Water Footprinting – A review in support of the Defra project WU0120.

Lillywhite RD, Allan AJ, Chapagain A & Garnett T

This review supports the Defra project WU0120 'The Water Footprint (WF) of selected UK produced and consumed products. The purpose of this review is to provide background to the project, describe how WF methodology has developed and to explore results from the academic literature.

This review is split into four main sections: Introduction, trade and policy, methodology and footprinting studies.

Contents

1. Introduction

In 2008, Defra commissioned Tara Garnett of the Food Climate Research Network at the University of Surrey to prepare a briefing paper on virtual water and water footprints (WF)s (Garnett, 2008). This introductory section expands on her briefing paper and we acknowledge her contribution.

The purpose of this section is to outline the key concepts and approaches that are being used, or are under development, to quantify the water used to produce the goods we consume. This section will also summarise how these approaches can be used to assess the economic, environmental and social impacts of water use.

Virtual water: The concept and its variants

The term 'virtual water' was introduced by Tony Allan (1993, 1994). It was defined as the volume of water required to produce a commodity or service (Allan, 1998, 1999; Hoekstra, 1998). In its initial form, virtual water was seen as a rational means by which water-scarce countries could import water, embedded in goods, from water-abundant countries.

Since then, it has been found that the impact of trade in moving water from the water-abundant to the water scarce countries may in fact be modest. One study of international cereal trade flows found that (for 1995) without trade, global crop water use in cereal production would have been higher by just 6 %. This suggests that most trade takes place for reasons unrelated to water. Moreover, not all water 'savings' can be or are reallocated to other beneficial uses. Finally, political and economic considerations, often outweighing water scarcity concerns, limit the potential of trade as a policy tool to mitigate water scarcity (de Fraiture et al., 2004).

The virtual water concept has evolved to represent the large quantities of hidden water 'embedded' in our goods and services. Importantly, the virtual water concept has gained nuance and depth of meaning as researchers have defined distinctions between different types of water, and different contexts within which this water is used. Note that the virtual water concept and its practical application (in the form of WFs) have lost their separate identities in the popular literature. The term virtual water has its related variants, including embedded water and 'shadow' water; the term virtual water is used through this review.

Water types

The Water Footprint Network (WFN) defines the volumetric WF as the virtual water content of a product; that is, the total volume of freshwater used within all stages of the supply chain. The adjective 'virtual' refers to the fact that most of the water used to produce a product is not contained in the product. The term 'WF' was chosen to be analogous to the ecological footprint and represents the appropriation of resources; its use can therefore be more "user focused" as opposed to virtual water, which is an inherent property of the commodity.

The real-water content of products is generally negligible if compared to the virtual-water content. For example, a litre of milk may contain nearly a litre of water but the whole supply chain consumed 1000 litres of water including water to grow the grass and concentrates to feed the cow, drinking water, washing water, cleaning water, cooling water and processing water (WFN).

The WF of a product comprises three colour-coded components, generally categorised and defined as follows:

Green water. This is soil water derived from rainfall. Green water supports all non-irrigated agricultural production (rain fed cropping) and is normally assumed to be the volume of water that is lost through evapotranspiration during crop growth. As evapotranspiration is a function of climate, crop location has a major impact on the volumetric WF. Consequently, a key issue for WFing of agricultural products is the treatment of green water. Initial work on virtual water (Chapagain & Hoekstra, 2003) did not capture green water use, although more recent work has incorporated it into studies on volumetric footprinting. However, the inclusion of green water is again being questioned since some workers contend that "green water (and other resources) is only accessible through access to and occupation of land" and that "the consumption of green water in agri-food product life-cycles is better considered in the context of land use" (Ridoutt & Pfister, 2009). This is discussed further in the methodology section. How green water is treated is critical to both the size of the WF and its interpretation and the current methodological discussions have not yet reached a common position. The inclusion of green water within the volumetric WF is a useful auditing tool but the need to consider water use within the wider context of land use and environmental impact has exposed its limitations.

Green water is often seen as 'free' and its use unproblematic but this is not necessarily always the case. In the majority of situations, interception of rainfall by the plant canopy of cash crops is less than that of natural vegetation; this leads to the scenario where replacing natural vegetation by cash crops can increase ground water and river flows (Scanlon et al., 2007). However where rainfall is limited and there are concerns over low levels of ground water or river flows, it may be economically, environmentally and socially preferable to grow an irrigated high value crop like strawberry or flowers rather than a rain fed high water requirement crop, like maize.

Blue water. This is surface (lakes and rivers) and ground water. This is the water abstracted by farmers for irrigation or by water companies to supply the general population.

Blue water can be used sustainably, and without long-term detrimental impact, where water abstracted during the growing season is fully replenished during the following wet season. These situations can be further improved by the efficient use of water, for example, scheduling and accurate irrigation, however, it should be remembered that efficient use is not necessarily sustainable use.

Grey water. This is the water that becomes polluted (contaminated) during the production of goods and products. Confusingly, grey water has two definitions: firstly, the usual commercial definition that it is the volume of water that is polluted within the supply chain of a product; secondly and this is the definition more commonly used with WFing, it can be the volume of water required to dilute the polluted water so that it may be discharged to the natural water system and meet agreed water quality standards.

The first definition is easily quantified as most businesses will have a discharge licence which states the volume of water that they may discharge but the second definition can create difficulties. The requirement to calculate a volume of water required to dilute another volume of water to an agreed discharge standard involves knowing the concentration of pollutants in both waters (background in one and added in the other) and the exact volumes required to achieve a set discharge concentration.

Not all grey water is derived from blue water. Rain fed agriculture will have a grey WF due to leaching by rainfall. In fact good irrigation management can reduce the grey WF compared to rain fed agriculture in a place like the UK. These reasons illustrate why grey water calculations are difficult to make and why grey water is often excluded from WF calculations.

Water in context

The use of water should always be considered in the context of location. The production of 'thirsty' crops in regions where rainfall is plentiful and there are no competing demands for the water is not a problem; indeed, in some cases the ability of a crop to use up water that would otherwise cause flooding (as in the case of rice) may be actively beneficial. Similarly a country may import a great deal of virtual water but it may be sourcing its supplies from regions where water is in abundance - or vice versa.

The volumetric WF is useful metric and auditing tool but on its own cannot be used to assess the economic, environmental or social impacts of water consumption; that currently requires qualitative interpretation. Consequently, when considering the 'virtual water' content of a product it is necessary to consider whether the country or region of production is water scarce, water self-sufficient or water dependant.

Renault (2002) argues that the value of virtual water of a food product should be assessed against five principles:

- Standard water use values per food product (this will differ from region to region)
- The marginal water requirements for an alternative production close to the consumption site
- The nutritional equivalence between food products (the nutritional value of one imported product as compared with an indigenous alternative).
- The substitution (or reallocation) effect: that is, how or whether water 'saved' through importing goods is allocated to other activities
- Historical trends in productivity in relation to water use.

However, it is not clear how far this has been taken up and pursued further in thinking on virtual water. Importantly, there is little mention of the need to consider virtual water use in relation to wider environmental concerns. Although it has been noted that major regions such as the water scarce Middle East have avoided even more serious negative impacts on environmental water services by the 'import' of virtual water. The principles also fail to take into account the fact that neither world trade in food products or any reallocation of water are not driven by virtual water of agri-food products.

It is important that the issue of virtual water be viewed within a broader environmental, social and economic framework that encompasses the sustainability of the region's hydrological system ; socio-economic concerns such as income generation, development, trade and access to water must also be factored into any analysis. Key questions relate to water management issues such as rights and allocations as well as environmental needs. Virtual water can only be one part of understanding the water balance of specific systems and cannot itself be an adequate instrument for policy.

Sustainability

The terms sustainable and sustainability are used throughout this document. Sustainability is a very important concept, perhaps the most important in the current global climate, however, it is also a very dangerous term and should be used with care. In places, especially when dealing with WF methodology, sustainability is based on the underlying fundamentals of hydrology and economics which are areas where environmental scientists and economists can agree.

However, society in general constructs its notion of sustainability on the basis of very different beliefs and experience. This is well illustrated by the current climate change science/policy discourse. The challenge of delivering a scientists' version of sustainability into the policy domain, into the farming community and the market etc is beset by the challenges of changing mindsets. Reporting is not enough.

The project

This section reproduces (and updates where required the objectives from the Defra SID3.

