and the crops being grown. However, it is generally recognised that about 40 percent of that water is used to support livestock farming, another 40 percent is used to produce field vegetables, and the protected and nursery crops sector uses the remaining 20 percent. Aquaculture (plants and fish) is also a very important part of our agricultural economy and is responsible for very large abstractions. Conventionally, these are almost all considered to be non-consumptive, but this is increasingly challenged due to the environmental impacts of aquacultural contamination (WRAP, 2011a).

The main types of water use (excluding rain-fed, green water) on UK farms are to provide drinking water for livestock and to irrigate. Other uses of water by the agriculture sector include vegetable washing, general farming, and domestic use (WRAP, 2011a). Table 3.1 lists the volumes of water used per agricultural activity in 2009/10 according to the Defra survey.

Table 3.1 Volumes of Water used by Agricultural Activity

Activity	Total Water Used (million m ³)	Percent of Total
Drinking water for livestock	75	41%
Irrigation	70	38%
Other non-agricultural uses	18	10%
Wash	13	7%
down	4	2%
Spraying	2	1%
Leakages	1	1%
Other agricultural uses	184	

Source: Data derived from 2010 Irrigation Survey and the Farm Business Survey 2009/10

3.3 Water Needs Vary for Different Foods

It is very difficult to appreciate how much water goes into making our food, but typically the ratio of water to food output is huge. For example, it is estimated that 1,500 litres of water are required per kg of wheat, at least 1200 litres to produce a kg of rice, and 15,000 litres per kg of beef (Water Footprint Network, online). In a study for EBLEX Cranfield University have estimated that UK beef has a water footprint of 17,700 m³/t carcass weight and lamb 57,800 m³/t. Of these, 84% and 97% respectively is green water use, i.e. evapotranspiration of rainfall on crop and grassland.

Producing meat and dairy is much more water intensive than producing arable crops but as indicated above, the majority of this water under normal UK conditions is water falling as rainfall on crop or grassland. However, including this green water, approximately 500 litres of water in total is needed to produce 1000kcal of plant-based food, but up to 8 times the amount of water (4000 litres) is needed to produce the same amount of kcal from animal-based food, although this varies between meat types and crop types. To put it another way, 500-4000 litres are used to produce a kg of wheat (depending on where it is grown, and the type of wheat) but to produce 1 kg of meat anything between 5000-20000 litres of water may be needed (Lundqvist et al., 2008).

Typically, more water per calorie is required to produce higher value crops, such as sugar and vegetables than staple cereal crops. Similarly, a kg unit of beef requires approximately 8 times more water than chicken (Lundqvist et al., 2008). Meat products require so much water because most livestock is additionally fed on feed crops, such as maize, which have their own water requirements.

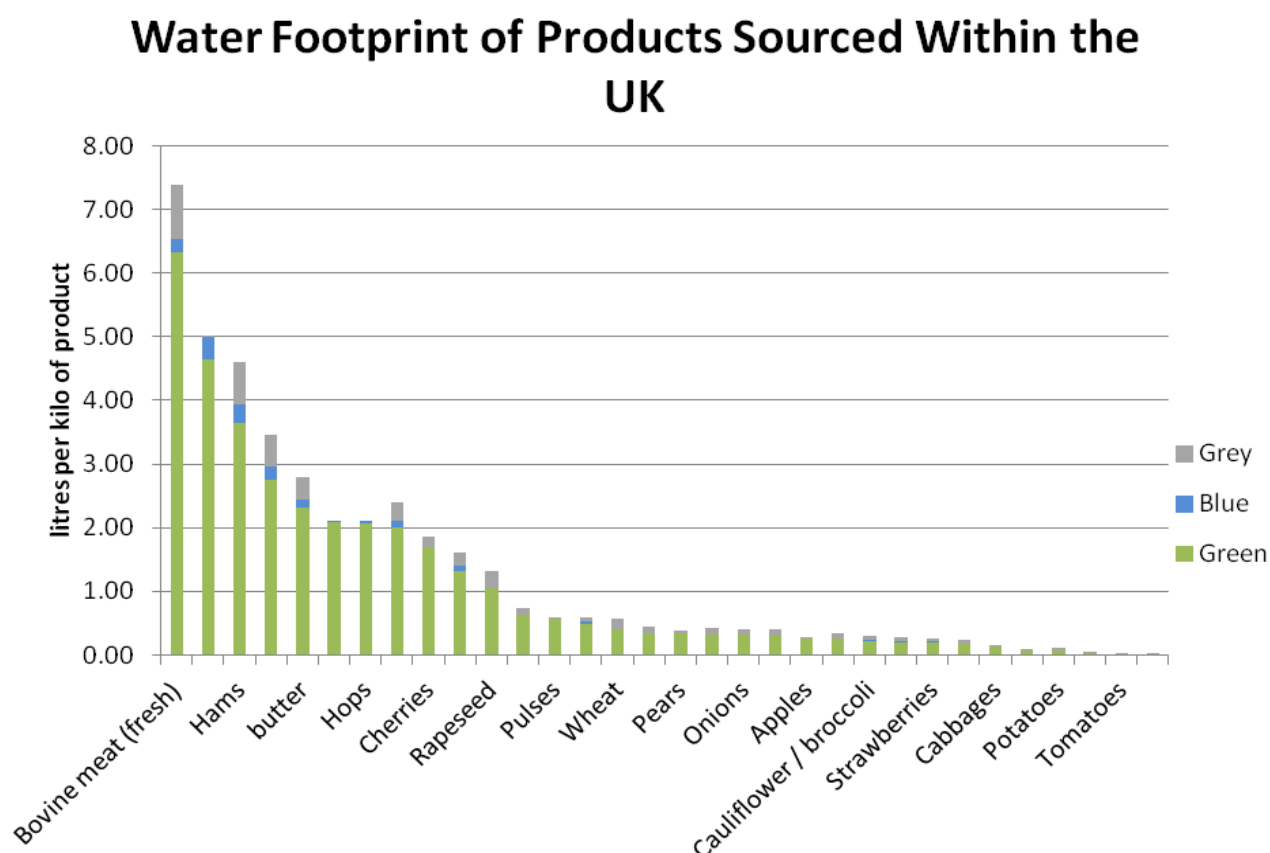


Figure 3.2 Water Intensity of Different Foods. Data source: Mekonnen, M.M. and Hoekstra, A.Y. (2010a) and Mekonnen, M.M. and Hoekstra, A.Y. (2010b)

Livestock

According to Defra Farming Statistics there are 9.4 million cattle (dairy and beef), 21.8 million sheep, and 4.8 million pigs. Total poultry meat for December 2020 was 153.2 thousand tonnes.

Most UK cattle and sheep farming is in the west where pastureland is supported by rainfall. Pigs and poultry farms are more evenly spread across the country, with concentrations of pigs occurring in Yorkshire, Humberside and Eastern England, and concentrations of poultry in Eastern England and the East Midlands.

