The Volumetric Water Consumption of British Milk

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Report to DairyCo by

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Executive summary

The water consumption of a range of dairy production systems was estimated for three contrasting locations in Britain up to the farm gate. The Cranfield Life Cycle Assessment (LCA) systems model was used for this analysis. This model calculates all the resources used to produce a litre of milk. This included direct water consumption (e.g. for drinking, washing, cleaning and feed processing) as well as virtual water in the diet (i.e. water used to grow grass and concentrate feedstuffs). This was partitioned into “blue” and “green” water. Blue water is that abstracted from rivers or groundwater, or taken from mains water supplies and is conceptually what most people consider to be water use. Green water is the rain water used by growing plants (e.g. grass, forage and feed crops) as evapotranspiration at the place where the rain falls. Most dairy feed in Britain comes from rain-fed crops with no irrigation (i.e. blue water) used.

The average water consumption for a range of dairy production systems shows that the blue water consumption is about 8 litres per kg fat and protein corrected milk (FPCM) (Table 1). Higher output systems tend to have slightly lower water consumption per unit of output. Although drinking water per head tends to increase as yield and metabolic demand increases, the higher water consumption per head is offset by higher milk output and a lower proportion spent on maintenance.

Table 1 Averaged total water used in British dairy systems, litres per kg fat and protein corrected milk (FPCM). This is to the farm gate, and does not include water used subsequently for milk processing.

Production system	Blue water, l/kg FPCM	Green water, l/kg FPCM	Total water use, l/kg FPCM
Spring calving	7.4	678	685
Autumn calving	7.5	683	691
All-year calving	7.5	681	688
Zero grazing	7.6	706	713
Organic	8.1	1,006	1,014

Notes.
Values for green water use would normally be rounded to 2 significant figures, but the whole values have been shown to illustrate the relatively small effect of blue water and be arithmetically correct.
1 kg FPCM is 1.01 litre milk

About 99% of the water used in milk production is green water. It can be argued that green water consumption has negligible environmental impact as it has a low, or negligible opportunity cost. The rain water consumed by growing grass or feed crops (by evapotranspiration) could only be used for growing alternative vegetation, that is, it could not be used to substitute for water for domestic or industrial use for example. Therefore, there is limited water benefit in saving green water. Indeed if cattle were removed from fields and milk production stopped, evapotranspiration would still continue, to a greater or lesser extent depending on land use and vegetation cover.

The blue water consumption is proportionally small for milk production under all systems. A third to a half of the blue water is drinking water. Most of the rest of blue water consumption is from

cleaning milking parlours and yards, and milk cooling. A small amount is from industrial feed processing and negligible amounts from growing feed. There is potential for on-farm interventions and the use of technology to reduce wastage or leakage, to reduce the overall blue water consumption.

Water stress does vary across Britain. The impacts of water use differ according to the characteristics of the catchment in which the use occurs. Blue water may be in demand from agriculture, human consumers and industry. A litre of blue water becomes increasingly precious as drought persists and water stress goes up. This does not suggest that dairying should cease in areas of high water stress, but that those in the more stressed areas should exercise more care in the use of blue water, while not compromising cattle welfare or public health.

The impacts of diffuse or point-source (grey) water pollution from milk production are not addressed in this report. A different study that can address causes, impacts and solutions within specific catchments localities is suggested.

The estimates of water footprint presented here differ from those produced by the Water Footprint Network (an alternative approach to quantifying water use impact). This is because “grey water” was not included in this study, on the basis that we consider the alternative approach being developed in ISO 14046 to be more appropriate for quantifying diffuse pollution. In addition, most crops were not irrigated so that the blue water consumption for feed production was relatively small.

The future international standard on water footprinting (ISO 14046) should enable agreed, objective assessments of water impacts to be made. This will include stress on blue water use as well as impacts of water quality degradation. The impact of dairying on water quality, through diffuse and point-source pollution, warrants further study, in which actual farm practices are systematically assessed.

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1. Introduction

Agriculture is the biggest user of freshwater resources in the world and globally accounts for about 70% of freshwater withdrawals. This proportion is much lower in the UK, for England and Wales representing about 0.4% of UK fresh water withdrawals overall. This ranges from 0.1% in the North West and Wales to 1.4% in the Anglian Region, as at 2008, (Defra, 2010). Much domestic and industrial water withdrawal is returned to the environment after use, following treatment to prevent degradation of receiving waters. In contrast, much of the water withdrawn for agriculture is either consumed (that is, evaporated or transpired from plants) or degraded. Clearly, agriculture is a response to demand for food and non-food products. Globally, agriculture has a huge impact on the quantity and quality of freshwater resources and aquatic ecosystems. Hoekstra and Mekonnen (2012) estimate that agricultural production contributes 92% to the global water footprint, of which milk is one important component.

The impacts of dairy production on the water environment affect water quantity and water quality. Water quantity impacts occur where water consumption in the dairy supply chain reduces water availability for other domestic, industrial or environmental uses. For example, abstraction of water from an aquifer may cause a lowering of local water tables and lead to desiccation of wetlands, or abstraction from a river may lead to low flows that are unsuitable for fish. Water quality impacts may occur where the activity results in a degradation of chemical, thermal or biological status of the source water body.

Public attention has been drawn to the amount of water required to produce milk and other livestock products, with large figures often quoted (e.g. Ashok and James, 2011). For example, the Water Footprint Network quotes global average figures such as 1,000 litres water per kg milk (Mekonnen and Hoekstra, 2010). These convey an image of huge quantities of water being used to produce food from livestock and suggestions that “promoting a dietary shift away from a meat-rich diet will be an inevitable component in the environmental policy of governments” (Mekonnen and Hoekstra, 2012, p.13). These headline figures require careful interpretation, particularly in the UK context:-

1. The proportion of freshwater abstractions used in agricultural production varies considerably. For the UK, annual freshwater withdrawals for agriculture represents a tiny fraction of available freshwater resources[1]
2. These global averages in water footprint conceal significant regional variation. For example, Hoekstra and Chapagain (2007) quote figures for milk ranging from 280 l/kg in Switzerland, through 820 in the USA and up to 15,060 for Tajikistan.
3. The water consumption varies according to the production system. Ridoutt et al. (2010) note the variability in water footprints between dairy production systems and products.

[1] FAO Aquastat. http://www.fao.org/nr/water/aquastat/main/index.stm

4. The total volume of water consumed does not reflect the impact of this water use on the environment or other water users. For example, if livestock are fed on concentrates produced under irrigation in water stressed environments, this water use may have a significant impact, however, if they are fed on grass grown under rain-fed conditions or domestically produced concentrates that do not require irrigation, the impact of water use may be negligible. In this respect, UK dairy production is very different to drier regions, such as parts of North America, where much of the diets are sourced from crops grown in dry areas and irrigation is more common.