The overall aim of this project is to produce, and review the impact of, WFs for a range of UK and imported food products. This work will contribute to Defra's Food Chain Programme objective to reduce the global impact of UK food consumption and production. The recent WWF report 'UK WF' (Chapagain & Orr, 2008) reported that large quantities of water are required to grow and process the food that is produced and consumed in the UK. WFs (virtual water) are useful indicators and this project will calculate them for selected products and assess their impact on UK and overseas water resources. The work will be split into the following objectives:

1. Assess current WFing methodology and determine the best method to use in the study
2. Review recent WFing studies and determine the UK and imported products to be assessed in the study
3. Collect data and prepare WFs for selected commodities and products
4. Explore the relationship between the production of UK commodities and domestic water resources
5. Determine the environmental and social impact of domestic and imported products
6. Assess the potential consequences of climate change on the UK's WF
7. Report on, and discuss, the results and make recommendations for future work

Background

A WF is a measure of the virtual (or embedded) water required to produce a product. The concept was introduced by Allan (1998) and has been developed by Hoekstra, Chapagain and others since. Virtual water refers to the amount of water required to produce a product, from start to finish. Virtual water is hidden and neglected and not accounted for. It is commonly considered in three categories: blue, green and grey. Blue water is the water contained in rivers, lakes and aquifers and is the water processed by the water companies to supply public and commercial demand; this water is used in the food processing industry. In countries that have extensive irrigated agriculture the use in agriculture is very substantial. Green water is the water supplied through rainfall and stored in soils; the majority of agricultural production worldwide is based on green water. The UK has very limited area of irrigated farming – less than five per cent of the arable area is equipped for irrigation. Grey water is waste or contaminated water.

The concept of footprinting has been used successfully to describe the impact of production (and consumption); it is most commonly applied to carbon, as in PAS2050 (BSI, 2008) but can also be applied to water. Agricultural production uses large amounts of water; for example, Chapagain & Hoekstra (2004) calculated that, in the Netherlands, it requires 619,000 litres of water to produce a tonne of wheat and 11,681,000 litres to produce a tonne of beef. The recent WWF report suggests that imported food and fibre account for 62% of the UK's total WF.

Food processing, whether it simply washing prior to sale (carrots) or more complicated preparation (preparing a pizza with multi toppings) uses large quantities of water. This is normally blue water, which once used, is normally discharged back to surface waters. Although little water has been "consumed" the returned grey water is usually of a lower quality than the abstracted blue water and additional blue water may be required to assimilate emissions (pollution) to the freshwater ecosystem from the production process. The definition of grey water is confusing.

A recent WRAP study revealed that households in the UK discard 5.4 million tonnes of food every year, accounting for around a third of all of the food we buy. This waste food contains large amounts of virtual water, used in production and processing, which is wasted. In the United States it has been estimated that wasted calories accounts for about a quarter of the country's freshwater consumption (The Economist, Nov 26th 2009).

The use of water always has an environmental impact. In water rich countries, like the UK, this is generally small and is concentrated in certain areas of the country (such as East Anglia) and is restricted to certain times of the year. Although blue water abstraction for agriculture is less than 1% of the total, in some catchments and at peak times it can exceed abstraction for domestic water supply. However, in water poor countries, water use can have severe impacts, for example, in Morocco, where water demand for horticultural irrigation has lowered the water table to the detriment of future supplies for all sectors. The impact of the UK's WF, both domestically and overseas, has environmental and social consequences.

This project has two individual, but linked, areas of investigation:

1. To determine the WF of selected UK produced agricultural commodities and relate the water used in production to current water resources;
2. To determine and compare the WF of selected food products which can be produced domestically or imported.

The following section details the specific activities, roles and responsibilities associated with each project objective.

1. Assess current water footprinting methodology and determine the best method to use in the study

Water footprinting methodology is still under development. Although the concept of blue and green water is established, the notion of grey water has only been partially recognised. Most current WFing methodologies account for the evapotranspiration of blue and green water from primary crop production but not the virtual water contained within any inputs, for example, the production of fertilizers can use large quantities of water. Many studies stop their investigation at the farm gate and so fail to consider water use in food processing and manufacturing. Boundary issues, such as these, require consideration to ensure that any analysis, especially comparative, is robust and address the full impact of water consumption in the supply chain. Waterwise are currently reviewing the current methods available for assessing water associated with food production; the report was due in May 2009.

In addition, the temporal variability of water demand in relation to water availability should be assessed and, crucially, a method to effectively capture the impact of the WF on the source water resources must be developed.

The team will conduct an assessment of current WFing methodology to support recent Defra commissioned work undertaken by the University of Surrey (Garnett, 2008). The results will be discussed by the project steering group to determine the most appropriate methods to be used within the study.

2. **Review recent water footprinting studies and determine the UK and imported products to be assessed in the study**

The team will conduct a brief review of recent work on WFing; the purpose of which is to inform the decision making process.

The review will identify domestic and international products for which WFs already exist and which could be used to inform our investigation. For example, WWF have assessed and reviewed the UK's WF (Orr & Chapagain, 2008) and Tony Allan (King's College London), Arjen Hoekstra (University of Twente) and Ashok Chapagain (WWF) has published extensively on WFing and techniques. The literature search will be international in scope, investigating relevant published research by cross-searching international databases using relevant search engines (e.g. Scopus; Academic Search Complete; Science Direct); the review will also identify 'grey' literature through targeted internet searches.

The choice of product was discussed by the project steering group at its first meeting in November 2009 to determine the most appropriate domestic and international commodities and products to be investigated within the study. The following products were selected:

- UK produced products (wheat, sugar beet, potatoes, strawberry, milk and lamb)
- UK consumed products – sugar cane (Swaziland), strawberry (Spain/Morocco), potato (Israel) and lamb (New Zealand)

3. **Collect data and prepare WFs for selected commodities and products**

Estimates of volumetric WFs already exist for a number of products, for example, The WF Network has calculated the virtual water content of many different products, however, these studies tend to be focused at a macro level and used standardized data sets to produce their results. More specific research has been published, Chapagain and Orr examined Spanish grown tomatoes but this type of investigation is in the minority.

WFing methodology uses evapotranspiration as one of the main input parameters and this varies with location, temperature and radiative input; evapotranspiration will be estimated using UK crop / soil / climate combinations from historical weather data and models. Data on blue water used for irrigation, spraying, washing and processing on UK agricultural commodities will be collected from different regions; this will allow variability to be assessed and comparisons to be made. An assessment of grey water will be made where possible.

This study will collect primary data (where possible) from multiple sources (growers, processors, retailers, trade organisations, Government and other published sources). Where primary data is unavailable, secondary data sources will be substituted (existing studies and literature). WFs will be calculated, using the methodology agreed on in Objective 1, for the commodities and products chosen in Objective 2.

4. **Explore the relationship between the production of UK commodities and domestic water resources**

In the UK, green water has limited environmental impact and opportunity cost although blue water is a different matter. Abstraction of blue water for agriculture has environmental and social impacts (both positive and negative) and it is likely that these impacts will increase with climate change (predicted to lead to hotter summers and lower average river flows in some parts of the country) and increasing population. There may come a point in time where the trade off between water for agriculture, people, industry and the environment requires difficult decisions to be made and it would be interesting to speculate on whether production of crops with high blue water requirements (such as potatoes), in areas where competition for water resources is high, would still be desirable.

The Environment Agency (EA, 2008) have developed water resource availability maps which show the availability status of water resources for the individual Catchment Abstraction Management Strategies (CAMS) areas. These are divided into water available for abstraction, water abstracted and the water abstracted for spray irrigation. These maps illustrate the demand and impact on a detailed scale. We suggest that it would be useful to use this type of mapping to explore the link between available water resources and the (blue) WFs calculated for agricultural commodities.

The commodity WFs (calculated in Objective 3) will be combined with Defra's agricultural production statistics to develop UK WF maps at CAMS level which will be compared to the EA's water resource maps. We will investigate and report whether WFing could be used as a decision support system for future water resource planning.

5. Determine the environmental and social impact of domestic and imported products

The quantity and quality of water resources is an issue in many parts of the world, for example, there is already sufficient evidence from water scare regions (Spain, North Africa, South Africa, Australia) to suggest that current production levels (for export) of many commodities are un-sustainable. The WWF report has shown that the UK imports virtual water from countries with limited or scarce water resources and it is likely that this practice may be encouraging un-sustainable use of water resources. There is a need to investigate how effectively water usage is priced, allocated and governed in countries which the UK imports food commodities/products from.