Of the water that is abstracted, up to 75 percent is used for drinking water. Dairy cows need the most water, drinking on average 90 litres/day; a beef cow drinks about 20 litres/day; and a calf just 5 litres/day (ADAS, 2006). The other main uses of water on livestock farms are to cool down machinery and to clean equipment and farmyards. Large volumes of water are also used in the slaughter and production of meat.

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The use of wash water for cleaning purposes is normally confined to dairy production, the milking parlour, the bulk milk tank, pipelines, and the collecting and dispersal yards. Unless there are specific animal disease or health reasons, no cleaning water is used in stock accommodation for both adults and young stock, whether dairy or beef.

Table 3.2 Volumes of Water used for Drinking Water and Washing down on Livestock Farms

Livestock Type	Total Drinking Water m ³ (million)	Average Water used per Farm for Livestock Drinking (m ³ per farm)	Average Water used per Livestock Unit for Drinking (m ³ per LU)	Total Wash down Water m ³ (million)	Average Water used per Farm for Wash down (m ³ per farm)	Average Water used per Livestock Unit for Wash down (m ³ per LU)
Dairy	34	4030	21	11	1300	7
Grazing Livestock	18	1130	13	0.2	20	0.2
Pigs and Poultry	8	4120	11	0.4	230	0.6

Source: Data taken from Defra report which has been derived from the 2009/10 Farm Business Survey

Due to the water quality standards required on pig and poultry farms they are more likely to use mains water than direct abstractions from rivers or streams (Defra, 2011). If abstracted water is used, assurance schemes that enable produce to be sold into the market for certain retailers, such as the Red Tractor standards, requires – for chickens for example – that non-mains water is tested every 6 months to ensure it is potable, and results are recorded.

In the field, cattle also drink from rivers and streams etc. Water use on these farms is fairly evenly distributed throughout the year with a small increase during the summer months when animals tend to drink more when temperatures are higher.

Farmers are increasingly looking to use water more efficiently and are harvesting rainfall from farm roofs and re-using water that has been used for washing down of cooling plates.

Field Crops

In the UK 47 percent of all the arable land (16.8 percent of all the agricultural land) is used to grow two cereal crops: wheat (28 percent) and barley (19 percent). The rest is shared between crops such as oilseed rape, peas and beans, potatoes, sugar beet and horticultural crops.

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Crops require water for growth and there must be sufficient moisture in the soil to provide this from rainfall or be ‘topped up’ artificially by irrigation to meet the crop requirement and maximise productivity. Potatoes, sugar beet and other field vegetable crops are particularly thirsty and so irrigation is usually required to maintain soil moisture. The primary reason for irrigation in the UK is to ensure quality of product to meet buyer standards, and farmers irrigate only when there has been insufficient rainfall during the main growth period (or to establish some vegetables). Field crop irrigation is dominant in Eastern England, the Midlands and Southern England, taking place during the drier summer period, and almost never in Wales.

An increasing proportion – though still less than 10 percent of all irrigation – is undertaken by drip or trickle irrigation, a method which is generally more efficient at providing water to the roots of plants when they need it, avoiding losses to runoff. Trickle irrigation is practised most in the South East where more than half of the national estimated quantity is used (ADAS, 2006). Outside of the organic farming sector, all arable crops require considerable amounts of water to be applied to them for the delivery of various pesticides by spray application (ADAS, 2006). Water is also used to wash vegetable crops. This removes unwanted material such as soil, to improve the appearance and possibly to remove pesticides. Water is also used to cushion/move crops through other processes such as size grading and ‘polishing’. Crop washing may take place in the field or in a packhouse or a combination of both. The scale of production will have an influence as will the tenderness or perishability of the crop and the quantities to be washed (ADAS, 2006).

All producers supplying food to retailers are generally usually obliged to follow crop assurance protocols to ensure food safety linked to washing. Water used for final product washing must meet national drinking water standards and recycled water must be filtered. Water is therefore mainly drawn from the public mains or from any other source (mainly boreholes), providing its quality is of a high enough standard (ADAS, 2006).

There are no statutory water quality requirements for irrigating field crops (although there are assurance requirements) and most irrigation water is abstracted by farmers directly from surface or groundwater sources.

Protected and Nursery Crops

The third largest sector in terms of overall agricultural water use is the protected and nursery crops sector (about 53 million m³ of water annually) (Charlton et al., 2010). There are no complete datasets to confirm the total land area given over to this type of agriculture at the UK level, but estimates from 2004 suggest 1,750 ha in England² (ADAS, 2006). This type of agriculture, and its associated water use is mainly concentrated in the South East of England; there is also significant activity in Eastern England and the Midlands, although it is present in all regions.

² 1ha is about the same size as an international rugby pitch

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Protected crops are described as those grown permanently under glass or plastic cover, e.g. tomatoes, sweet peppers, cucumbers, lettuce, strawberries, mushrooms. For covered horticultural crops, significant amounts of irrigation are required. This is because all protected crops require irrigation throughout the year, peaking during the summer months (ADAS, 2006). According to the Royal Agricultural Society of England, 'polytunnel crops' use significant amounts of irrigation water but the process is more efficient than for field crops. While previously most protected crops would have been irrigated with public water supplies (e.g. ADAS, 2006) the number using public water supplies has fallen considerably, and most major growers now used abstracted water that is treated as necessary to meet crop assurance standards.

Figure 3.3 shows the proportion of the total irrigated area by crop type according to the Defra 2010 survey. The total volume (83 million m³) was almost a third less than in 2005 due to a reduced number of irrigated holdings and wetter weather in 2010. It clearly shows that main crop potatoes are the single most water demanding crop in the UK irrigated sector, followed by field vegetables. These are both high value crops with yield and quality directly responsive to irrigation.