2. Aims & objectives

The aim of this study was to estimate the volumetric water consumption of British dairy production in relation to its potential environmental impact. The specific objectives are;

1. Estimate the average green and blue water consumption (l/kg) of raw milk at the farm gate for British milk production.
2. Estimate the variation in average green and blue water consumption (l/kg) for an indicative range of production systems (incorporating a range diets and levels of intensity) and geographical location (reflecting climatic variation).
3. Put the impacts of blue water use in different climatic/geographic regions into context. Consider the location of dairy farms in relation to catchments and areas of water stress.
4. Review opportunities for water conservation and efficiency in the dairy industry.
5. Identify data and knowledge gaps.

3. Methods

3.1. Framework for analysis

The dairy system can be envisaged as three sub-systems (Figure 1):

1. feed system
2. livestock system
3. processing system (not covered in this study)

Each of these sub-systems uses physical water. For example, water is used to grow fodder, for cattle hygiene, to wash the milking equipment and to process milk. However, each of these systems also discharges water. For example, water used for washing dairy parlours is returned to the environment (through spreading on land) or discharged to ditches (after treatment). The water **consumption** at each stage is the difference between the water withdrawn (or falling as rainfall) and water discharged to the same water body and in the same condition. Some water is physically transferred from one sub-system to another as **incorporated** water. For instance, a litre of milk leaving the farm contains about 0.9 litres of water. However, each sub-system inherits the water consumption from upstream sub-systems as **virtual** water. For example, the water used to grow fodder is a virtual water flow from the feed system into the livestock system. Compared to the virtual-water flows between sub-systems, the incorporated water flows are very small and are often ignored. Throughout the system from feed to product, there are also small contributions of virtual water from minor inputs, such as water used in electricity generation; water used in the production of fertilisers; or water used in the production of animal bedding. Compared to virtual water flows in the feed, livestock and processing systems, these are usually small and are often ignored.

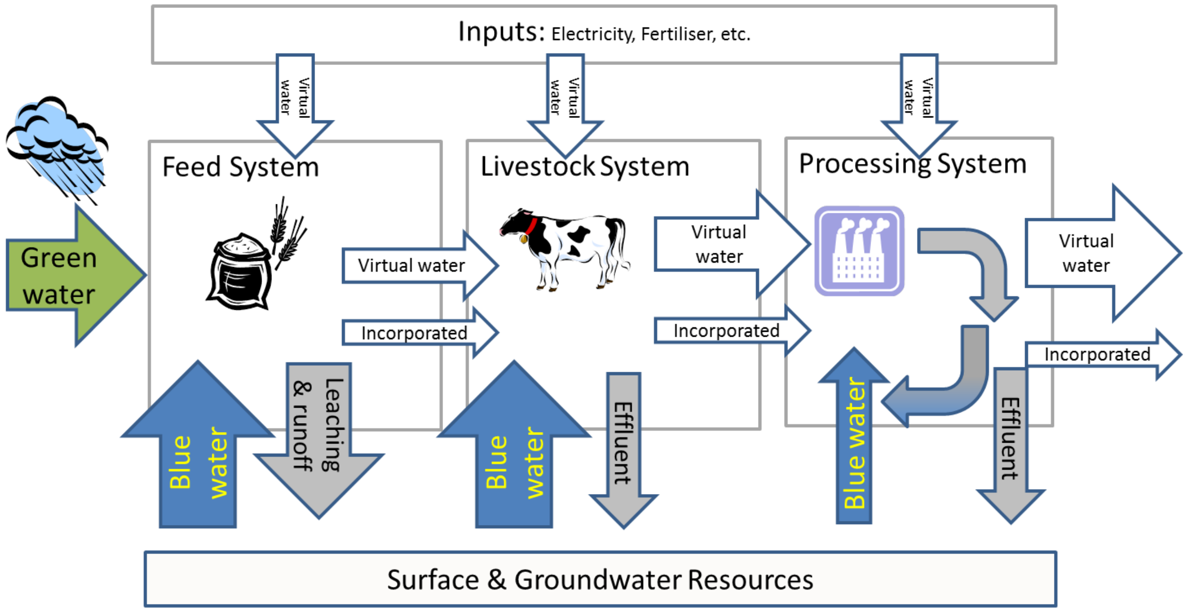

Figure 1 Physical and virtual water flows in the whole dairy system. Note that this analysis only goes up to the farm gate, so that processing is limited to cooling in the dairy parlour.

3.2. Water consumption assessment and functional unit

The water consumption of the dairy system is the sum of the water consumed in all three sub-systems. In general, the largest component is from the feed sub-system, accounting for approximately 98% of the total consumption (Mekonnen and Hoekstra, 2012). In this study, we are concerned with the consumption up to the farm gate. As such, only the feed and livestock systems will be considered, apart from water used to cool milk on-farm. The water consumption of other minor inputs has been ignored.

3.3. Functional Unit

The functional unit is commonly used in Life Cycle Assessment (LCA) studies. The water consumption can be expressed per unit of output, e.g. litres water/litre or kg milk. In this study, the functional unit is 1 kg fat and protein corrected milk (FPCM[2]). In practice, this differs relatively little from litres of milk under typical British conditions. The correction is made using the following formula for 1 kg FCM.

FPCM = 0.25 M * 12.2 F + 7.7 P

M is the mass of 1 litre milk (1.03 kg), F is the weight of fat and P is the weight of protein. For UK milk with 4.1% fat and 3.3% protein, 1 litre milk is equivalent to 1.01 kg FPCM.

[2] That is milk normalised to 4% fat and 3.3% protein content

3.4. **Boundaries**

As with LCA, the water consumption per unit milk includes all the inputs within the scope of the study. In this case, breeding overheads of replacement heifers and the dairy cows themselves are included along with all feeding and cleaning requirements. In this case, water used in upstream industrial processes such as electricity production, has been excluded as the amounts are likely to be negligible compared to the agricultural components.

3.5. **Allocation**

A dairy herd produces milk as its primary output, but also generates other non-milk products, including calves (mainly male) and cull cows that go into the beef sector. Manure may be exported to other enterprises, but this is assumed to be a minor activity and so is ignored. An approach to the allocation of water consumption to milk and other outputs is required. In LCA, allocation is preferred to be based on bio-physical flows, but it may be addressed using economic allocation if there is no more functional approach available. Some approaches also overcome allocation by expanding the product system, but for this study, allocation between milk and non-milk products seems more appropriate. Mekonnen and Hoekstra (2012) summed the direct and indirect water-use by an animal over a year (averaged over its lifetime) and allocated this to the annual output of milk. In this study, we adopted the biophysical based approach used for carbon footprinting (a sub-set of LCA) by the International Dairy Federation (IDF, 2010). The allocation factor, AF, is the proportion of total environmental burdens allocated to milk from milk and meat potential. The allocation factor for milk (AF) is given by:

$$AF = 1 - 5.77\ R$$

R is the ratio of the sum of live weight of all animals sold (bull calves and culled mature animals) to the sum of FPCM sold, and given a default value of 0.025. This results in about 85% allocation of the total water consumption to FPCM. We assumed that all viable male and female cross bred calves and any surplus pure dairy female calves had meat potential, while pure dairy males were more likely to be culled soon after birth and not enter the human food chain.