For selected products, which can be produced both domestically and imported, we will calculate comparative WFs; for example, UK produced glasshouse tomatoes versus Spanish tomatoes grown under polytunnels. We will analyse, in terms of water usage, which production site has the lower environmental impact in relation to local water resources.

We will identify those countries with limiting, or scarce, water resources and comment on the environmental, economic and social impact of exporting virtual water. We will seek to identify areas where conflicts exist, for example, between the export of high value products to generate foreign income against the pricing and depletion of local water resources. We will determine where the import of products into the UK is having an adverse long term effect on the water resources of the exporting country and suggest solutions to mitigate the long term environmental and social consequences.

6. Assess the potential consequences of climate change on the UK's WF

The IPCC's 4th Assessment Report (IPCC, 2007) suggests that southern Europe and the Mediterranean Basin, Southern Africa, western United States and southern and eastern Australia will suffer a decrease in water resources with a consequential reduction in crop production although benefits are projected for other more temperate regions. This forecast suggests that the UK may need to produce more products domestically and should rely less on imports from the most adversely affected countries and that imports may instead come from countries like New Zealand and Canada.

Increased UK production will have a number of subsequent environmental and social effects, both in the UK and around the world. Based on selected products, we will assess how the UK's WF will vary using a number of different scenarios. For example, if the majority of tomatoes were produced domestically instead of imported from Spain, how would the volume of imported virtual water change and how would it affect the UK's water resources. We will investigate the environmental and social impact, of any changes to the UK's overall WF, both in the UK and overseas.

Individual catchments

The first meeting of the steering group took the decision that the project should concentrate on collecting data for three UK catchments: The Eden in Cumbria, the Hampshire Avon and the Wensum in Norfolk. The rationale was that these three catchments are the subject of the Defra Demonstration Test catchment programme and that it would add to the total sum of knowledge of water consumption and resources.

The Eden in Cumbria

"The principal watercourses are the Eden, Eamont, Irthing, Petteril and the Caldew, with a total catchment area of approximately 2,400 square km. The catchment is predominately rural with only 1% classified as urban. Around 244,000 people live in the catchment, the principal population centres are Carlisle, Penrith and Appleby. The upper catchment is dominated by the steep gradients of Skiddaw, Helvellyn and surrounding fells. Below Kirkby Stephen, the Eden's valley widens. The Lower Eden is characterised by wide floodplains and washlands. These areas are important in providing storage capacity during high water levels. The catchment is subjected to some of the highest rainfalls in England. Upstream of Penrith, average annual rainfall exceeds 2800mm compared to 920mm across England and Wales. In the upper catchment, high rainfall and the steep terrain make the Eden a 'fast-responding' catchment where high river levels occur soon after heavy rainfall, and it can reduce the time available to provide advanced warning of flooding."

"The Eden Valley contains areas of high quality farmland in the low lying areas, and less intensive farming in the foothills of the North Pennines. There are also some areas of intensively managed pasture on the Solway Plain. However, the main land use is livestock with grazing pasture. Agriculture forms an important part of the local and regional economy, with tourism growing in importance. The rural nature of the catchment provides an opportunity to manage land use to reduce run-off and increase the time between rainfall and peak flows. However, holding water for longer periods of time on agricultural land can lead to increased crop damage and adversely affect rural economies" (Environment Agency, 2009a).

Agriculture within the Eden catchment is dominated by grass based systems: dairy and sheep. Table 1 contains a breakdown of selected products.

Table 1. Estimated agriculture in 2007 within the three catchments

Catchment	Catchment (km^2)	Wheat (ha)	Potato (ha)	Sugar beet (ha)	Strawberry (ha)	Dairy cows (head)	Lamb (head)
Eden	2396	2534	228	0	0	60,885	380,691
Hampshire Avon	1733	24,310	75	122	40	16,554	48,319
Wensum	557	8,936	289	3646	0	1,264	7,201

The Hampshire Avon

"The Hampshire Avon catchment is located in the south of England. The Hampshire Avon rises in the Vale of Pewsey to the north of Salisbury. The watercourses here receive significant flows from the chalk aquifers underlying Salisbury Plain, and then flow in a southerly direction towards Christchurch Harbour and Christchurch Bay on the south coast. At Salisbury, the Avon is joined by two of its major tributaries - the River Bourne and the River Nadder (including the River Wylye), and a short distance downstream by the River Ebble. The overall catchment area is about 1,750 square kilometres, and has a population of around 230,000. Only two per cent of the catchment is urbanised. As well as Salisbury and Christchurch, its main urban areas include Warminster. The Hampshire Avon catchment is characterised by open chalk downland with steep scarp slopes, sheltered valleys, chalk hills, ridges and limestone plateaux. These significant variations in the topography have a strong influence on the rivers' response to rainfall. The upper Avon catchment is typified by the undulating, chalk downlands of Salisbury Plain, which are cut by steep combes and river valleys. The lower catchment is characterised by rolling farmland and the New Forest. The main watercourses have wide floodplains and flow through farmland, woodland, scrub and open heathland" (Environmental Agency, 2009b).

Agriculture with the Hampshire Avon is dominated by arable systems although according to agcensus data it is the only one of the three catchment where all the products are produced.

Wensum

"The Wensum catchment drains an area of Norfolk in East Anglia about 40 km west-east and 25 km north-south with relatively low-lying topography ranging from about 80 m in the west to a few metres above sea level where it joins the River Yare at Norwich. The whole of the Wensum catchment is underlain by the Cretaceous Chalk. In the eastern part of the catchment, the Chalk is overlain by Pleistocene Crag sands and gravels. Both these bedrock strata are overlain by a complex sequence of Pleistocene glacial tills and glaciofluvial sands and gravels and Holocene deposits (blown sand, alluvium, peat and river terrace deposits). In 1993, 71 km of the River Wensum was designated a Site of Special Scientific Interest (SSSI). The Wensum is widely recognised as one of the most important chalk river habitats in England with over one hundred plant species and a rich invertebrate fauna" (UEA, 2010).

Agriculture within the Wensum is dominated by arable crops, especially wheat, sugar beet and potatoes with only very limited livestock.

2. Trade and policy issues

Purpose of the section

The purpose of this section is to identify the policy areas and issues with which the analysis and its recommendations must engage. It also draws attention to all the water resources which are used to produce food commodities. These waters being used will include both green and blue water by first, those engaged in managing water – the farmers, secondly, those who process and market the commodities produced with water, thirdly, those who consume the commodities, fourthly, those who could possibly regulate the use of water and impact the commodity chain, fifthly, those who advocate improvements in the stewardship of water resources, and sixthly, the international impacts of crop and livestock production and current trade policies. It may be concluded that the market and regulation can provide only limited means of impacting the way water is used and re-used. It may also be concluded that it will be the way consumers impact the demand for food commodities that has and will determine the use of water. The education of consumers may be the key factor in shifting the use of water in crop and livestock production in ways consistent with the sustainable intensification of production.

The section will have two parts. First, the policy areas and policy landscapes of relevance will be indentified and the main policy issues highlighted. Secondly, there will be a preliminary discussion of communication and how to engage in the political landscapes identified

Policy contexts and landscapes - agricultural production, economic and commercial, consumption, environmental and political landscapes

'Only if those marketing and consuming farm outputs share in the environmental and market risks of crop and livestock production will there be a fair supply chain.'

Agricultural production and farm policy

In the UK, farming and crop and livestock production are in a long and painful transition from a period characterised by the UK 1947 Agricultural Act reinforced by the supportive policies of the EU after the UK joined the European Community in 1973. Until the mid-1990s UK and other EU farmers operated in this supportive context with price support and guaranteed markets and until the 1980s with limited regard for the environment. Impacts in economies beyond the Commission – now Union – have been subject to WTO negotiation and it has proved to be very difficult to get EU and US interests to unpick the policies which favour their farmers. The process has been slow but the outcomes have made it increasingly difficult for farmers – especially in some sectors such a dairy farming – to have secure livelihoods. A sensible balance has not yet been achieved.

The way water is used is a consequence of the practices evolved in this supportive but environmentally and internationally blind approach. The international blindness is the tendency of European and North American farming and government interests to be indifferent to the impacts of subsidised production and 'global trade' on farmers in poor developing economies. Global prices determined by EU and US subsidies have very negative impacts on these very numerous poor farmers.