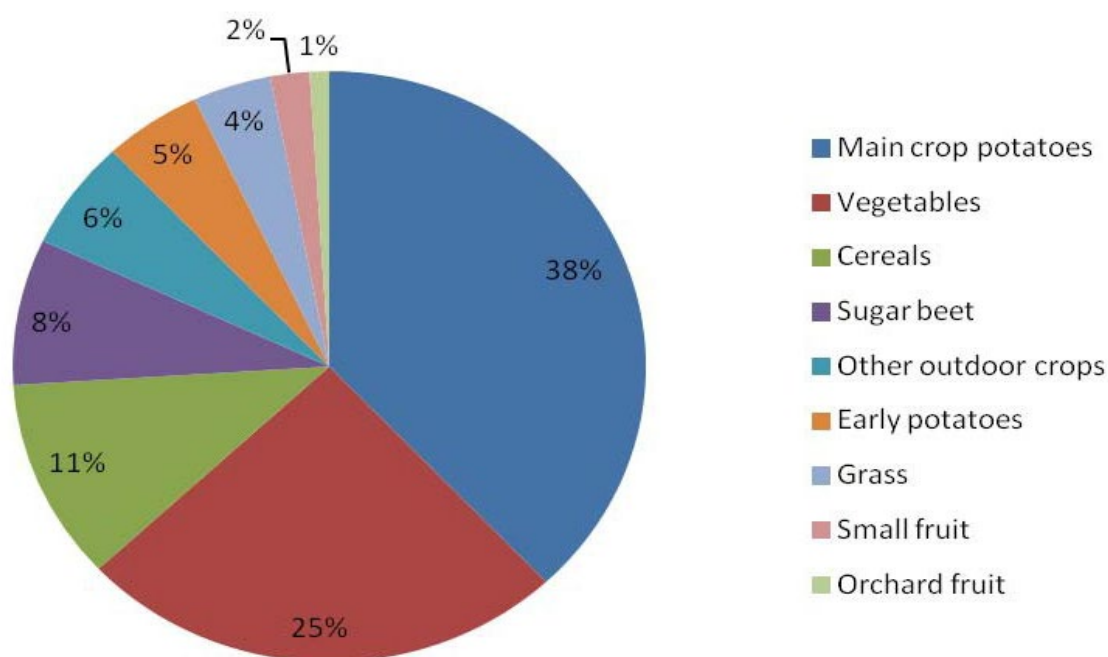


Figure 3.3. Crops irrigated as a percentage of the total. Source: Defra Irrigation Survey 2010.

3.4 Rainfed versus Irrigation in the UK

Most water in UK agriculture is rain-fed with less than 5% requiring irrigation even in a dry year. However, irrigation is often essential for some crops to ensure water is available at the right time and in the right quantity to achieve the standard of crop required. Irrigation prevents disease (such as scab in potatoes) and aids timeliness of establishment and harvest. Product quality and quantity are often highly dependent on the availability of water in the right volume and at the right time to ensure product quality and yield and profitability. Irrigation in the UK is, therefore, “supplementary and the aim is not to meet the plant’s full water demand but to provide enough water to get the plant through the critical growth stages” (Lundqvist et al., 2008). How much irrigation is required depends upon the amount of rainfall received on a season-to-season basis (ADAS, 2006) in the location where the crop is grown.

In the UK irrigation occurs mainly during the summer months when the pressure on water resources is already at the highest level, but demand varies from year to year depending on rainfall levels and temperatures. Spray irrigation is the most common type of irrigation in the UK and accounts for up to 88 percent of agricultural consumptive use. In East Anglia demand can be significant in the summer months where irrigation abstractions can average 20 percent of the total for all uses over a typical summer. Farms across East Anglia use as much as 16 percent of the national farming total. Sometimes more water is used on a hot dry day for spray irrigation than for public water supply. However, agriculture is a relatively small abstractor compared to other uses (e.g. public water supply, power sector, other industry); just 1 percent of licensed abstraction volumes are allocated to agriculture (Environment Agency, 2008).

3.5 Water and food manufacturing in the UK

The food and drink industry has a high demand for clean and fresh water. Access to an abundant source of high-quality water is one of the essential factors in designing a food plant. Contaminated water would generate substantial threat to the product quality and safety so there is always the pressure to ensure it meets an appropriately high standard. It is estimated that 80 percent of water requirements for the food and beverage industry are sourced from public water supplies.

Water use during food production is significantly lower than during primary production, but it is still a significant component of many foods. It can either be added directly as an ingredient or be present in the processing. Water has been added to food as an ingredient by food producers since food processing began. For example, the primary steps in processing livestock in the meat, poultry and seafood sector include rendering and bleeding; scalding and/or skin removal; internal organ evisceration; washing, chilling, and cooling; packaging; and cleanup (UNIDO, 2004). Another example is the fresh fruit and vegetable sector where the primary steps include general cleaning and dirt removal; removal of leaves, skin, and seeds; blanching; washing and cooling; packaging; and cleanup (UNIDO, 2004). There are many examples of water being used as a processing aid, including use as a thermal transfer medium, as a transport medium, and in cleaning (Kirby et al., 2003).

Food processing can be divided into four major sectors, including: fruit and vegetables;

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meat, poultry, and seafood; beverage and bottling; and dairy operations. All of these sectors consume a huge amount of water for processing food (United Nations Industrial Development Organisation (UNIDO), 2004)), see Table 3.3.

Table 3.3 Typical Rates for Water Use for Various Industries

Industry	Range of Flow gal/ton Product
Fruits and Vegetables	
Green beans	12,000-17,000
Peaches and pears	3,600-4,800
Other fruits and vegetables	960-8,400
Food and Beverage	
Beer	2,400-3,840
Bread	480-960
Meat packing	3,600-4,800
Milk products	2,400-4,800
Whiskey	14,400-19,200

Sources: UNIDO (2004)

3.6 Impact of climate change on UK agriculture

Over the 15 years between mid-2021 and mid-2036, the UK population is projected to grow by 6.6 million people (9.9%), from an estimated 67.0 million to 73.7 million. This growth means that demand for water is likely to increase. The UKCP18 medium emissions climate change scenario indicates that by the 2050s the average drought severity is projected to increase for 3-, 6-, 12- and 36-month-long droughts.

In recent years we have already witnessed changing patterns of rainfall, which has had a direct impact on water availability for agriculture, leading to a shortage of irrigation water in some regions of the UK as well as increased flooding from high intensity rainfall events. The Potato Council reports that due to climate change, the amount of arable land suitable for rain-fed potato production in the UK is expected to decrease by at least 75 percent, increasing the need for irrigation (refer back to current situation illustrated in Figure 2.1). With the likelihood of increased water demand and reduced water supply in the UK, particularly in Eastern England, there are potential risks to UK agriculture.

Without adaptation, changes to rainfall due to climate change threaten the areas of both rain-fed and irrigated agriculture. If water management practices respond appropriately,

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then potentially longer and hotter summers will extend livestock grazing seasons, potentially increasing yields. For arable and other crops, climate change may affect sowing and harvesting dates, and rates of spring growth. Some crops may prosper but others may struggle. Based on evidence from recent droughts in the UK (Charlton *et al.*, 2010) the impacts of reduced water availability on farming include:

Livestock:

- Grazing (e.g. beef and sheep): forage supply reduced with a loss in both yield and quality and consequently the need to provide more supplementary feed (with its' own inherent water requirements);
- Dairying: reduced grass growth and less silage cutting lowers winter feed stocks; and,
- Pigs and poultry: animals reduce their feed intake during hot weather lowering productive output.

Cropping:

- Shorter harvest period with longer more unsocial hours;
- Early maturation of crops may require logistical changes;
- Increased yields and quality of cereals (providing water is available to irrigate);
- Increased yield of oilseed crops although irrigation requirement could increase the cost of spring crops (provided water is available);
- Yields of peas and bean crops could fall;
- Yield and quality of potato, sugar beet and field vegetables could diminish if irrigation facilities are overstretched. This could create difficult conditions for weed and insect pest control, and crop disease;
- Yields of orchard fruit crop may decline but eating quality may improve;
- The yield of protected crops would decline if additional water were not available to meet transpiration requirements of existing volumes of crop. Increased irrigation, using mains supplies, would increase production costs; and,
- Reductions in yield may have some financial benefits (at some point in the food supply chain) as shortages may be offset by higher prices.