3.5.1. The “colour” of water

Water consumed in the production of livestock products may be “blue” or “green”. Green water consumption is the evapotranspiration of rainwater at the place where it falls and is the most significant component of the water consumption of feed production in most environments. In general, green water consumption has negligible environmental impacts as green water has a low opportunity cost. Therefore, it is important to isolate the green water consumption in the total water consumption. Blue water is that which is taken from renewable water resources (rivers, lakes and groundwater) and in this case is primarily mains water or water pumped from rivers and wells.

Water used for livestock drinking, sanitation and processing is blue water. In the UK, pasture and home-grown fodder is almost entirely rain fed and so the blue water consumption for these inputs is negligible, however, imported feed may be grown under irrigated conditions, and therefore have a blue water component (Table 2).

Table 2 Green and blue water in the various components of water use in the livestock production system.

Source	Green water	Blue water
Virtual water in diet	✓	✓
Feed processing		✓
Drinking water		✓
Washing and cleaning		✓

3.5.2. Water consumption and 'grey' water

There is a lack of consensus on what water should be considered as "consumed". From a hydrological perspective, of the water that is drunk by a cow, only that proportion that contributes to the metabolism of the animal or is evaporated from sweat is consumed. The rest returns to the environment in the form of urine and faeces. Similarly, water that is used for cleaning dairy parlours is not "consumed" but returns to the environment in an altered state. Some studies have dealt with this in terms of a "grey water footprint" by expressing the water used, but not consumed in terms of the volume of freshwater required to assimilate the pollutant load.

In a survey of DairyCo levy payers in the UK, of the 1014 dairy farmers responding, 74% of were using metered water, often supplemented by water from boreholes. Most water used on the farm is withdrawn from wells or taken from the mains supply, and waste water is discharged to land or surface water courses (after storage and cleaning). That is, the destination of the waste-water is generally not the same water body as that from which the freshwater was taken. Consequently, all water pumped from the well, or taken from the mains has an impact on the water source, even if, in the long term, waste water applied to land may eventually recharge the aquifer. Therefore, in this study we have considered drinking and cleaning water to be consumed.

Whilst it is clear that diffuse and point-source water emissions from dairy systems may play a significant role in degradation of the quality of fresh water bodies, we have not considered this within the present study and have therefore not calculated "grey" water footprints. The potential magnitude of this must not be dismissed lightly. We consider, however, that this requires a separate study that includes detailed farm practice assessments of manure management, silage making and management and rainwater management. There are also aspects of diffuse pollution that can be addressed by modelling approaches, such as nitrate leaching, which is associated with fertiliser and manure practice and crop (including grass) management.

3.6. Modelling selected livestock systems

The dairy industry in Britain was described and parameterised in a systems model by Williams et al. (2006) for use when coupled with LCA. This formed the basis of the study, but was enhanced with data from DairyCo's Milkbench[+] and other sources of publically available data.

The model takes a systems-based approach to modelling the environmental burdens associated with meat and dairy production, accounting for all inputs and outputs crossing a defined system boundary, in order to produce a given quantity of a commodity i.e. the functional unit (in this case, 1 kg fat and protein corrected milk at the farm gate).

The model calculates the physical resources needed to produce the functional unit. For UK dairy, the critical terms are the feeds coming from grazed grass, conserved forage and concentrates. The systems LCA model was used to quantify these feed inputs and hence calculate the green water consumption of these inputs. The feed requirements of different types of stock were also used in deriving theoretical drinking water needs. The systems-based approach enables the complexity of agricultural systems to be captured and ensures that additional requirements and by-products of the systems are accounted for, such as replacement heifers and male dairy calves. By taking this approach, as opposed to an empirical approach, production systems are defined by sets of equations that describe their characteristics and these ensure that any changes in a production system are reflected throughout to ensure consistency of analysis. This gives much greater flexibility as it enables each characteristic to be changed individually and sensitivities to be explored.

The original systems model considered spring and autumn calving non-organic herds and all-year organic herds. Each system was defined by three yield levels and the proportions of each can be set to obtain a weighted average yield. An all-year non-organic system and a zero-grazed system were added for this study. While being informed by data from Milkbench^{+}, care was taken not to assume that it is wholly representative, as the dataset may contain a higher proportion of more progressive producers than the national average.

The systems model includes relationships for estimating cow weight as a function of milk yield. Feed intake is calculated from the AFRC (1993) equations for metabolisable energy and protein requirements and voluntary feed intake. Factors are included to estimate the proportion of forage obtained from grazing and conserved forage. The proportion of concentrates in the diet is obtained by solving the feed equations (Williams et al., 2006). It should be noted that the largest uncertainty in any such analysis is the amount of dry matter (DM) obtained from grass. Concentrates and silage weights can be determined reasonably reliably, but farmers have no practical way of measuring grass DM intakes. The Milkbench^{+} data includes records of conserved forage, straw and concentrates used and simple metrics can be derived, e.g. litres milk per kg concentrates fed.

Feed requirements include the requirements for maintenance, gestation and lactation in dairy cows plus growth for replacement heifers. Feed for calves destined for beef is not included.

The herd characteristics, such as numbers of lactations, are related primarily to the milk yield. Numbers of replacement and surplus calves are determined from the number of lactations.

We assumed that all systems could occur anywhere in the country, although subsets will vary, e.g. maize silage inclusion rates tend to be higher in the South and East of England than in the North and West of England or in Scotland.

The main characteristics of the herds used in the study are in Table 3, with distinctions between spring and autumn calving, through the proportion of feed types, is shown in Table 4. The organic herd was modelled as all-year calving.

Table 3 Main characteristics of herds modelled in the study

	Non organic- spring and autumn calving			Milk Herd (Organic)			All-year calving	Zero grazing
Yield Level	Low	Mid	High	Low	Mid	High		
Proportion of system	25%	50%	25%	25%	50%	25%		
Milk, litres per year	5,500	7,500	9,500	5,000	6,500	8,000	7,900	9,200
Productive life, lactations	4.9	3.8	2.7	5.4	4.5	3.6	4.0	3.1
Calving Index, days	401	415	430	386	400	415	430	430
Cow weight, kg	540	600	650	500	550	600	600	650
Energy Needs, GJ[ME]/lactation	63	82	101	61	75	90	82	95
Voluntary feed intake t[dry matter]/lactation	6.0	7.1	8.1	6.5	7.4	8.2	7.1	9.1
Proportion of diet concentrates				11%	23%	34%	35%	38%
Proportion of forage as grazed grass	Expanded under Table 4 below			50%	50%	50%	43%	0%
Maize proportion of silage				0%	0%	0%	34%	54%

Table 4 Proportions of feed dry matter in non organic spring and autumn calving herds

	Non organic- Autumn calving			Non organic- spring calving		
Yield Level	Low	Mid	High	Low	Mid	High
Proportion of diet concentrates	28%	41%	54%	20%	34%	48%
Proportion of forage as grazed grass	35%	35%	35%	50%	50%	50%
Maize proportion of silage	20%	30%	35%	20%	30%	35%