Farmers, operating in these less than ideal market circumstances in the case study regions of this study are, however, the key players in the management of water in these regions. Farmers are the professionals who combine all the inputs that determine the levels of returns to water. Including the crop per drop, the jobs per drop and the value per drop. Currently they operate in very risky markets and have to cope with uncomfortably variable climate and water environments. They determine whether there is progressive *sustainable intensification* of water use. If they are forced to operate in circumstances where the risks are unreasonably high they will cease to farm. The market is not the best or only way to ensure that the interests of farming communities and of the environment are best served. Only if those marketing farm outputs and consuming them share in the environmental and market risks of crop and livestock production will there be a fair supply chain.

Main farm policy issues
Farmers are water managers of the majority of green water; 95% in the UK. Along with engineers they are also the main water managers of blue water. The mis-management of blue water has a higher profile as low flows in rivers and exhausted aquifers are more evident than crop production constraints of low green water availability. Farmers play a key role in stewardship and water use efficiency. Motivating and supporting farmers is a key policy area.

Processing and marketing – the supply chain

Food commodity markets are diverse but in the EU they are dominated by the super-markets and major corporations. These organisations have only recently become aware of the role of water in their supply chains. They are much more aware of the carbon footprints of their activities than of the WFs. Providing consistent and agreed metrics for embedded water is much more difficult than for embedded carbon. Reflecting the value of embedded water in commodities is very challenging indeed. Pricing is therefore an unlikely means of affecting consumer behaviour. Using these metrics to influence producers or consumers is unlikely to be a useful policy tool.

Main policy issues in the supply chain
Food manufacturing and supermarkets are the main players in this policy area. Using the embedded water metrics will require careful review and analysis. Labelling likewise.

Consumers and human health policy issues

What people purchase, actually consume and waste is of vital significance. A vegetarian diet requires only about half of the water per day of a beef intensive diet – c2.5 m^3/day versus c5.0 m^3/day. Meat intensive diets are also associated with ill health. There is a line of thinking that suggests that beef should be a luxury item so that the returns to grass-fed beef production are economically viable, the stewardship of water is a priority and the health of the population is achieved.

It has been estimated by WRAP that consumers in the UK waste about 30 per cent of the food purchased. Personal choice and behaviour determines major proportions of actual water consumption in food eaten and wasted. Existing pricing in markets, nor the assumptions of those who believe that markets bring effective outcomes, will address these behavioural issues. Reorienting advertising to reduce food waste is non-intuitive. Public awareness campaigns are more likely to be implemented.

Collective and individual food consumption patterns and the levels of consumption of different commodities are influenced by culture, income, and the market services in place. These market services also advertise to stimulate consumption. NGO activists campaign to promote approaches to consumption that protect the environment and promote human health. The current coordinated concern of a number of UK departments of state indicates that chief scientists and those around them have begun to recognise the need to encourage sensible consumption. They also recognise that these initiatives require engagement with the consumers.

Main policy issues in relation to food consumption and human health
The *beliefs and preferences of consumers* determine how much water is used to produce commodities. Understanding the ideas and preferences of consumers and how they can be influenced by those who *manage the market and its advertising and packaging arms* is key. Those in government who want to *regulate consumption to protect human and environmental health* need to engage closely with market and NGO activists.

Regulation policies

The use of water in agriculture and livestock production is normally embedded in long standing rainfed and irrigated farming practices. Over the past half century European farmers with the help of inputs including crop science, improved seeds, fertilizers, herbicides and pesticides have increased water productivity - from an already high level – by three times in rainfed farming and even more in irrigated farming. EU farm policies also lowered the risks for farmers and they responded by increasing production and yields. European farming is currently facing a number of challenges. First, the secure EU regime is changing. First, farmers are facing increased market risks. They are at an increasing disadvantage vis-à-vis the major super-markets. Secondly, they are being asked to adopt principles of environmental stewardship.

In these circumstances farmers – the major managers of water – will only be able to respond to calls to allocate water to advance human and environmental health if those managing the markets into which they sell their products take the costs of precaution and stewardship into account. There is also a potential role for public policy but such interventions will have to take into account international trade rules.

Main policy issues with respect to regulation of water use on farms – human health and environmental stewardship
Farmers manage water. The extent to which they can give attention to precautionary policies will depend on the willingness of the food processors and distributors to recognise the additional costs of these practices. The complex nexus between farming and the supply chain will be very significantly affected by attempts to regulate the use of water on farms. Public policy would have to be sensitive to the costs of precautionary and protective approaches.

International trade - impacts and policy

Food production and marketing are global systems. International trade has a long history and a feature of that long history is that trade relations are asymmetric and elements of them have been and remain unfair. International food trade has a particularly unpleasant history. As is normal the current phase of the international food trade favours those players that are well organised, that use advanced transport and information technologies, can hedge and insure their activities and can dominate the international bodies that develop and make the rules. Ask the New Zealanders and the Australians for examples. And then consider how much more difficult it is for the poor farmers in other continents. Any attempts to get farmers to re-allocate water according to principles of human and environmental health must expect to engage with much more elemental political forces than these abstract ideas.

The issue of international trade is not considered in depth here. It is flagged as a major feature of the political landscape into which any ideas on optimising the allocation and use of water would have to find a place.

Main issues in relation to international food trade
The conventions and rules of international trade are complex and highly charged politically. We must not underestimate the challenges of introducing new approaches that contradict the interests of powerful players with long-established practices.

Next steps

After comments by the steering Committee and DEFRA on the above approach and framework it is proposed to investigate the areas of *Policy* and *Communication* a programme of enquiry will be initiated to determine the extent to which consumer interests, farming interests, supply chain interests and international trade interests can be engaged and impacted.

3. Methodology

This section on methodology includes a full description of the volumetric footprint and a brief description of the stress-weighted WF.

Volumetric WF

The WF is an indicator of freshwater use that looks not only at direct water use of a consumer or producer, but also at the indirect water use. It is a comprehensive indicator of freshwater resources appropriation, next to the traditional and restricted measure of water withdrawal (Hoekstra *et al.*, 2009). The WF of a product is the volume of freshwater used to produce the product, measured over the full supply chain. It is a multi-dimensional indicator, showing water consumption volumes by source and polluted volumes by type of pollution; all components of a total WF are specified both in time and space.

The WF offers a wider perspective on how a consumer or producer relates to the use of freshwater systems. It is a volumetric measure of water consumption and pollution. As argued by Hoekstra *et al.* (2009), it is not a measure of the severity of the local environmental impact of water consumption and pollution. The local environmental impact of a certain amount of water consumption and pollution depends on the vulnerability of the local water system and the attributes of water consumers and polluters making use of the same system. WF accounts give spatiotemporally explicit information on how water is appropriated for various human purposes. They can feed the discussion about sustainable and equitable water use and allocation and also form a good basis for a local assessment of environmental, social and economic impacts.

Evolution of the concept

The concept of WF has a very close link with the concept of virtual water, a term coined by Allan (1998b; 1998a; 2001) inspired by his investigation into the suitability of virtual water imports as a partial solution to problems of water scarcity in the Middle East. He argued that trade of water intensive products to the Middle East region relieved the need for those import countries to use their own water to produce the same product. The concept of virtual water took on more precise and practical applications once Hoekstra and Hung (2002), Chapagain and Hoekstra (2003), Zimmer and Renault (2003), Oki *et al.,* (2003), Yang et al., (2006) and de Fraiture *et al.,* (2004) began to quantify and calculate global virtual water flows. With the framework of quantifying the volume of water flows related to the transfer of water intensive products, it is then possible to quantify the volume of water needed to support any specific consumption pattern, be it a nation, group of consumers or an individual. This led to the evolution of the concept of WF (hereafter termed as WF).

The first preliminary assessment of the WF of nations was carried out by Hoekstra and Hung (2002). This study used the volume of blue water withdrawal (*e.g.* water from lakes, rivers, reservoirs) in a nation as a measure of water use from domestic resources, added to the net virtual water import related to the international trade of a limited number of primary crops to calculate an average WF of a nation. A more extensive assessment was later carried out by Chapagain and Hoekstra (2003) including the international trade of livestock and livestock products.

However, neither studies accounted for the volume of green water (soil moisture fed by the effective rainfall) used to produce crops consumed domestically, a situation later rectified by

Chapagain and Hoekstra (2004). While numerous studies on various WF scenarios exist (Hoekstra and Hung, 2002; Chapagain and Hoekstra, 2003; 2004; Hoekstra and Hung, 2005; Orr and Chapagain, 2008), the nature of their scope has detracted from their potential to speak meaningfully about specific growing sites. Firstly, they use average climate data to calculate the virtual water content of a product. For a country with greater spatial variation of climate, such as the USA, China or India, the average virtual water content of a product varies significantly over time and space. Secondly, they assume that in all cases the potential crop evaporation is met. *This means that deficit crop water requirements are always fulfilled by supplementary irrigation, which is far from reality, as only 20% of global arable land is irrigated.* Therefore there is an overestimation of the virtual water content of crops and livestock products in these studies. Lastly, these studies do not account for any pollution effect of production on local fresh water bodies.