The review of outputs from Defra's climate change research programme suggests that most farmers will be able to maintain their existing crop and livestock enterprises. However, the UK Climate Change Committee indicated there will be direct risks to crops, livestock and commercial trees through increased exposure to heat stress, drought risk, waterlogging, flooding, fire, and pests, diseases and invasive non-native species.

3.7 Impact of Agriculture on UK Water Resources

One important aspect of this regional difference in farming types and their water demands is that whilst livestock has a higher annual total demand than arable farming, that demand is relatively constant across the year (although there will be a higher demand during hot dry weather in the summer). Arable farms' demand for water is much more acute and intense, during the main growth period in early summer, and in the regions which are least capable of supplying it (ADAS, 2006). These regions are some of the most productive for agriculture in the country, so the challenge is securing that water for irrigation while at the same time protecting the aquatic environment and providing water for an increasing population.

Most farmers irrigating field crops abstract water directly, from boreholes or surface water local to their farm. Farmers in England and Wales who abstract more than 20m³/day are required to obtain an abstraction licence from the Environment Agency (England), and Natural Resources Wales. Abstraction licences specify the volumes that abstractors are permitted to take, the purpose of use, and the dates during which abstraction is permitted.

Since the 1960s, the way water is managed in the UK has become more and more sophisticated. The abstraction licensing system was introduced in the 1960s without the level of knowledge about the water system or the demands on the system we have currently. The Environment Agency is in the process of reviewing abstraction licensing on a catchment-by-catchment basis to remedy this historic over licensing of available water. From 2028, the intention is that all licences will be time-limited (only valid over a specific period) and the EA will be able to change or revoke licences without compensation where they believe it could be detrimentally impacting the environment.

Over time, farmers and agricultural groups have become more involved in helping to manage water resources, and now initiatives such as catchment-sensitive farming are integral to water management in many parts of the country. Farmers, particularly in Eastern England, are increasingly concerned about securing their access to water and have formed farming abstraction groups to work more collaboratively with the Environment Agency to find ways to protect farming, and the environment.

However, for most other uses, farmers use mains water supplied by the water utility companies, and the farmers pay per volume. The water companies now have a statutory duty to develop long-term water resource management plans to safeguard supplies to their customers, and this includes understanding and forecasting demand, including from agricultural customers. Because of the way that water companies manage their water supplies (strategic water supplies) mains water may be sourced a considerable distance from where it is ultimately used.

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Food Waste

Food waste is a big issue. According to the most recent report by the charity Waste and Resources Action Programme (WRAP), the UK produced around 9.5 million tonnes of food waste in 2018. Some of this waste will be foods from the 40 percent of our needs that are met from farms in the UK, and thus wasting the rain-fed and irrigated water used here, and some of it will be foods from the 60 percent that are imported, therefore wasting water that in all likelihood is from regions that are already water scarce.

“Overeating, and throwing away food is like leaving the tap running”

(Lundqvist *et al.*, 2008)

The environmental impact of avoidable household food and drink waste is now around 4 percent of the UK total water footprint (and 17 million tonnes of CO₂e, equivalent to the emissions of 1 in 5 cars on UK roads).

Imported Water

Food demands and markets are global with all countries importing and exporting huge amounts of food every day. The UK imports around 40% of its food.

As well as trading in food, by transporting food, the process also results in the trade of ‘virtual’ or ‘hidden water’ and exerting pressure on water environments around the world. Countries that export food export virtual water, and countries that import food import virtual water. Thus, “water is increasingly becoming a global resource” (Hoekstra, *et al.*, 2008).

Only 38 percent of the UK’s agricultural-related water footprint is sourced within the UK, affecting UK water resources (28.4 Gm³/year, 1292 litres/person/day). 46.4 Gm³ of virtual water is imported from other countries (WWF, 2008). The fact the UK produces 60% of its food using 38% of the UK food water footprint highlights that the UK tends both to import foods from water stressed countries and foods that require high water input. This has been driven by dietary changes away from dietary seasonality and towards exotic foods, with sourcing often reliant on water-stressed countries. Examples include year-round consumption of soft fruit and increasing consumption of avocado and jackfruit.

³ <http://www.wrap.org.uk/content/new-estimates-household-food-and-drink-waste-uk>

4. Water and food production: Globalisation of food

The total water footprint from all products and sectors, across all countries in the world, is 9087 Gm³/yr (Mekonnen and Hoekstra, 2011a) and 92 percent of this comes from agricultural production. Global water demand is predicted to increase by 20 to 30% by 2050 (Mekonnen and Gerbens-Leenes, 2020). Agriculture takes the largest share of the total water footprint within each individual country, highlighting the significance of this sector on global water consumption. The total water footprint of agricultural products in the UK is approximately 75 Gm³/year.

From an agricultural perspective, the UK is a net importer of virtual water, highly dependent on global water resources, to provide for our agricultural demands. Despite the pressure on our own water resources, by importing food we are to some extent relieving the pressure that we would otherwise face. We import huge volumes of thirsty crops, e.g. cocoa and sugar. The top ten food products contributing to our external agricultural water footprint due to imports are:

1. Cocoa beans (7346 Gm³/year)
2. Bovine products (5458 Gm³/year)
3. Swine products (3775 Gm³/year)
4. Oil palm fruit (3171 Gm³/year)
5. Soybeans (3092 Gm³/year)
6. Sugar cane (2500 Gm³/year)
7. Coffee (2069 Gm³/year)
8. Milk (1782 Gm³/year)
9. Rice (1490 Gm³/year)
10. Maize (1420 Gm³/year).

Some of the main reasons why we import food (and drinks) whilst at the same time exporting large amounts of food are generally due to our agro-climatic conditions, our tastes, and established trading markets. For instance, wheat, apples, carrots and dairy products are relatively easy to produce in the UK, whereas bananas, pineapples and other foods are not. As a population, our food tastes have become more diverse, but also less seasonally inclined. For example, strawberries and tomatoes grow very well in the UK, but despite growers increasing the seasonal availability from early spring to autumn, the demand for strawberries is annual and this type of demand is met by imports.

Food retailers depend on reliable supplies and so may source foodstuffs from overseas, even whilst these crops are harvested in the UK, if the supply is thought to be more reliable. Retailers may also find it is cheaper to work with suppliers overseas than in

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the UK. Global growing and trading patterns are complex as there are many factors driving imports and exports.

Figure 4.2 illustrates where the majority of the UK's food water footprint comes from and demonstrates that the UK imports virtual water from all over the world. Our single largest import of water is from Brazil (4,141 million m³/year), followed by France (3,055 million m³/year), and Ireland (2,828 million m³/year).