3.7. Water use in the feed system

The water used in the feed system depends on the mix of grazing, conserved grass, fodder crops and concentrates in the diet. With the exception of fully housed systems, almost all dairy cows in British systems graze grass, but spring calving herds graze proportionally more than all-year or autumn calving herds. Grass is replaced by silage (mainly grass or maize) in the winter. Cattle also receive supplementation from a range of feeds depending on location, price and availability. These are derived from domestically produced crops, such as wheat, barley, oilseed rapemeal, wheatfeed, brewers' grains, other by-products and imported feeds like soya meal and palm meal. Fully-housed (zero grazing) systems are becoming more common, for which diets comprise a mixture of conserved forage and concentrates (and possibly some fresh cut grass). Although some whole-crop silage is used, we have modelled it as though it were maize silage. The exact proportions of ingredients in commercially concentrated feeds are not known, owing to commercial confidentiality. Audsley et al. (2010) estimated these for all livestock sectors and these proportions have been used. These were sense-checked against formulations presented by the Scottish Government in work on Carbon Footprinting of dairy production[3] and they were in broad agreement.

The feed given to animals contains 'virtual' water (used by the growing plant in evapotranspiration) and 'embedded' water (the physical water embodied in the harvested crop). Evapotranspiration (ET) accounts for more than 99% of the total water use by most plants, with very little water physically carried in the harvested product. Therefore, the specific water use is determined from the total crop water use (ETc) over the growing period of the crop and the crop yield, thus

$$WU = 10\frac{ETc}{Y}$$

Where WU is the specific water use, m^3/t, ETc is crop water use (in mm), Y is the crop yield (in t/ha) and 10 is a scalar to ensure consistent units.

Water consumed in industrial feed processing was derived in earlier work for EBLEX and used an average value of 3.9 litres blue water per t.

3.7.1. Water use of grazing and conserved grass

Water use per unit grass DM was calculated using the expression shown above. The DM yields were obtained from the grass sub-model in the Cranfield systems-LCA model (Williams et al., 2006), which was developed from previous work at Silsoe Research Institute. Grass production is affected by the site class and Nitrogen (N) supply. The N supply may be from clover, mineral fertiliser or excreted by grazing animals. The results for site classes 1 to 6, where site class 1 represents a high grassland yield potential, are given in Table 5.

Table 5 Estimated green water consumption to produce 1 t grass DM through average management at site classes 1-6 in England & Wales

Site Class	Average ETa, mm	Water consumption, m^3/ha	Grass Yield, t/ha	Water consumption, m^3/t
1	570	5660	9.5	600
2	580	5770	8.6	670
3	570	5650	7.9	720
4	550	5460	7.2	760
5	540	5380	6.7	800
6	530	5260	5.9	890

[3] http://www.scotland.gov.uk/Resource/Doc/342092/0113816.pdf

Dairy production is concentrated in areas with better grassland yield potential, that is, where the site class is typically 3 or lower. Part of the analysis for the grass model required an analysis of grassland use and grazing animal density over the country, using the Agricultural June Census-Survey and other land use data. This resulted in the distribution in Table 6.

Table 6 Distribution of site classes determined for averaged British dairy production

	Site Class		
Soil Texture	**1**	**2**	**3**
Light	0%	0%	3%
Medium	0%	14%	8%
Heavy	4%	12%	59%

3.7.2. Grass yield estimation

Water consumption per hectare was converted into water consumption per tonne grass and conserved forage dry matter ranging from 600 to 890m^3/t DM depending on the grass site class (Table 5 and Table 7). The Cranfield LCA model calculates dry matter intake requirements of both grazed grass and silage for each production system so that the green water consumption per unit of milk can be determined.

This was further refined to give a geographic breakdown according to **NUTS** (Nomenclature of Territorial Units for Statistics) region codes for Britain, resulting in green water use values per t of DM for grazed grass and silage (Table 7). The highest green water use in South West England is about 20% higher than the lowest (East Midlands), reflecting different climatic regions. It should also be noted that there is variation within each region, typically a range of ± 7.5% around the mean.

Table 7 Green water use for dairy cattle grazing and silage across NUTS regions of Britain

Area	Grazing, m^3 per t DM #	Silage, m^3 per t DM #	Weighting by dairy cow numbers
South West England	730	570	26%
North West England	690	540	18%
Wales	710	560	14%
Scotland*	690	540	12%
West Midlands of England	660	510	12%
Yorkshire And The Humber	610	470	6%
South East of England	720	560	5%
East Midlands of England	600	470	4%
Eastern England	650	510	2%
North East England	630	490	1%
National	690	540	

* Green water in Scotland was assumed to be the same as the North West of England, given the general similarity between the climates, given that Scottish dairying is concentrated in South West Scotland

Rounded to two significant figures

3.7.3. Water use of concentrated feeds

Typical concentrate mixes were estimated (Appendix 1). The water consumption of crops was taken from Chatterton et al. (2010), and Mekonnen and Hoekstra (2010a). Where the country of origin was known, average country values were used, for other crops world average values were used (Appendix 1). Economic allocation was used to partition the water consumption of crops that are processed before feeding to cattle (e.g. wheatfeed). This is in accord with the IDF approach to Carbon Footprinting (IDF, 2010).

3.8. Water use in the livestock system

Water consumption in the livestock system was quantified using the Cranfield LCA systems model, updated and using contemporary industry data from DairyCo's Milkbench[+]. The model quantifies major terms related to water use, e.g. feed DM intake from grass, silage and concentrates in different production systems.

3.8.1. Drinking water

The drinking water consumption of cattle was based on data from standard texts and, so far, must substitute for detailed surveys of dairy farms. The drinking water intake of lactating cows was derived from the following relationship, which was based on farm study measurements (Thomson et al., 2007):

$$I_w = 2.15\ I_d + 0.73M + 12.3$$

Where:

I_w = water intake, kg/day
I_d = dry matter intake, kg/day
M = milk yield, kg/day

Drinking water for replacement heifers was calculated using the Agricultural Research Council (ARC) review of water (cited in Thomson et al., 2007). This is based on dry matter (DM) intake and ambient temperature. It was estimated that the average ambient temperatures would be approximately 10°C and therefore a value of 3.5 l kg^{-1}DM ingested was used. Drinking water, and thus abstracted blue water, was taken to be the balance of this less the water content of feed.

3.8.2. Washing and cleaning water

Wash water for lactating dairy cows was also taken from Thomson et al. (2007) and assumed to be 25 l $animal^{-1}$ day^{-1}. There are no available data on wash water for non-lactating cattle and it has been assumed to be negligible.

3.8.3. Milk cooling on-farm

It was assumed that a ratio of 2:1 water to milk is used by the plate cooler to achieve optimum cooling (DairyCo, 2009). Plate coolers require additional water for washing, so that a total ratio of 3:1 was assumed to include both milk cooling and washing functions. It should be noted that this water is frequently reused for washing down yards and cattle drinking water, but the extent of this and the amount lost to waste water has not been modelled here. In some cases, more traditional water-based alternatives may still be used for cooling and may consume less water, however all newly installed cooling systems are plate coolers and these were modelled to avoid underestimating blue water use.