Chapagain *et al.,* (2006) extended the WF concept by quantifying the impacts of pollution related to the consumption of cotton products. This required establishing the water volumes needed to dilute waste flows to such an extent that the quality of water would remain at least equal to agreed water quality standards. The authors further refined existing studies by using climate data from climate stations effectively covering production regions. This accounted for more specific climatic variations within countries. The cotton study also used local crop characteristics together with the water availability during crop production (the volume of supplementary irrigation available). Chapagain (2006) and later Hoekstra and Chapagain (2008) presented the evolution of the concept of virtual water and WF into one coherent framework. Though this provides a useful methodology to calculate the WF related to the consumption of crop products from open systems, it does not address the different conditions of production under covered systems. Also, in these studies the crop water requirements calculated for one dominant season is assumed to be valid for crops grown at different seasons in a year. Thus, they ignore the inter-seasonal variability of virtual water content of crops in countries where there may be more than one major growing seasons. These deficiency in the accounting framework is later on ratified by Chapagain and Orr (Chapagain and Orr, 2009). A coherent framework of WF accounting has recently been compiled as a manual on WF accounting by WF Network (Hoekstra *et al.*, 2009).

Any WF assessment has 4 distinct phases: scoping; WF accounting; WF sustainability assessment; and WF response formulation (Hoekstra *et al.*, 2009). The first phase is necessary to clearly set the goals and scope of the study. A national government may be interested in knowing its dependency on foreign water resources, or water dependencies within its various regions, or it may simply be interested to know the sustainability of water use in the areas where water-intensive products are imported from. A river basin authority may be interested to know whether the aggregated WF of human activities within the basin violates environmental flow requirements or water quality standards at any time. It may also want to know the extent to what the scarce water resources in the basin are allocated to low-value export crops. A company may be interested to know its dependence on scarce water resources in its supply-chain in the light of minimising various associated business risk.

The second phase of WF assessment is the phase where accounts of WF are developed. This phase has gained major focus in much of the earlier publications on WF until recently a wider debate on the impact assessment has started with publications (Chapagain and Orr, 2008; Mila` i Canals *et al.*, 2009; Pfister *et al.*, 2009; Ridoutt *et al.*, 2009b; Ridoutt and Pfister, 2009). The impact assessment is the third phase of WF assessment where the WF is evaluated from environmental, social and economic perspectives. Assessing the sustainability of a WF will depend on a range of criteria. The selection of the criteria and its relative importance to weigh them can differ as there is no standard set of such criteria established yet. However each criterion can be categorised in a logical way so that it can be assessed empirically. Broadly speaking these two phases of WF assessment studies, accounting and impact assessment, are the most time taking exercises, and also has been the focus of the existing literatures on WF. However the most important phase of the WF assessment is the 4th phase where the focus is on to formulate response options, strategies or policies etc. which has received very little attention so far.

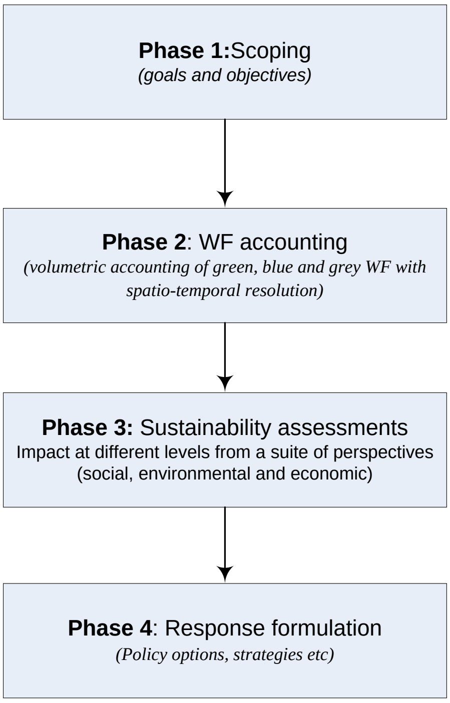

Figure 1. WF assessment phases (Hoekstra *et al.*, 2009).

Phase 1: Scoping

There are a wide range of publications available on WF accounting at product level (category or brand), regional level, national level etc. As this project (Defra WU0120) has objectives beyond accounting WF, selection of a set of commodities and products with respect to the production and consumption in a few selected river basins in the UK would provide a consistent framework to see the usefulness of the concept of WF for policy making. There are not many studies focusing on river basin level with a few exceptions such as a study at two river basins levels (Lower Fraser Valley and Okanagan basins) in Canada (Brown *et al.*, 2009), Guadiana river basin in Spain (Aldaya and Llamas, 2008) etc. One problem faced by this type of study is that river basins are rarely the spatial unit of policy making within political economies. Thus, this review mainly focuses on phase 2 and phase 3 of WF assessment process in detail.

Phase 2: WF accounting phase

The total WF (WF) of a product/supplier is made up of two components; the direct WF and indirect WF. The direct WF of a supplier is calculated as the sum of volume of water either evaporated or polluted at the point of operation. The indirect WF is equal to the sum of total WFs of the predecessor suppliers in the product supply chain.

$$WF\ \ i\ = WF_d\ \ i\ + WF_{sc}\ \ i$$

where $WF[i]$ is the total WF of supplier *i*, $WF_d[i]$ is the direct WF of the supplier *i*, and $WF_{sc}[i]$ is the indirect WF of the supplier *i.*

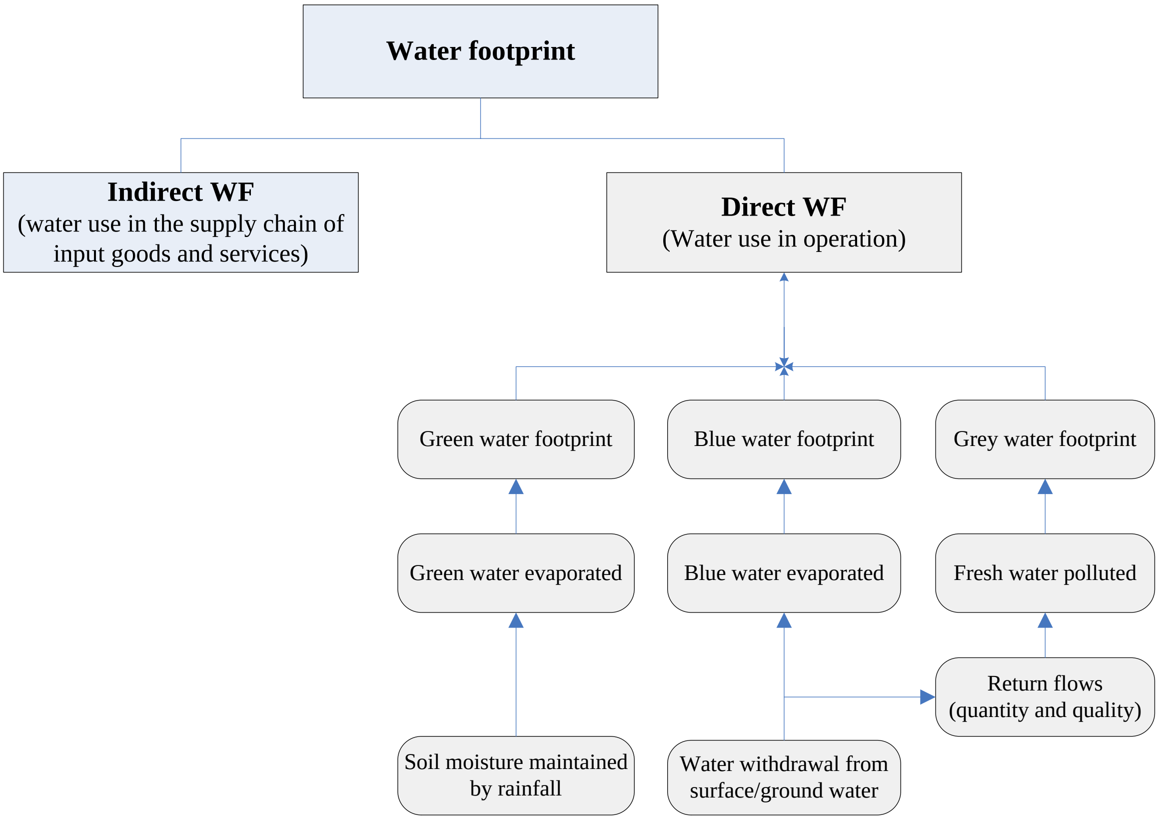

Figure 2. WF of an agricultural product/supplier.