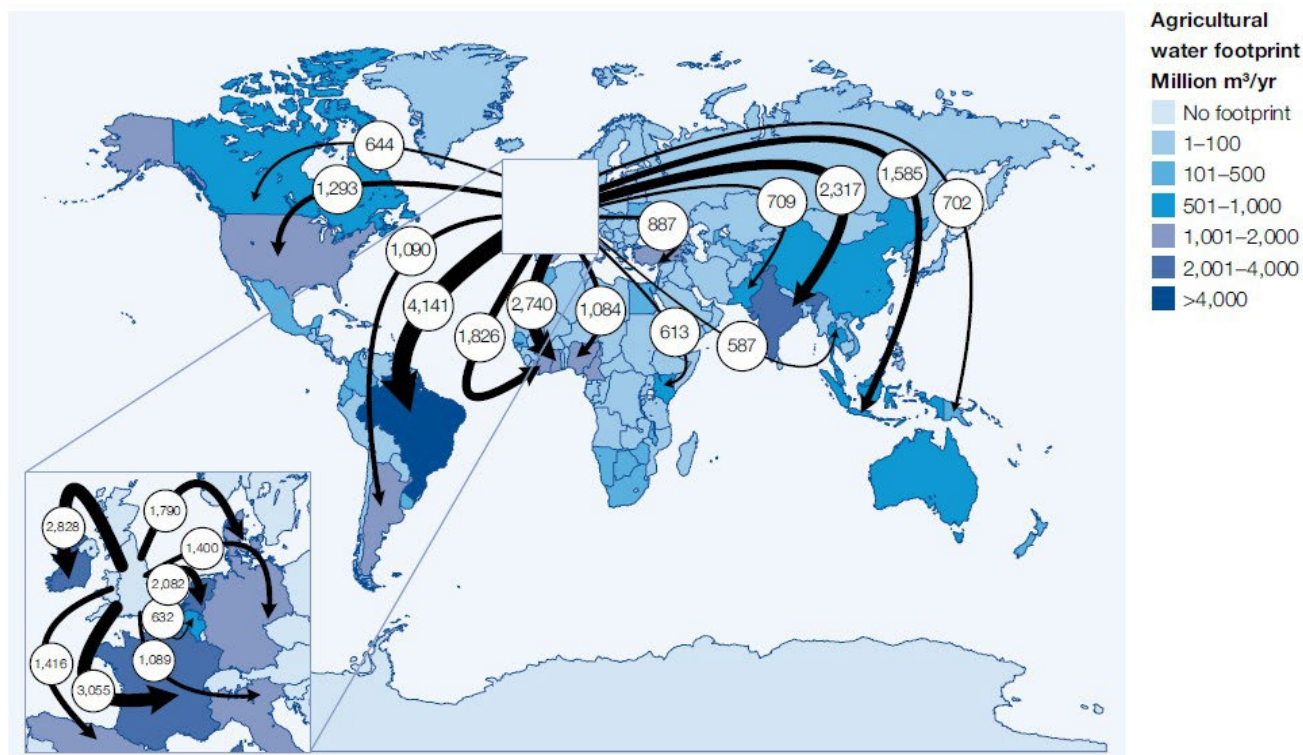


Figure 4.2 The UK's External Water Footprint. The arrows indicate the source of virtual water from agricultural goods imported. Source: WWF, 2008. UK Water Footprint: the impact of the UK's food and fibre consumption on global water resources. Volume one © [August 2008] WWF (panda.org). Some rights reserved.

The UK is the sixth largest net importer of agricultural virtual water behind Brazil, Mexico, Japan, China and Italy (WWF, 2008). We import 'virtual water' from all around the world, including from countries that have high water stress conditions. This was expertly analysed for the WWF (WWF, 2008) and the results are illustrated in Figure 4.3.

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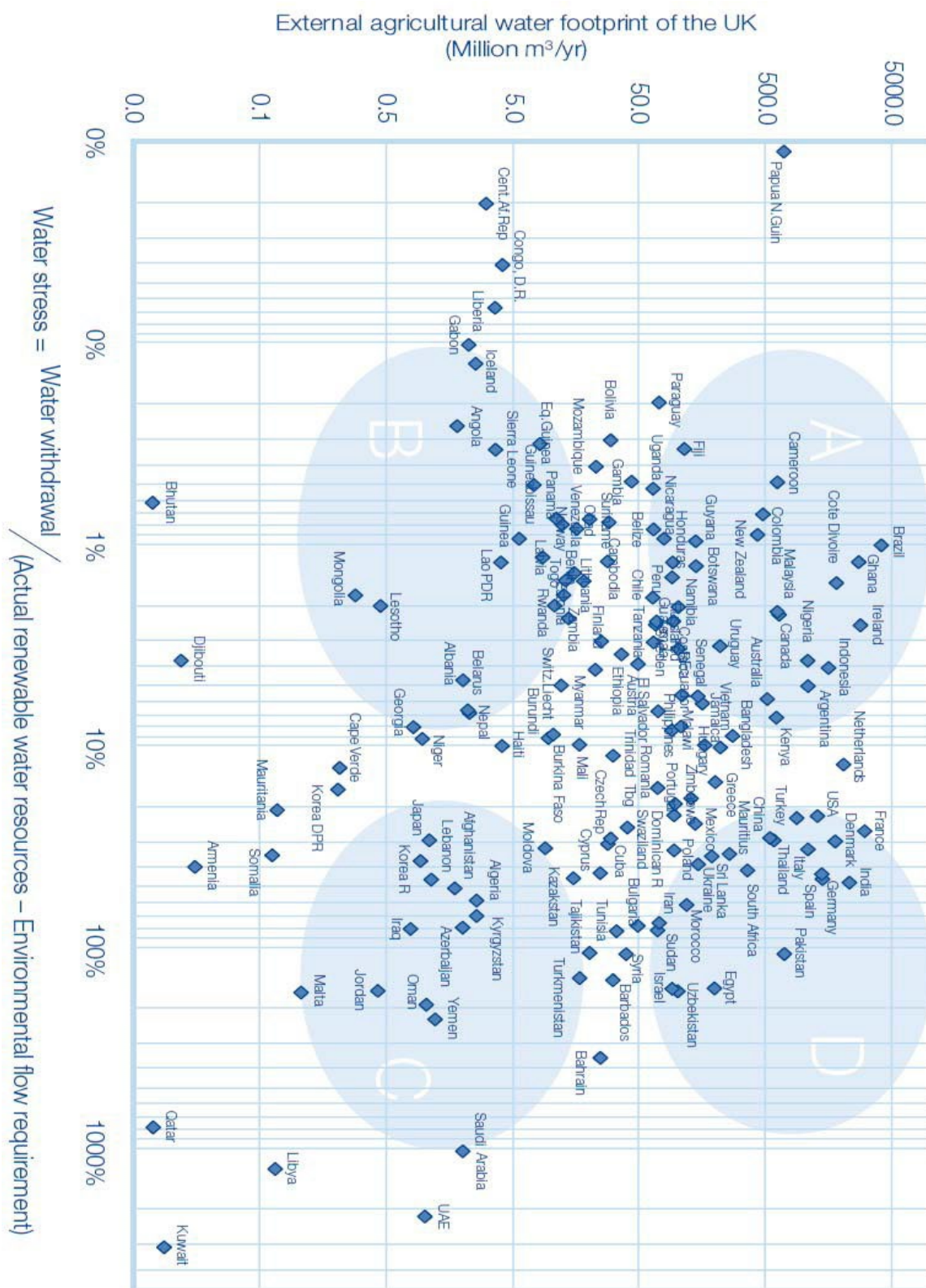