The water used for milking machinery and the bulk tank was estimated to be an average of 0.31 litres per kg milk, but this could depend on herd size and the frequency of bulk tank collection.

4. Results

4.1. Water consumption in feed and milk production systems

Water consumption was calculated for the systems across the NUTS2 British regions and the weighted average was calculated to represent a national average using the values in Table 7. Table 8 shows averages based on distribution of grass site classes in each region. The headline value is that it takes about 8 litres of blue water to produce 1 litre of milk (which is very close to the average kg FPCM in British systems). Green water use is about 90 times higher giving total water consumption ranging from 685 to 1,014 litres water per litre milk. The higher yielding systems having slightly lower water consumption per litre FPCM. In all cases, blue water accounts for ≈1% of the total water consumption.

Table 8 Average blue and green water use for British dairy systems, litres per kg FPCM

Production system	Blue water, l/kg FPCM	Green water, l/kg FPCM	Total water use, l/kg FPCM
Spring calving	7.4	678	685
Autumn calving	7.5	683	691
All-year calving	7.5	681	688
Zero grazing	7.6	706	713
Organic	8.1	1,006	1,014
Values for green water use would normally be rounded to 2 significant figures, but the whole values have been shown to illustrate the relatively small effect of blue water and be arithmetically correct.			

There was no opportunity to estimate significant differences in blue water use across regions, but this was possible for green water. The systems behaved in a similar way across regions, although the effects for organic were somewhat larger than non-organic counterparts. The results (Table 9) show how green water use is least in the East Midlands and highest in the South West of England, in line with the grazing and silage green water use (Table 7). It is important to recognise that while these differences exists, they would be similar for other crops and taking dairy cows off grassland would not stop evapotranspiration *per se*. Evapotranspiration would continue, but without milk production.

Table 9 Effects of region on green water use across British regions, compared against national use per kg FPCM

Region	Green water use compare with use at national level
East Midlands	-8%
Yorkshire and Humberside	-7%
North East	-5%
Eastern	-4%
West Midlands	-3%
North West	0%
Scotland	0%
Wales	2%
South East	2%
South West	3%

The effects of yield on water consumption were examined for three systems (Table 10) and shows that water use per unit milk falls as yield increases. This results from the proportion of feed being used for production (rather than maintenance) increasing with yield, even though direct feed consumption per cow per day increases with yield. Despite allowing for imputed lower herd replacement rates, the higher green water use in organic production is mainly a consequence of lower crops yields and higher maintenance overheads due to lower milk yield ().

The range of values across yield levels is of similar magnitude to that for green water use between regions.

Table 10 Effects of milk yield level on the water consumption in average British milk production

Production system	Yield, kg /year	Blue water consumption relative to medium yield	Green water consumption relative to medium yield
Organic	5470	115%	118%
	6470	100%	100%
	7470	90%	89%
Autumn calving	6770	107%	116%
	7770	100%	100%
	8770	91%	93%
Spring calving	6770	116%	116%
	7770	100%	100%
	8770	91%	92%

4.2. **Breakdown of blue and green water use**

The breakdown of blue and green water use in milk production (Figure 2) shows that drinking and wash water together completely dominate blue water use and they are of approximately equal proportions. Feed production dominates green water use with a roughly equal split between concentrates, silage and grazing for the averaged production system. In organic milk production, the proportion of green water from concentrates is smaller (20%) than average (34%), mainly reflecting lower concentrate use.