The schematic to calculate the WF of various actors along the supply chain of one typical agricultural product is presented in a scheme (Figure 3). The indirect WF of the supplier *i,* $WF_{sc}[i]$, is equal to the total WF of its immediate supplier $WF[i\text{-}1]$. The direct WF of the supplier *i* for product *m* from its operation, $WF_d[i,m]$ is calculated as:

$$WF_d[i,m] = \frac{WU[i,m]}{Q\ \ i,m} \times \frac{v_f[i,m]}{p_f[i,m]}$$

$$= \frac{Water\ evaporated[i,m] + Water\ \ polluted[i,m]}{Q\ \ i,m} \times \frac{v_f[i,m]}{p_f[i,m]}$$

$$= \frac{Water\ evaporated_{blue}[i,m] + Water\ evaporated_{green}[i,m] + Water\ \ polluted[i,m]}{Q\ \ i,m} \times \frac{v_f[i,m]}{p_f[i,m]}$$

$$= \left\{ \frac{BWevaporated}{Q\ \ i,m} \times \frac{v_f[i,m]}{p_f[i,m]} \right\} + \left\{ \frac{GWevaporated}{Q\ \ i\,\text{[redacted]}} \times \frac{v_f[i,m]}{p_f[i,m]} \right\} + \left\{ \frac{Water\ \ polluted}{Q\ \ i\,\text{[redacted]}} \times \frac{v_f[i,m]}{p_f[i,m]} \right\}$$

$$= WF_{blue}[i,m] + WF_{green}[i,m] + WF_{grey}[i,m]$$

where WF [*i,m*], expressed in m^3/ton, is the WF of output *m* and *Q* [*i,m*] is the quantity of the product *m* in ton produced from the supplier *i.* The WF [*i,m*] is calculated based on the method given in Chapagain and Hoekstra (2008). *WU [i,m]* is the volume of water use in the operation of the supplier which is made up of the volume of water evaporated and equivalent volume of water polluted. Volume of water evaporated is further separated into two based on the source of water use, blue (*BWevaporated,* evaporation from the use of surface and ground water) and green (*GWevaporated,* evaporation from the use of rain water).

The p_f [i,*m*] is the product fraction (dimensionless) and v_f [i,*m*] is the value fraction (dimensionless) of the product *m*. If a supplier has more than one output product, the total WF of the supplier should be attributed to each product in a rational way such that there is no double counting of WFs. The distribution of WF among different output products is made on the concept of product fraction and value fraction. Chapagain and Hoekstra (2003) first introduced this concept to estimate the virtual water content (volume of water used per unit of a product) of processed products. Later on the concept is embedded in the methodological frame work of estimating virtual water content (WF) of any processed products (Chapagain *et al.*, 2006; Chapagain and Hoekstra, 2007; Hoekstra and Chapagain, 2008; Chapagain and Orr, 2009). For this purpose, the different stages of production are hierarchically presented in a product tree.

A product tree has product fraction (ratio of the weight of the individual output products to the weight of the input product) and value fraction (ratio of the market value of individual output product to the total market value of all the output products combined) at each stage of production. The product tree of rice is presented in figure 4 as an example. In this example, 1 ton of rice paddy produces 0.80t of husked rice and 0.20t o hull. The share of market value of husked rice is 95% and that of the hull is only 5% as shown as their value fractions respectively in the product tree.

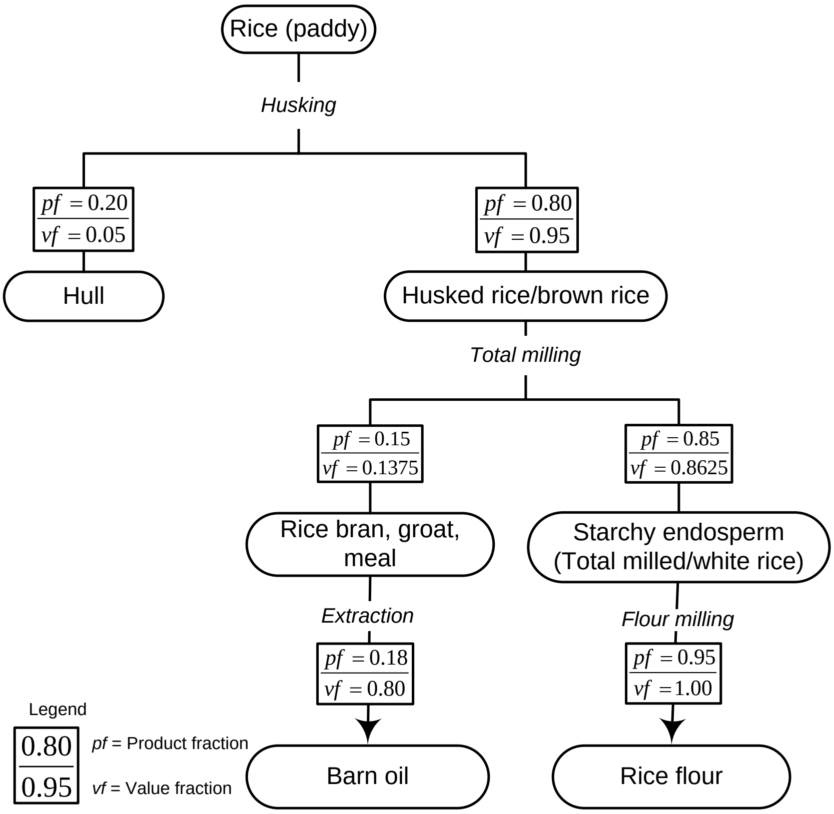

Figure 3. A typical product tree for rice processing.

Thus, the WF of each product is composed of three separate WFs, namely blue (WF_{blue}), green (WF_{green}) and grey (WF_{grey}). The volume of water polluted is estimated based on agreed water quality standards in the recipient water bodies and the pollution load in the return flows from the factory (Hoekstra and Chapagain, 2008; Chapagain and Orr, 2009). The total volume of water evaporated in the stage of crop growth is calculated using the maximum daily crop water requirement and the available effective rainfall calculated using the model CROPWAT (FAO, 1992); however, as noted previously, this approach is not always appropriate. Using the outcomes of the CROPWAT, the volume of blue and green water evaporated are separated following the methodology presented in Chapagain and Orr (2009). Figure 4 presents a detailed schematic for the calculation of WF along the supply chain of a typical product from farm to its end use.