Figure 4.3 UK Agricultural Water Footprint and Water Stressed Food Production Locations. Source: WWF, 2008. UK Water Footprint: the impact of the UK's food and fibre consumption on global water resources. Volume one © [August 2008] WWF (panda.org). Some rights reserved

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The main points to take away from this illustration are that countries within the Group D circle contribute significantly to the UK agricultural water footprint whilst also having relatively high – high water stress conditions. This situation has many implications that we should consider.

4.1 Impact of Agriculture on Water Resources around the World

Where a very high proportion of a country's freshwater that is available is abstracted (for all types of need) then the area is highly stressed. Currently, 1.42 billion people live in areas of 'high or extremely high' water vulnerability (Unicef 2021).

Water stress is a problem because it means there is a very fine balance between how much water there is and how much is being abstracted. Environmental flow requirements, and the needs of existing abstractors are precarious. It means that there is very little (if any) water available for new abstraction needs. Stressed conditions means there are high risks of environmental degradation and high risks of social and economic demand for water not being met. The introduction section of this ROCK highlighted that global food supply may need to increase by 70 percent and that food requirements in the developing world could double.

The U.S.A., much of Europe, central Asia, the Middle East, India and eastern China are already close to, or exceeding, the limits of their water resources, and their populations and food output requirements are still growing.

Regions that are under water stress may exhibit a number of agriculture-related water problems including reduced water quantity, pollution, and salinisation. The 'Green Revolution' of the 1960's was a global phenomenon which extended and intensified food production in many countries. This would not have been possible without irrigation. The widespread intensification of farming has altered the natural hydrology of surface water, groundwater, and the environment in many water catchments (OECD, 2010).

Intensified farming in wetter regions generates problems of water quality and pollution. Problems include reduced flows in rivers and groundwater levels lowering; wetlands shrinking or disappearing (also happens due to drainage) and less water often means lower oxygen levels which can damage flora or fauna; salinisation of groundwater (in coastal areas) and salinisation of land (particularly if irrigation water has high mineral levels); dams and water diversions to support irrigation; leaching of nitrates and pesticides from agricultural land into water courses.

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Box 3 Regions under stress

- The vulnerability of rain-dependent food production systems and the people who depend on them was brought into stark relief by the situation in East Africa in 2011. It was widely reported that more than 13 million people were at risk of starvation after the worst drought to hit East Africa in 60 years;
- In large areas of India and China, groundwater levels are falling by 1 to 3 m per year, causing intrusion of seawater into aquifers, higher pumping costs and jeopardising agricultural production (FAO, undated, b); and,
- 300 million ha of land are irrigated and around 10% of that irrigated land is in a degraded state due to salt accumulation (FAO, undated, b).

Traditionally, surface water has been the main source for irrigation, typically because it tends to be more accessible. However, as access to groundwater reserves is improved, this is increasingly seen as a preferable source since water quality is usually much higher than surface waters, and it is less vulnerable to drought. Around half of all new crop irrigation schemes globally are now in highly water stressed areas (Dineen, 2022).

Agricultural production in the Ogallala aquifer region, covering 450,000 km² of the U.S.A., is already unsustainable due to extreme groundwater depletion from irrigation (Basso, Kendall and Hyndman, 2013) (Griggs, Miller-Klugesherz and Sanderson, 2020). Parts of India face a similar challenge after rural development incentives led to groundwater-based irrigation for export market crops, greatly exceeded natural aquifer replenishment rates leaving some areas incapable of supporting future cropping (Shah, 2012) (Dangar, Asoka and Mishra, 2021).

The environmental system supports local communities. Damage to the water environment is bad enough but there are also real human costs: water scarcity forces people to rely on unsafe sources of drinking water, and water scarcity encourages people to store water in their homes. This can increase the risk of household water contamination and provide breeding grounds for mosquitoes - which are carriers of dengue fever, malaria and other diseases. A lack of water has driven up the use of wastewater for agricultural production in poor urban and rural communities. More than 10 percent of people worldwide consume foods irrigated by wastewater that can contain chemicals or disease.

Food waste at a global scale is huge. One study estimated that the volume of water lost in a year due to food loss and food waste could be as much as half of the total volume of water that is abstracted for irrigation, about 1350km³, equivalent to about half the volume of Lake Victoria (Lundqvist et al., 2008).

5 Water Security

5.1 Water risks

As demand and competition for water resources continues to grow and water stress levels become more intense, the number of places finding that water is scarce will continue to increase, jeopardising economic development, threatening political instability and public health. Where water is scarce food, production is also at risk. Water security is a term that reflects the aspiration of both governments and corporate business to manage these risks.

Water security is a truly global issue in that water risks are present all over the world, and global trade – particularly in agricultural products – transfers and shares the problems and risks in one country with others. However, unlike carbon it is a global issue which clearly manifests itself in local problems. These problems can be complex, and, in many cases, there is conflict between water use priorities in adjacent water catchments, or across international boundaries. Sharing surface and groundwater across national boundaries for agriculture is important for countries such as Mexico-US, and Portugal-Spain (OECD, 2010). The Nile basin is a prime example of a water resource under pressure from multiple competing countries, namely Egypt, Ethiopia, Sudan, and Uganda. Here, the development of the Great Ethiopian Renaissance Dam to facilitate hydropower and crop irrigation has raised serious political tensions with Egypt, whose agriculture is threatened by the change in Nile flow regime (Matthews and Vivoda, 2023).

As a net virtual water importer, 40 percent of the UK food supply is inherently at risk from our reliance on water systems which are outside our control. At the moment there is no clear governmental position on this. There are high-level policies on food trade, e.g. the European Common Agricultural Policy, but ultimately the risks of our ‘suppliers’ failing to meet our needs (e.g. due to inadequate water resources and climate change), or even deliberately choosing to switch from water intensive agri-economies to other potentially higher value water intensive economies, is a risk which food brand companies and retailers may face. Following Brexit, the UK has increasingly sought free trade agreements with countries outside the EU, notably including Australia, that face water challenges, but count food commodities amongst major exports they expect to benefit from these agreements. It is unclear whether water resource impacts on reliability of such trade have factored into these politically driven agreements.