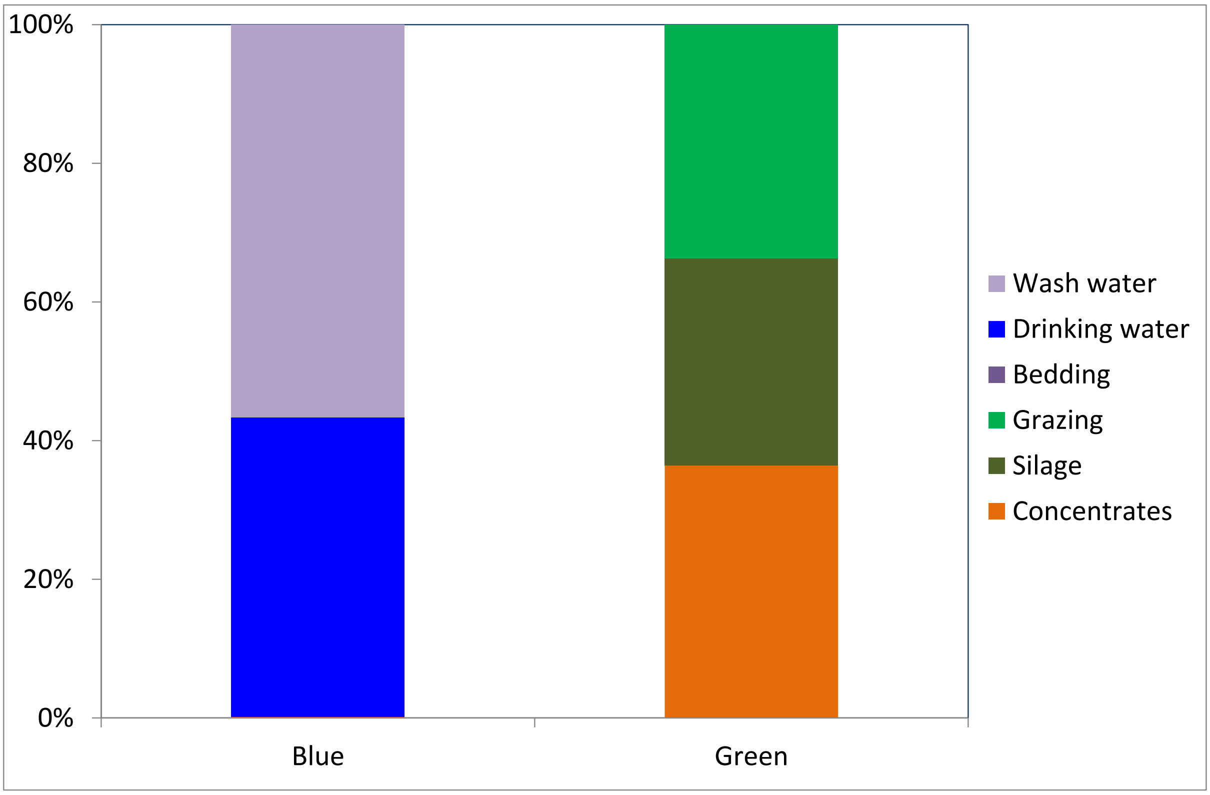

Figure 2 Breakdown of blue and green water use in average milk production

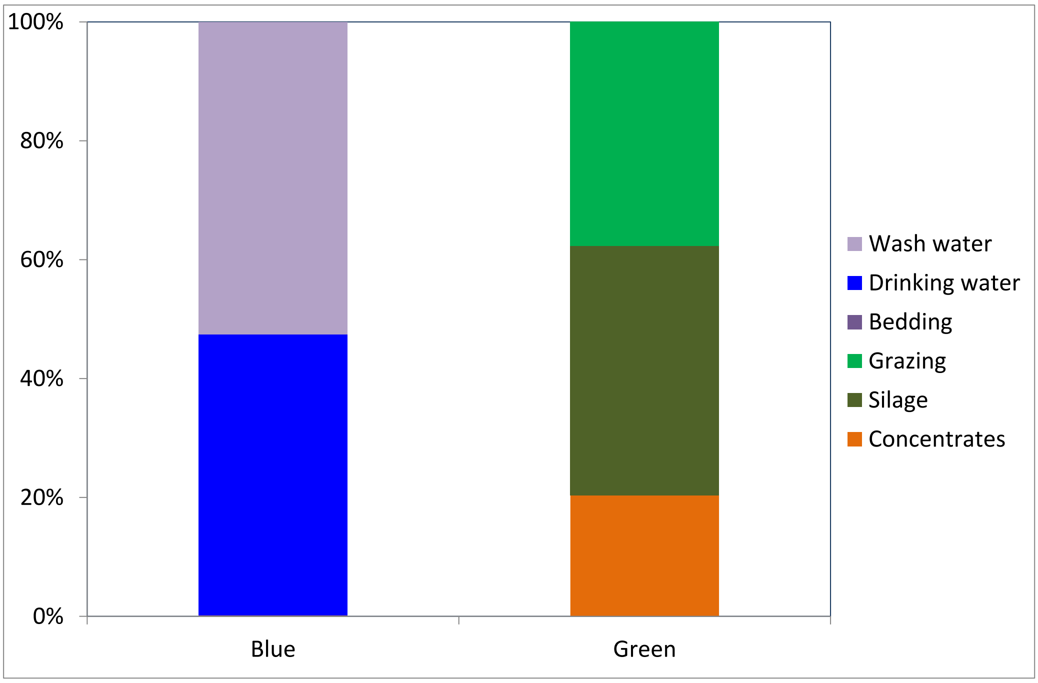

Figure 3 Breakdown of blue and green water use in organic milk production

5. Discussion

5.1. Comparison with other studies

The estimates of water consumption in the livestock system are generally lower than found in other published reports. Green water consumption for milk is slightly lower than values quoted by Mekonnen and Hoekstra (2010b). Grass yields in the UK are high, reducing the water consumption per tonne of grass dry matter. In addition, the relatively low proportion of concentrates in the diet may reduce the green water consumption in comparison to feed from overseas locations where water consumption is higher.

However, our estimates of blue water consumption are considerably lower than those of Mekonnen and Hoekstra (2010b). This may be due to a number of reasons, as follow.

- The proportion of grass in most UK dairy system diets is reasonably high. Drinking water requirements are likely to be lower for grass-fed animals than for cattle fed on more cereal or concentrate based diets where the dry matter content is higher, and thus less water is supplied in food so more of the daily water intake requirement must be met through abstracted drinking water. It is also clear, but not readily quantifiable, that grazing in wetter areas will cause more passive ingestion of water and thus reduces the demand for abstracted (blue) water, since most dairying is in wetter parts of Britain.
- There is very little virtual blue water in concentrated feeds in the UK as most concentrates come from rain-fed crops, as opposed to irrigated crops.
- A large proportion of concentrated feeds are by-products (e.g. wheatfeed or brewers' grains) and therefore relatively little virtual water is allocated to such feeds.

- This study does not include water for industrial processing of milk post farm gate, which has been included in some other studies. UNEP (2000) considered that post-farm processing used 1.3–2.5 litres water/kg of milk intake.

5.2. Limitations in the analysis

Drinking and cleaning water requirements were estimated from standard figures and simple models relating to diet and ambient temperature. It is difficult to account for the variable efficiency of water use on farms, e.g. leakage, different use by operators, osmotic pressure variation in diets, biological variation between animals etc. In addition, the likely absence of sub-metering on farms makes actual farm accounting a challenge.

However, it is very likely the uncertainties are smaller than those in carbon footprinting and we believe that the calculations are correct to within ± 25%. It is also important to recognise that the uncertainties are internally correlated, and so the uncertainties are not totally independent between production systems. So, the significance of differences between systems actually depends on the differences in activity data (e.g. days to finishing or weight of feed consumed) rather than in the uncertainties in, say, the evapotranspiration of water from grass. It is therefore quite possible for small differences between values for the water footprints of similar products to be significant despite the large overall uncertainty.

6. Water "footprint" impacts

6.1. Blue water

The estimates of water consumption themselves do not provide any information on the impact of water consumption on the source water bodies. It is clear that the same volume of water abstracted from a plentiful water resource, for which there is little competition, will have a lesser impact than that taken from an over-exploited or scarce resource. Therefore, many suggest that the water "footprint" should reflect the impact of water consumption on the source water body, rather than simply a volume of water consumed, which we term the volumetric water footprint. This differs from the definition of water footprint used by the Water Footprint Network, but is compatible with the draft ISO 14046 standard on Water Footprints (http://www.iso.org/iso/catalogue_detail?csnumber=43263).

The significance of blue water use depends upon the status of the water resource from which it is withdrawn. There are alternative approaches to the quantification of water impact or stress indices. These were reviewed by Lennard and Hess (2012). These include the stress-weighted water footprint (Ridoutt & Pfister, 2010) and methods developed under the life cycle assessment (LCA) approach (Milà i Canals et al., 2009) and the identification of 'hot spots' where blue water footprints are large and water scarcity is high (Jefferies *et al*., 2012). These methods differ in scale of application and approach, including the use of annual or seasonal water demands. It cannot be stressed too highly that this whole subject is a fast developing area and these is no single agreed method than can be applied yet.

It is clear that competition for blue water and the subsequent fate of blue water in a catchment are very important in any analyses, and that the scale of application needs to be appropriate for the purpose of the study. What is suitable for comparing water stress at a country scale may not be resolvable to a local catchment or farm level. One example is the Water Stress Index (WSI), which has been used to normalise blue water scarcity (i.e. include stress conditions) in water footprint studies (Pfister et al., 2009). It is based on the withdrawal-to-availability ratio (WTA), which is the ratio of total annual freshwater withdrawal for human uses by sector to the annually available renewable water supply in a specific region, river basin or catchment.

Much of the UK has a Water Stress Index (WSI) <0.2 (0.01 is minimum and 1 is maximum water stress), particularly the agricultural areas in which the index is usually much lower. The WSI can be used to normalise blue water use and so correct for “local” water stress.

This, however, leads to the apparently counterintuitive result that normalised blue water use for milk production in NW England is about twice as high as Eastern England. This results from several features of the method such that values in England are much influenced locally by urban areas and it does not allow for blue water reuse in a catchment. Also, the implementation of the method by Pfister et al. (2009) used relatively coarse grid squares rather than the shapes of catchments, so that actual water supplies were not accurately represented.