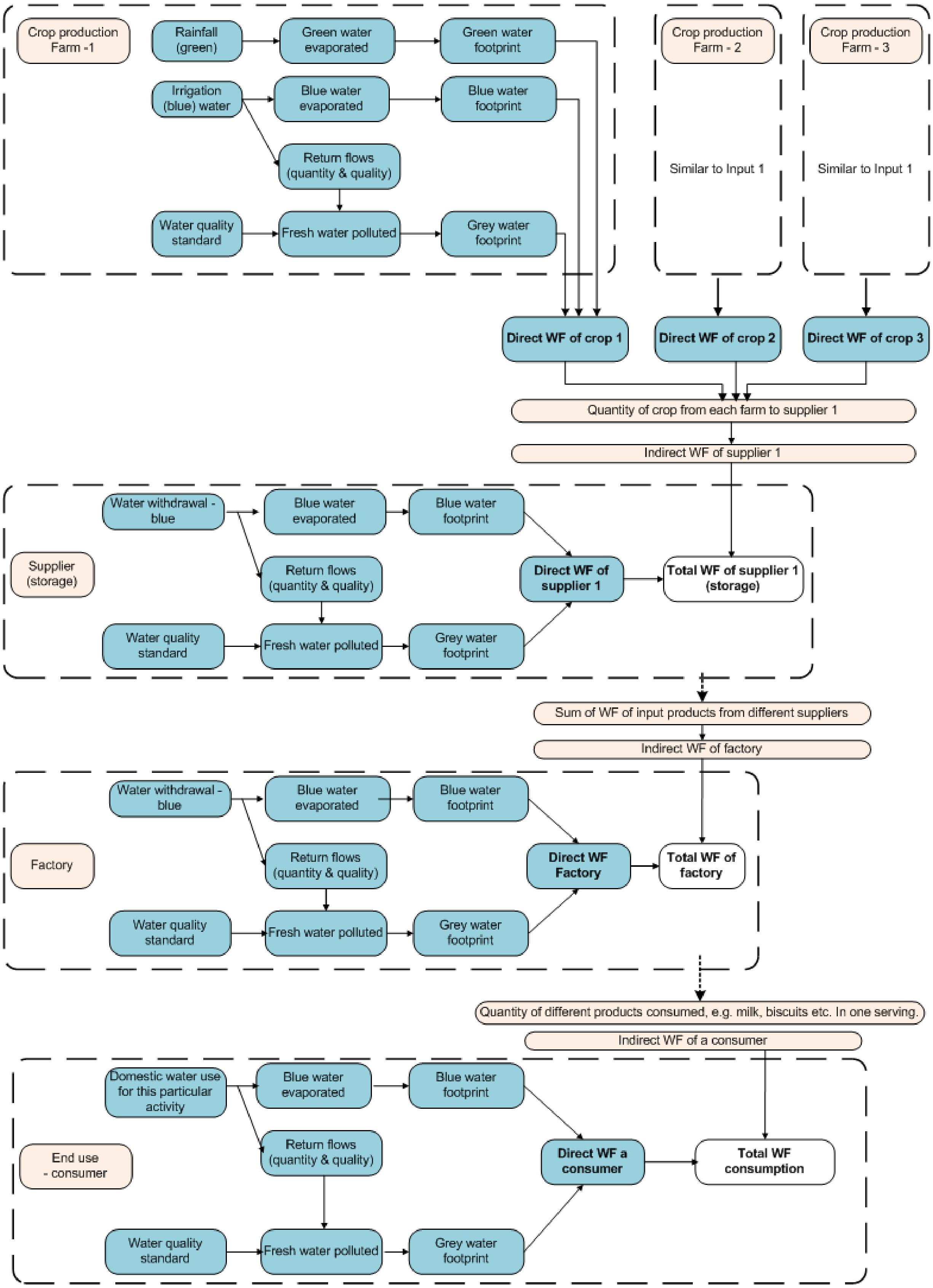

Figure 4. Layers of calculating WF of different actors along the supply chain of an agricultural product.

Phase 3: WF sustainability assessment

At the end of the phase 2, a 3-dimensional output matrix can be constructed where the WF of a product/service/business/nation is disaggregated both in time and space with a clear distinction on kinds of water evaporated (blue and green) or polluted (grey).

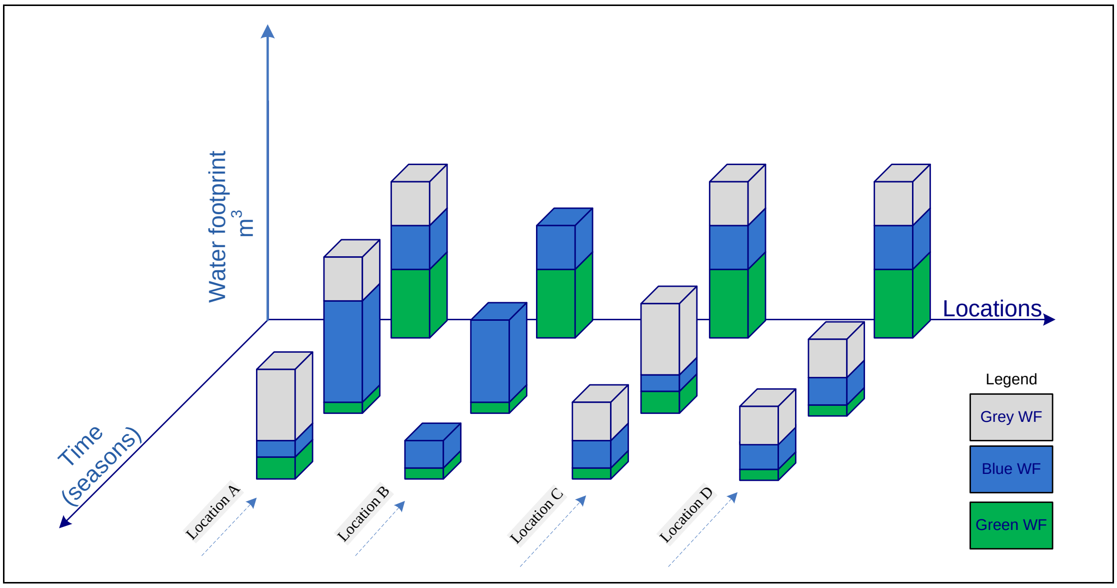

Figure 5. WF accounts along the value chain of product, service, business or region.

Whether the WF of a process, product, consumer or producer is sustainable depends on the characteristics of the WF (size, timing, location and colour) and the local conditions in the places where the footprints are located (Figure 5). The assessment should also encompass wider socio-political dimension of the action. The sustainability issue should not be limited to local level, but should capture the global context as sustainability is a global issue (Brown *et al.*, 1987). The sustainability assessment, also referred as impact assessment, can be done both quantitatively as well as qualitatively (Figure 6). Furthermore, the quantitative assessment can be carried out from different perspectives using either 'Hydrological attributes', 'Ecological attributes', 'Social attributes', or a combination of any of them (Figure 6). Figure 6 does not capture the livelihood significance which would be relevant within both 'Economic attributes' and 'Social attributes'.

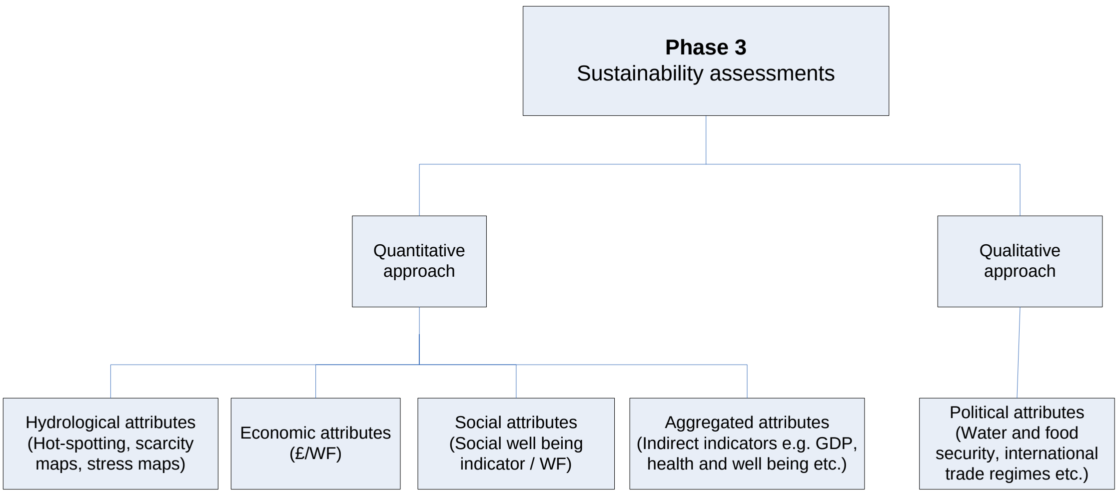

Figure 6. Sustainability assessment of a WF.

Hydrological approach:

Most of the recent literatures on WF have taken this angle to analyse the impacts of WFs. For example, the WWF report on WF (Chapagain and Orr, 2008) has used water scarcity to find the hot-spots (locations where UK has larger WFs and at the same time these places are under higher water scarcity) to locate the critical nodes where the products are sourced from for UK consumption, and to analyse the impacts. Similar approach is taken in another study conducted by University of Twente in assessing the impacts of the WF of the Netherlands (Van Oel *et al.*, 2008). However, these studies are using the aggregated WFs both with respect to time and quality. Thus, though such assessments are good at national level, it is hard to quantify the sustainability of WF in real terms. For informed policy options, one need to carry out detailed WF accounting to obtain the 'WF account matrix' (Figure 5) for each and every individual products concerned. Then, one need to aggregate the different colours of water for each time steps for each location so that the distinct attributes of a WF is preserved. This is crucial as only then such impacts can be treated separately with respect to the local hydrological attributes. Though it is useful to know the total WF at each place from the wider perspectives of water resources management, such aggregation would lose the importance of opportunity costs associated with different kinds of WF in the matrix.