There is an increasing awareness that the economic value of water can be increased by prioritising its use to support ‘high value’ industry, e.g. the outputs of using water to produce micro-chips and semi-conductors may be significantly more than using the water to grow bananas.

Arguably, it is the financial sector that is driving water security up the global agenda. Investors seek assurance that their investments are secure and will prosper, and critically that water will not be a constraint. The UK Government Pension Fund Global is broadly invested in several water-intensive sectors including food and beverages. At the global level, institutions such as the World Economic Forum are taking the lead, exploring and pushing the issue. The Forum encourages and facilitates organisations and business leaders around the world to discuss the issues and call governments and business to action.

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The CEO Water Mandate is an international public-private initiative where through the direct involvement of corporate CEOs, companies are empowered to develop, implement, and disclose water sustainability policies and practices. The Mandate recognises that the business sector impacts on water resources both directly and through supply chains. Endorsing CEOs acknowledge that in order to operate in a more sustainable manner and contribute to the vision of the UN Global Compact and the realization of the Millennium Development Goals, they have a responsibility to make water-resources management a priority, and to work with governments, UN agencies, non-governmental organizations, and other stakeholders to address this global water challenge.⁴

Whilst the international business community continues to grapple with the problem, individual national states and companies are also taking steps to improve their water security. California is one of the leading states with a comprehensive package of water legislation, including the Agricultural Water Management Planning Act. The state has developed a plan which presents the status and trends of California's water-dependent natural resources, water supplies, and agricultural, urban, and environmental water demands for a range of plausible future scenarios, and is developing policies and action plans that take all of these issues into account.⁵

Individual businesses are also recognising that water is not just an 'environmental issue' but that the continued success of their business requires that they identify and respond to the various water risks to which they are potentially vulnerable. There are several water-related business risks:

- Physical: Too little or too much water, water of the wrong quality, risk of production outages, risks increased by climate change;
- Geo-political: Conflict (local/regional) for water rights; transboundary rivers; virtual water trading;
- Community: Actual or perceived conflicts; (access / degradation of water resources) can directly impact on a business' social licence to operate;
- Reputation: This is easily damaged by real or perceived impacts on the water environment, or by being seen as an aggressive water competitor to other users e.g. domestic supplies. This can directly affect brand value;
- Regulation: Too little regulation or unstable regulatory regimes create uncertainty over resource, too much regulation can incur bureaucratic burdens, regulations can constrain water use; and
- Investment: All risks may reduce investor confidence, jeopardising investment and finance options; onus on due diligence.

⁴ <http://ceowatermandate.org/>

⁵ <http://www.waterplan.water.ca.gov/>

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In reality, any number of risks may be present and may trigger further risks, all of which manifest themselves as financial risk, impacting on the future resilience of the business.

Ultimately, for a business to be water secure, it needs to be in control of the water risks in its supply chain, or at least to be aware of the risks and have an appropriate resilience plan to adapt to or mitigate against forecast and unexpected changes in the water environment.

5.2 Water Security Strategies

As in all areas of management, the first step in managing a situation is to understand and quantify that situation. Primarily, as a response to investors' concerns over water risk, companies have begun to quantify, report, and disclose their water related performance. This is typically referred to as Water Accounting and includes metrics on water use, wastewater discharge volume and contaminant loads in water.

A study by Ceres in 2010 benchmarked 100 companies in terms of how they report water risk. The study found that even for companies operating in sectors and regions of the world facing significant water risk, disclosure of risk and corporate water performance was surprisingly weak (Ceres, 2010). At that time, 63 percent of the companies were able to report how much water they abstract, but only 3 percent were able to present the total 'supply chain' water footprint of their products.

At the same time the UK based Carbon Disclosure Project launched its Water Program to encourage companies to submit and disclose their water related performance. In its first year 137 financial institutions with assets of over US\$16 trillion signed up to the CDP Water Disclosure programme and 150 out of 300 companies that were approached from around the world completed the 2010 questionnaire. The response rate from the food and drink (and tobacco) sectors was 65 percent, third behind the chemicals and pharmaceuticals sectors. At that time, the results indicated little evidence that the food and drinks companies (among others) were working with suppliers to manage water risk.

According to CDP's 2023 "Riding the wave" report, private sector water data disclosures increased 85% in the preceding 5 years, but 107 countries were still off track to sustainably manage their water resources by 2030. Whereas In 2013 1000 companies were invited to report and just under 600 participated, in 2023 8477 were invited and 3909 disclosed. The Consumer Staples sector, which includes Food and Drink had the highest response rate (76 percent) of all of the sectors. This demonstrates the increasing awareness and recognition of the high level of importance that the sector places on water. 51 percent of companies report that their direct operations are at risk from water scarcity, and 74 percent claim that they are at risk from water scarcity in their supply chains. Other risks include flooding, declining water quality, rising discharge compliance costs, limits on abstraction, higher water prices, reputational damage and restricted operational water permits (CDP, 2013).

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Many companies, particularly food and drinks companies, also have their own corporate water strategies. Currently, many of these focus on water use in their own operations, as these are easier to assess and control, are benchmarking their performance and setting themselves water performance targets, e.g. to reduce water use in their own operations by a set percentage by a target date. In parallel, some companies have established 'water stewardship' projects, e.g. water resource replenishment projects and community water supply and sanitation projects.

Water stewardship is an inherently local response to a local problem. Businesses and governments may have strategic water security plans, but stewardship is much more about resolving specific water needs in the local environment. To support this, the Alliance for Water Stewardship (a collaboration of organisations including the WWF, the United Nations Environment Programme, and the CEO Water Mandate) has developed a Water Steward Standard to provide guidance to potential water stewards and to provide accreditation for stewardship actions.

Water Security Resilience Actions

The key challenge is to produce more food, of better quality, with less water. There are a number of actions that could support this, at different stages in the food supply chain. Clearly, the solution to the forecast increases in demand for food from all around the world cannot simply be to further intensify food production. Inefficient agricultural practices need to be targeted to reduce water demand and waste. Farmers are acutely aware that they need to make themselves and their business more resilient to the emerging climate, with its unpredictable weather patterns, and often shortages of water.

Action on Farms

Smarter use of water generally goes hand in hand with smarter use of all resources. Several strategies to improve water productivity on farms ('more crop per drop') are available:

- Target water lost in the field. Only 30 percent of rainfall that hits the ground is converted into productive transpiration in plant growth.

More food can be produced with the same amount of rainfall if non-productive evaporation is minimised by mulching, cover cropping, weed and pest management, early plant vigour, optimal planting density and no-tillage systems. Zero tillage is a very effective soil water conservation technique for rainfed, mechanised farms (FAO, 2011). It also uses less power and so contributes less to the water problems arising from climate change. Growers can also save water by improving furrow, basin and border irrigation methods to ensure that watering meets crop water requirements while limiting runoff and deep percolation (California Department of Water Resources, 2009).