This method does have some value, but at much larger physical scale and the authors have since updated the approach with more temporal data.

6.2. Green water

Green water cannot be diverted to other uses (except alternative vegetation) so the green water consumption is often excluded from water impact studies. However, the choice of crop (including, in a broad definition, trees, which evaporate more than annual crops) does influence the water that might pass into watercourses within a catchment. The evapotranspiration that causes green water use continues whether land is being used for agriculture or not. So, the opportunity cost of green water is really associated with land. In general, as long as low rainfall does not limit the green water use, the real water use impact is therefore associated with the blue water consumption only.

6.3. Grey water

Grey water in the Water Footprint Network footprint is a calculation to estimate of the amount of clean water that is needed to dilute any water contaminated by pollutants in the particular process under analysis, until it is of an acceptable quality. This could be based on nitrate leaching, but when considering dairying, there are other sources of diffuse or point-source pollution that may arise. These include silage effluent, manure management and dirty water management. This requires a separate study of causes, impact levels and solutions for different farms. In its current form, the method used by the Water Footprint Network sums the colours of water (blue, green, grey) and does not, yet, consider impacts.

In the forthcoming water footprint standard (ISO 14060), water impacts are to be quantified in two ways. The first relates to the water stress and the supply of blue water. The second relates to water degradation, which is the same broad concept as grey water, but will be addressed in more targeted way.

6.4. Catchment based impacts

For farmers in England and Wales, one useful approach is to consider their location within catchments. The Environment Agency has quantified water resource availability through the Catchment Abstraction Management Strategies (CAMS), (http://www.environment-agency.gov.uk/business/topics/water/119927.aspx). This is illustrated in Figure 4 and shows the large regional and local variation in blue water availability.

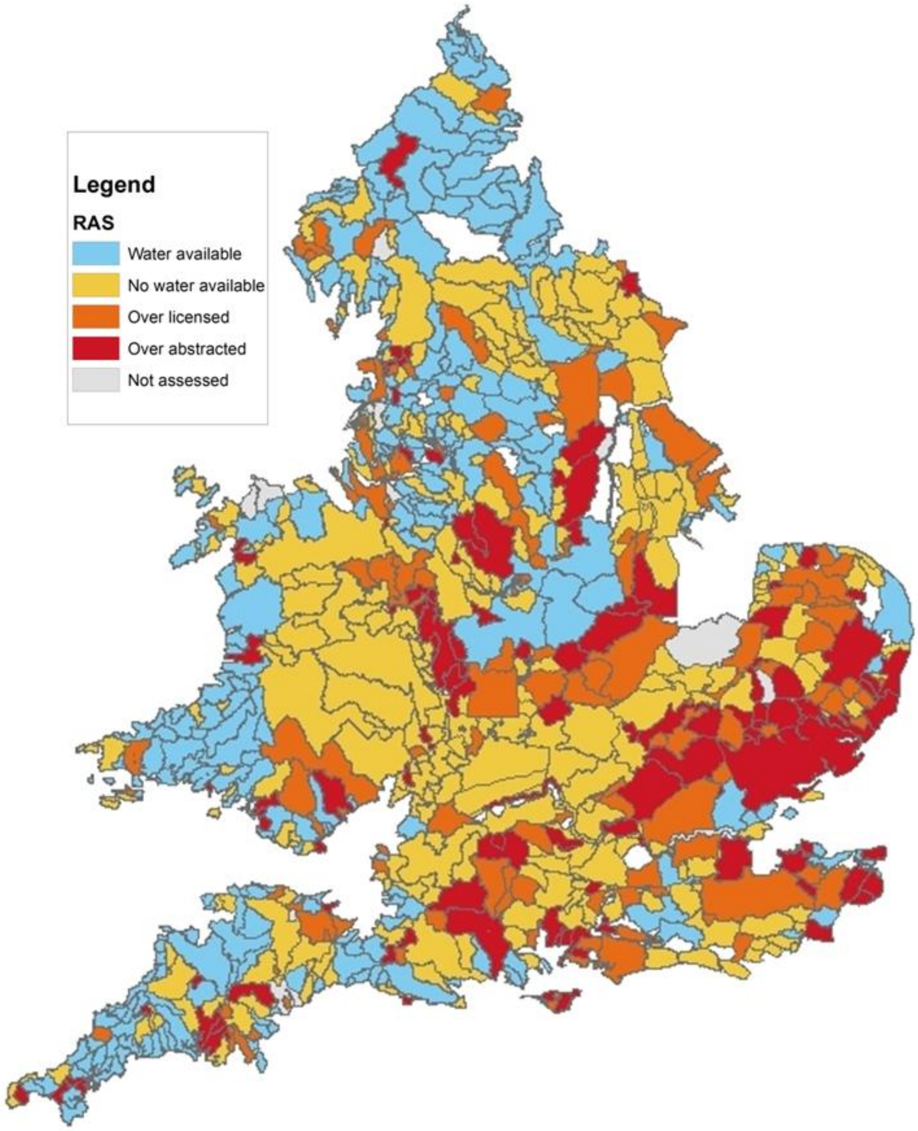

Figure 4 The Environment Agency's Catchment Management Abstraction Strategies showing the degree of blue water supply in catchments.

We do not suggest that dairying should cease through being in an over-abstracted area. Cattle need drinking water to maintain health and this is a legitimate demand. Dairying may be in areas of relatively high water stress for perfectly good reasons, such as making good use of natural resources and meeting local market needs. The degree of stress should be used more to highlight the need for awareness of water use and to avoid wastage through conventional routes, such as leaking pipes, drinkers etc. There is an economic cost to water wastage, whether to a water supply company, pumping costs of extra fresh water, or handling additional volumes through the farms dirty water or slurry management system.

7. Conclusions

The water consumed in milk production on British farms has been quantified and it takes about 8 litres of blue water to produce 1 litre of milk (or more correctly, 1.01 kg of fat and protein corrected milk) at the farm gate. The blue water use is about 1% of the total: the bulk being green water from evapotranspiration of feed crops (including grazed grass). Most feeds are rain fed and do not require blue water for their production. There are some differences between production systems and the location of production, but most are of green water. Green water has a very limited impact on overall water use or impact, and need not be the main focus of attention in considering water use in milk production.

The blue water consumption, by itself, gives little indication of impact in a specific area. Existing international indices of water stress give a general indication of the relative impact of blue water use, but not at farm level. Methods are still under development to provide catchment level indices to normalise blue water use across regions or countries.

The Environment Agency's Catchment Abstraction Management Strategies in England and Wales help identify where water abstraction is under stress. This should be used to identify areas in which greater care should be taken over blue water use, but without any compromise of cattle welfare or public health.

There were some differences in water use between production systems and production levels. Lower yielding systems use somewhat more blue water than higher yielding ones, because the overheads of maintenance are relatively higher with lower yielding systems. The differences are not very large and are probably smaller than farm to farm variation.