Stress-weighted WF

In a modified version of this approach it is suggested that such aggregation should be done taking into account the weighted value of WFs at each node of the matrix based on water stress characterisation factors for each individual nodes (Ridoutt *et al.*, 2009a; Ridoutt and Pfister, 2009). These characterisation factors are derived based on Water Stress Index (WSI) developed by Pfister et al. (2009). The value of WSI ranges from 0.01 to 1, where a value of 0.5 represents a withdrawal-to-availability ratio of 0.4., with a spatial resolution of 0.5 degrees. These values are derived based on the outcome of a global hydrological model, WaterGAP2 (Alcamo *et al.*, 2003).

The approach of weighing different kinds of WFs to get one representative value of impact provides an opportunity to compare the WFs of different products in a level field, similar to that in accounting Carbon Footprint (Ridoutt and Pfister, 2009). The benefit of such approach is that it is easy to communicate a single number, and the calculation scheme has strong resemblance with the one for carbon footprinting. Though one of the most difficult task in this approach is to get a standard set of weighing factors (characterisation factors) for each and every individual products concerned. Even for a single product WF at brand level, a number of general assumptions were needed to be made for WSI at different levels of product supply chain in a study by Ridoutt and Pfister (2009).

Economic approach:

There are hardly any major study made looking into WF sustainability assessment from this approach. One of the recent studies focused on WF of Spain (Aldaya *et al.*, 2010) has briefly touched upon this approach to analyse the WF not only in the context of water availability in different regions in Spain but also by looking it from an economic angle. It gives better insight on comparative advantages of relocating WF to a different region as a policy option.

Qualitative and other approaches:

So far there are not any studies on WF that has used the social or aggregated approach in assessing the sustainability of WFs. However, on qualitative side, there is a strong set of publications (Allan and Mallat, 1995; Allan, 1996; Allan, 2001; Allan and Olmsted, 2003; Hoekstra and Chapagain, 2008), bulk of which do not use the term WF to denote the water used in production process but rather a term famously coined by Allan (1993) in mid-90s.

4. Water footprinting of products

The body of literature related to water use by crops is considerable although the number of actual WFing studies is relatively small. The review is restricted to those products in the current Defra study. All the studies report volumetric WFs but a comparison of individual methodologies has not been undertaken.

Winter wheat

Winter wheat can be both a rain-fed and irrigated crop depending on location although the majority of wheat grown globally is rain-fed; all UK wheat is rain-fed. The WF of Nations report (Chapagain & Hoekstra, 2004) prepared volumetric WFs for 210 countries and the results for wheat ranged between 465 (Slovakia) and 18,070 litres/kg (Somalia). Hotter and drier countries had larger WFs which reveal a lot amount the relative evapotranspiration of the countries, fertilizer and irrigation use but very little about the amount of water required to grow a crop of wheat. Wheat in the UK required 501 litre/kg.

Zwart and Bastiaanssen (2004) reviewed crop water productively values for twenty-eight wheat crops across five continents and reported green water consumption between 588 and 1667 litres/kg with the greatest frequency in the range of 909 to 1111 litres/kg. No European crops were considered in their review and it is unclear which, if any, of the crops were irrigated with blue water.

The global crop water model (GCWM) developed by Siebert and Doll (2009) was used to calculate virtual water contents (WFs) for 30 crops. The value for wheat was 1469 litres/kg and was split between 1113 litres/kg green water and 356 litres/kg blue water. The relatively high blue water content is due to the assumption that 37% of wheat crops are irrigated. Hanasakai et al (2009) modeled the volumetric WF of some major crops and reported values for wheat between 366 (France) and 1359 litres/kg (USA).

Blue WFs for rain-fed crops comprise water for spraying and washing (not plant growth) and as such are relatively easy to calculate. As part of preparing environmental footprints for a range of UK crops, Lillywhite (2009) reported that volumetric blue WF of wheat was 0.1 litre/kg.

Potato

Potato is both a rain-fed crop and an irrigated crop. In the UK, both production systems are employed although water can be used to supply crop requirement and to control potato scab. In Israel, all potato crops are irrigated. The WF of Nations[13] reported that the volumetric WF of potato was between 25 (New Zealand) and 2082 litres/kg (Central African Republic); the UK was 74 and Israel 190 litres/kg.

Sugar beet & sugar cane

The UK sugar beet crop is almost entirely rain-fed although irrigation may be used under very dry conditions. The WF of Nations reported that the volumetric WF of sugar beet was between 29 (Chile) and 1043 litres/kg (Georgia); the UK was 56 litres/kg. More recent data taken from The WF of a Sugar-Containing Carbonated Beverage (Ercin et al., 2009) reported volumetric WF values for sugar beet between 84 litres/kg (Netherlands) and 355 litres/kg (Iran) and for sugar cane between 142 litres/kg (Peru) and 544 litres/kg (Cuba); the average values were 169 litres/kg and 299 litres/kg, for sugar beet and sugar cane, respectively.

The same report calculated the volumetric WF of sugar to be between 520 litres/kg (Netherlands, sugar beet) and 3340 litres/kg (Cuba, sugar cane).

Strawberry

Strawberries are produced using many different systems: rain-fed field, irrigated field, under polythene and under glass. Strawberries for the UK market (both UK and Moroccan) tend to be grown under polythene to ensure product quality meets market requirements. This type of system is dependent on the supply of blue water. The WF of Nations reported that the volumetric WF of strawberry was between 62 (New Zealand) and 2509 litres/kg (Belarus); the UK was 229 and Morocco 196 litres/kg.

The University of Hertfordshire (2005) reviewed the sustainability of the UK Strawberry crop and reported that irrigation water use of protected strawberries was 91 litres/kg of class 1 fruit; the range was 47 to 140 litres/kg. Since protected strawberries are not rain-fed we assume that irrigation water is blue water use. Williams et al (2008) compared the production of protected (under polythene) strawberries in the UK and Spain and reported the use of irrigation water (proxy to green and blue volumetric WFs) to be 108 and 128 litres/kg of fruit, respectively. Their work was restricted by a lack of data and the UK results were based on the University of Hertfordshire work. Experimental work conducted by East Malling Research (Else et al., 2009) returned volumetric WFs between 9 and 36 litres/kg depending on the system under investigation although this did not take cop establishment into account; overall they suggested that average values were around 70 litres/kg although 'water conscious' growers used 50 litres/kg.

In Japan, Yuan et al (2004) working on drip irrigations systems for strawberries grown under polythene showed that the volumetric WF was 230 litres/kg.

Milk

The WF of milk is more complicated than that of field crops. Water is required to grow feed (grass or concentrates), for the cattle to drink, for washing and cleaning and in processing. The water consumption for the first two categories is dependent on the country of production but tends to be fixed for the latter two categories and although there is a strong relationship between cow water consumption and milk yield, the WF will vary with yield.

Due to its importance, direct water consumption within the dairy industry has been the subject of many studies. DairyCo (part of the Agricultural and Horticultural Development Board) undertook a water use survey in 2009 to provide a baseline benchmarking value for water usage on dairy farms. Unfortunately, the small sample size has prevented them from publishing the results although they intend to repeat the survey annually.

The WF of Nations reported that the volumetric WF of milk for selected countries and found values ranged between 695 (USA) and 2382 litres/kg (Mexico) with a world average of 990 litres/kg. Aldaya & Hoekstra (2009) estimated that the average WF of the Italian milk is 1308 litre/kg. In Morocco, Srairi et al (2009) found that 1700 litres/kg was required.

The Milk Road Map (Envirowise & DairyCo, 2007) has established a water efficiency benchmarking system for the milk processing sector. Evidence suggests that the best performing site had water use of 0.5 litres water used per litre of milk produced and the average ratio was 1.3 litres water used per litre milk produced.

Lamb

Water use within the sheep sector is confined to three main areas: embedded water within concentrate feed, drinking water and washing water during processing. Drinking water is likely to be the biggest contributor overall but it is fragmented between metered use on many lowland systems which rely on drinking troughs and drinking from natural sources on upland systems.

The WF of Nations reported that the volumetric WF of sheep meat for selected countries and found values ranged between 3,571 (Japan) and 16,878 litres/kg (Mexico) with a world average of 6,143 litres/kg.

Summary

Some obvious conclusions may be drawn from the data. Industrialised economies clearly achieve very much higher levels of water productivity than non-industrialised economies. Farmers in Africa get very low returns to water especially in rainfed farming. When comparing yields and returns to water the future will be different from the present.

If the UK were to adopt an ethical policy on water it should commit to assisting non-industrialised economies to increase their sustainable intensification of water use as a precautionary measures to reduce impacts on water resources, economies and on farmers.

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