Occasional deep tillage deepens the effective root zone and increases the porosity of soil, but all tillage operations risk damaging soil structure, especially if heavy machinery travels land in wet conditions. Planting crops in strips, crop rotation, rotating grazing

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fields, and surface shaping all enhance water retention in the soil, promote infiltration into groundwater, and help to control runoff (FAO, 2011). Encouraging increased soil organic matter through regenerative agricultural methods not only sequesters atmospheric carbon but increases both soil drainage rates and soil available water holding capacity, thus helping mitigate the yield loss risks as our climate changes.

Secure water for agriculture through capture and storage

Countries which benefit from high winter rainfall and flood water can employ features such as pools, pits, retaining ditches etc to manage water. More significant infrastructure may include local and small-scale reservoirs.

Significant water savings can thus be achieved through land use management, but there will remain a need for irrigation. Improvements in irrigation are also possible to generate more crop per drop. Across OECD countries, between 1990 and 2002 the average water application rate per hectare irrigated decreased by 7 percent, while in most cases, the volume of agricultural production increased. More efficient irrigation systems include:

- Drip irrigation (precision irrigation);
- Low pressure sprinkler systems;
- Lining irrigation ditches;
- Using micro-irrigation systems;
- Upgrading flood irrigation systems (e.g. levelling of fields, neutron probes for soil moisture measurement, and scheduling irrigation to match plant needs); and
- Small scale technologies like treadle pumps (which provide irrigation from shallow aquifers) can help improve water efficient use.

In water-scarce regions, options to improve water efficiency can vary depending on wealth. Where there is enough investment, water efficiency can be high-tech. In California, farms are installing Advanced Irrigation Systems which use advanced technologies such as Geographic Information Systems (GIS), global positioning systems (GPS), and satellite crop and soil moisture sensing systems to monitor and apply water precisely where it is needed, minimising waste (California Department of Water Resources, 2009).

California continues to make great strides in increasing the economic value and efficiency of its water use (SIWI, 2012). Elsewhere, particularly in developing countries there is less state money available to implement state-of-the art technology and this may be reflected in the water efficiency of food production. Globalised food companies however are more likely to have funds to invest in the food production stage of the supply chain. Improving farmers' ability to produce more food with less water makes good business sense and many companies have started to investigate this.

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However, there is a tipping point where irrigation water efficiency can actually create problems. The Californian Department of Water Resources has calculated that the maximum proportion of applied water that should be expected to convert into agricultural productivity is 85 percent; beyond this, reductions in water on the land can lead to soil salinity, soil degradation, and loss of productivity (California Department of Water Resources, 2009).

Not all irrigation water has to come from freshwater sources. Depending on the quality of water that is required – and specifically any irrigation-standard drainage water – treated urban wastewater, brackish, and desalinated water offer further opportunities for irrigation in conditions of water scarcity. “To this extent, agriculture has been much more accountable for the freshwater that it withdraws and uses” (FAO, 2006). There is significant scope to increase the volume of recycled water in agriculture to relieve the pressure on freshwater sources, and to improve the resilience of agriculture to climate change.

A study in 2020 found it costs between US\$ 0.35 and 1.87 to desalinate 1000 litres of sea water (Eke *et al.*, 2020). Whilst this is considerably less than the price of a litre of bottled water, desalination is too expensive for staple food production.

Crop choice and farming systems can also influence plant water uptake and thus water productivity. For example, by switching rice cultivation from flood irrigation (which uses very high volumes of water and emits high levels of Greenhouse gasses) to aerobic (oxygenated) conditions, water use can fall by 50 percent, cutting GHG emissions and possibly even increasing yields. The consultative Group on International Agricultural Research (CGIAR) has released more than 8000 improved crop varieties during the last 40 years, some of these with drought- resistant characteristics.

‘Climate-smart farming’ is a term coined by the UN FAO. The organisation is clear that “climate-smart farming systems that make efficient use of resources like water, land, and energy must become the basis of tomorrow’s agricultural economy”⁶.

Organic Farming

In 1999, 20 percent of arable land (in Europe) was engaged in some form of voluntary agri-environmental action and over 2 million ha were devoted to organic farming (Strosser *et al.*, 1999). Organic farming is generally considered to be less water-intensive than standard farming. It is also praised for using fewer pesticides, or pesticides that are less soluble and therefore have less impact on the water environment. However, a 2012 study published in *Nature* (Seufert *et al.*, 2012) reports that organic yields are lower than in conventional farming. Also, as artificial products are replaced with natural fertilisers, e.g. animal manure, it can be more difficult to monitor and control nitrate and phosphate concentrations.

⁶ FAO comment at the Bonn 2011 Nexus Conference

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Knowledge Exchange

Water security, and the specific actions to improve resilience, are complex and multi-faceted, and so research, policy, and business sectors are starting to work together to better understand the science of water security. The Water Security Knowledge Exchange Programme (WSKEP) is an initiative in the UK funded by the Natural Environment Research Council to “accelerate the uptake of research and help inform the direction of future science to ensure a sustainable use of water in the future”. One of the WSKEP priorities is water and agriculture.

In the irrigated crops sector, there is a need for knowledge transfer regarding irrigation techniques and improving application, and research into producing crops with less demand for water focusing on drought resistance and improving quality traits without water use. The emphasis in plant breeding programmes could be on drought resistance.

In the livestock sector, efforts should focus on more efficient use of water for the washing of plant and machinery, particularly within dairy enterprises, through knowledge transfer initiatives regarding opportunities to capture excess winter waters and making better use of available water. It is not feasible to suggest efficiency savings in drinking water requirements (majority of livestock water consumption).

Retailers and Brands

It is in the interest of retailers (i.e. the supermarkets) and major brands to ensure that their product lines and the supply chains which support their business are secure against water risks. They have a key role in influencing and managing activities within their supply chains, as well as maximising water efficiency in their own stores and factories. This part of the food supply chain is in a position to help support water efficient farming methods (and many retailers and brand companies do this). They are also in a position to re-assess the implications on water consumption of aesthetic related food ‘quality’ standards, and the implications on water of food losses at the farm site (i.e. food rejected and food lost through on-farm storage methods), storage and transport facilities, food processing sites, and at retail units.

Customers

A hidden problem is that farmers have to produce food to take care of both our necessary consumption, and our waste. Big supermarkets offer a wide range of foods, but not all perishable goods can be sold before their expiry date. With consumers increasingly concerned about food safety and demanding high quality fresh produce, this inevitably ends up with food being thrown away even before it is sold and often whilst it is still perfectly good to eat (Lundqvist *et al.*, 2008). The food losses are huge (possibly as much as 50 percent between field and fork, Lundqvist *et al.*, 2008) and are equivalent to huge losses of water. Individuals have the power to limit waste by moderating food shopping habits, avoiding buying more food than is necessary, or more food than can be consumed before it needs to be thrown away. Individuals may also wish to consider the water footprint of their food and drink choices, but footprints should be considered in the context of the water stress or scarcity of the source location (which may also be temporal).

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