The study has not had access to recent actual farm data on blue water use. A well-structured survey would be of great benefit and eventually could be used to help create a benchmarking method. In addition, a further study to address the impacts of dairying on water quality and addressing methods to minimise these is suggested.

8. References

AFRC (1993) Energy and Protein Requirements of Ruminants. An advisory manual prepared by the AFRC Technical Committee on Responses to Nutrients. CAB International

Ashok, A., James, K. (2011) The water and carbon footprint of household food and drink waste in the UK. WRAP and WWF Report. ISBN: 1-84405-444-6. http://www.wrap.org.uk/downloads/Water_and_Carbon_Footprint_report_Final_Nov_2011.b94cb7f6.10610.pdf Last accessed 25-Mar-2012

Audsley, E., Angus, A., Chatterton, J., Graves, A., Morris, J., Murphy-Bokern, D., Pearn, K., Sandars, D. and Williams, A. (2010). Food, land and greenhouse gases. The effect of changes in UK food consumption on land requirements and greenhouse gas emissions. The Committee on Climate Change. http://downloads.theccc.org.uk.s3.amazonaws.com/4th%20Budget/fourthbudget_supporting_research_cranfield_dietsGHGLU_agriculture.pdf

DairyCo, 2009. Effective Use of Water on Dairy Farms. Available from: http://www.dairyco.net/library/farming-info-centre/environment/effective-use-of-water-on-dairy-farms-(1).aspx [Accessed 20th October 2011].

Defra, 2010. Observatory monitoring framework – indicator data sheet. Environmental impact: Water. Indicator DA5: Water abstraction for agriculture. Available from: http://archive.defra.gov.uk/evidence/statistics/foodfarm/enviro/observatory/indicators/d/da5_data.htm . [Accessed 29/03/2012]

Hoekstra, A. Y. and Chapagain, A. K. (2007), Water footprints of nations: Water use by people as a function of their consumption pattern, .

Hoekstra, A.Y. and Mekonnen, M.M. (2012) The water footprint of humanity. Proceedings of the National Academy of Sciences of the United States of America. doi: 10.1073/pnas.1109936109

IDF, 2010. A common carbon footprint approach for dairy. Bulletin of the International Dairy Federation 445/2010. Available from: http://www.idf-lca-guide.org/Files/media/Documents/445-2010-A-common-carbon-footprint-approach-for-dairy.pdf [Accessed 12th January 2012].

Jefferies, D., Muñoz, I., Hodges, J., King, V. J., Aldaya, M., Ercin, A. E., Milà I Canals, L. & Hoekstra, A. Y. (2012), Water footprint and life cycle assessment as approaches to assess potential impacts of products on water consumption. Key learning points from pilot studies on tea and margarine, Journal of Cleaner Production, vol. 33, pp. 155-166.

Mekonnen, M. M. and Hoekstra, A. Y. (2010a), The green, blue and grey water footprint of crops and derived crop products. , UNESCO-IHE, Delft, the Netherlands.

Mekonnen, M. M. and Hoekstra, A. Y. (2012), "A Global Assessment of the Water Footprint of Farm Animal Products.", Ecosystems, .

Mekonnen, M.M. and Hoekstra, A.Y. (2010b), The green, blue and grey water footprint of farm animals and animal products, Value of Water Research Report Series No.48, UNESCO-IHE, Delft, the Netherlands.

Milà i Canals, L., Chenoweth, J., Chapagain, A., Orr, S., Antón, A., & Clift, R. (2009), Assessing freshwater use impacts in LCA: Part I- inventory modelling and characterisation factors for the main pathways. International Journal of Life Cycle Assessment, vol. 14, no. 1, pp.28-42.

Pfister, S., Koehler, A., & Hellweg, S. (2009), Assessing the environmental impacts of freshwater consumption in LCA. Environmental Science & Technology, vol. 43, no. 11, pp. 4098-4104.

Ridoutt, B. G., Sanguansri, P., Freer, M. and Harper, G.S. (2012) Water footprint of livestock: comparision of six geographically defined beef production systems. International Journal of Life Cycle Analysis 17:165-175.

Ridoutt, B. G., Williams, S. R. O., Baud, S., Fraval, S. and Marks, N. (2010), "Short communication: The water footprint of dairy products: Case study involving skim milk powder", Journal of dairy science, vol. 93, no. 11, pp. 5114-5117.

Ridoutt, B.G. and Pfister, S. (2010) A revised approach to water footprinting to make transparent the impacts of consumption and production on global freshwater scarcity. Global Environmental Change, 20 (1), 13–120.

Thomson, A.J, King, J. A., Smith, K.A., Tiffin, D.H., (2007). Opportunities for Reducing Water use in Agriculture. Defra Research Project Final Report for WU0101.

UNEP (2000) Cleaner Production Assessment in Dairy Processing. http://www.unep.fr/shared/publications/pdf/2480-CpDairy.pdf last accessed 28-Mar-2012

Williams, A.G., Audsley, E. & Sandars, D.L. (2007) Environmental burdens of livestock production systems derived from life cycle assessment (LCA). In: Garnsworthy, P. (Ed), 41st University of Nottingham Feed Conference, Sutton Bonington, Nottingham, 171-200.

Williams, A.G., Audsley, E. &.Sandars, D.L. (2006) Determining the environmental burdens and resource use in the production of agricultural and horticultural commodities. (IS0205). www.agrilca.org

9. Appendix 1

Grass and concentrate feed water use

Table 11 Non-organic concentrate composition with blue and green water use

Concentrate Ingredients	Non-organic Standard Dairy	Blue water, m^3/t	Green water, m^3/t
Wheat non-org†	21.9%		690
Palm Kernel meal*	10.5%	0.2	800
Rape meal non-org†	9.0%		730
Winter Barley†	6.7%		740
Molasses*	5.7%		140
Wheatfeed non-org†	4.8%		150
Oat feed non-org UK†	4.8%		2100
Malt Culms / brewers grains†	4.8%	10	320
Wheat Straw†	4.8%		
Citrus Pulp*	4.8%	19	340
Beet pulp†	4.8%	1	80
Sunflower meal	3.8%		
Spring Barley†	3.8%		850
Limestone	2.9%		
Soy meal†	2.6%		2640
Biscuit Blend	1.9%		
Feed Beans†	1.2%		1600
Rice bran	1.0%		
Salt	0.7%		

Table 12 Representative organic concentrate mix with water use

Concentrate Ingredients	Organic Standard Dairy	Blue water, m^3/t	Green water, m^3/t
Wheatfeed weighted†	36%		280
Maize grain. †	18%		1300
Soya whole†	16%		2620
Feed Beans. †	15%		1760
Feed Wheat Straw. †	6%		
Feed Wheat. †	4%		1150
Limestone	4%		
Spring Barley. †	1%		1570
Winter Barley. †	1%		1570

*Derived from WFN values (Mekonnen & Hoekstra, 2010a).

†Derived from agroclimatic modelling and Cranfield LCA systems model.