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Abstract

The virtual water content (VWC) of food has been widely discussed as a key driver of future global food policy. This paper seeks to analyse current methodology used in the determination of VWC of poultry meat and the conclusions that can be drawn with regard to different methods of poultry meat production. The research has assessed the impact of intensification of livestock production on the VWC of poultry meat. Furthermore, the paper suggests that VWC cannot be assessed as an ecological benchmark in isolation. Instead VWC should be determined together with the calorific value (CV) of food and this factor CV-VWC should be used to propose effective water use for human food production in the future.

Keywords: virtual, water, content, footprint, meat, poultry, methodology, policy

Introduction

Essentially, agriculture takes items of little or no calorific value such as seeds, soil and water and turns them, using solar energy and animal metabolism, into calories that are accessible to humans for food (Manning, 2009). Food products have varying ecological footprints depending on the efficiency of the particular path of conversion, but agriculture can be described as the complex "process" of producing macronutrient and micronutrients for people. The Foresight report (2011) determined six drivers for change in the global food supply chain namely:

- Global population increase;
- Change in the size and nature of per capita demand for food especially for meat and fish;
- Future governance of the food system at both national and international levels;
- Climate Change;
- Competition for key resources (land, water and energy); and
- Changes in values and ethical stances of consumers.

A number of these themes and their interrelationship are discussed in this paper. The term "*water footprint*" describes the extent of personal water use in relation to consumption (Hoekstra and Chapagain, 2006). However, the term can be extended to represent the demand for water resources by a family, community, nation or indeed in a global context. Hoekstra and Chapagain (2006) calculated that the average global personal water footprint was $1240m^3$/capita/yr; with the United States (US) having an average footprint of $2480m^3$/capita/yr; in contrast to China where the average footprint was $700m^3$/capita/yr. Research by the Organisation for Economic Co-operation and Development (OECD, 2006) suggested that by 2025, global water use is estimated to rise by up to 30% in developing countries and over 10% in the developed world. The research also concluded that the global population which is living in water-stressed areas is set to double over the period 1995-2025, and predictions suggest that by 2030 some two-thirds of the world's inhabitants may experience moderate to high water stress in parts of Africa and Asia (Manning, 2008a).

Global estimates for the rise in human population predict an increase in our global population from 2.56 billion in 1950 to 9.40 billion in 2050 (USCB, 2008). Human water demand is influenced by demographic trends and patterns of food consumption (Allan, 1998). Allan (1998) determined that 10% of the water consumption of a community was for drinking water with the remainder used for agriculture and food production. Van Hofwegan (2007) argued that the average per capita consumption of drinking water was between 0.05 and 0.15 m^3/capita/day, whilst the per capita consumption of virtual water varied between 1 m^3/capita/day for a survival diet; 2.6 m^3/capita/day for a vegetarian diet and over 5 m^3/capita/day for a US style meat based diet. Therefore the key contributor to water footprint is the food consumed and the goods utilised rather than the volume of drinking water. There has been an ongoing rise in food consumption per capita. The predicted changes in global food consumption from have been collated (Table 1) and they demonstrate a rise in average calorific intake from 1964 – 2030 from 2358 kcal/capita/day to 3050 kcal/capita/day (WHO, 2007).

Table 1: Global and regional per capita food consumption (Source: WHO, 2007)

Region/ capita food consumption (kcal/capita/day)	1964 - 1966	1974 - 1976	1984 - 1986	1997 - 1999	2015	2030
World	2358	2435	2655	2803	2940	3050
Developing countries	2054	2152	2450	2681	2850	2980
Near East and North Africa	2290	2591	2953	3006	3090	3170
Sub-Saharan Africa (excl. South Africa)	2058	2079	2057	2195	2360	2540
Latin America and the Caribbean	2393	2546	2689	2824	2980	3140
East Asia	1957	2105	2559	2921	3060	3190
South Asia	2017	1986	2205	2403	2700	2900
Industrialised countries	2947	3065	3206	3380	3440	3500
Transition countries	3222	3385	3379	2906	3060	3180

Helms (2004) in a separate study proposed that from 1960 to 1995 per capita food availability grew from 2300 kcal to 2700 kcal per capita per day; the author also suggested that the range that was considered a safe food supply was 2700 kcal – 3200 kcal per capita per day. The increase in calories is one element that is driving demand for water to support food production the other is the transition in many regions of the world towards a meat and dairy product based diet.

The total amount of water that is used in the "production" of a food item good is termed the "*virtual water content*" or VWC (van Hofwegen, 2007). The author determined that the VWC of wheat is 1 m^3/kg whereas the VWC associated with meat production can vary between 5 and 13.5 m^3/kg. Further research supported this by suggesting that the VWC of wheat and barley is 1.3 m^3/kg, poultry meat 3.9 m^3/kg, sheep meat 6.1 m^3/kg and beef 15.5 m^3/kg (Waterfootprint, 2011). Helms (2004) determined that there has been an increasing demand for meat within the diet and the consumption of meat in kg/capita has been estimated to double between 1964-1966 when the consumption was 24.2 kg/capita, 1997 – 1999 where consumption was 36.4 kg/capita, and by 2030 consumption is predicted to be at 45.3 kg/capita. The author argued that "*providing an average food supply of 2,900 kcal with half of all protein derived from animal products would nearly double the grain demand by the year 2050*". Ringler (2006) agreed stating that global per capita demand for livestock products is expected to rise due to increased demand and income growth. Nutritional data suggested that a suitable daily intake for an adult with low physical activity i.e. a sedentary lifestyle is 2,400 kcal (Helms, 2004). However, Nestle (2002) argued that it is difficult to translate average calorific intake into required calories for energy and provision of essential nutrients. Within this context, therefore it is important to determine not only the VWC of food but also how it relates to CV. The VWC of a range of products has been calculated by Chapagain and Hoekstra (2004) who developed a series of equations to determine the VWC of foodstuffs including live animals, primary crops and processed crops and livestock products. The VWC and CV have been compared for a range of foods (Table 2).

Table 2: The calorific value: virtual water content (CV:VWC) ratio for a range of foods

Food Item	Calorific value (CV) (kCal/100g)[1]	Virtual water content (VWC)(L/100g)[2]	Calorific value: virtual water content ratio (CV:VWC)
Beef (ground)	332	1600	0.21
Bread	266	133	2.00
Cheese (cheddar)	403	500	0.81
Chicken meat (deboned)	216	390	0.55
Potatoes	77	90	0.85
Rice	365	340	1.07

[1]USDA (2011) [2] www.waterfootprint.org

If the virtual water content alone is considered it could be determined that potatoes are a better crop to grow in a water scarce area at 90 litres/100g for potatoes compared to rice 340 litres/100g on a weight for weight basis . However, if CV is taken into consideration rice would be the favoured crop as the calorific value: virtual water content ratio (CV: VWC) for rice is 1.07 and potatoes 0.85. Therefore, determining water footprint in terms of water use alone per kilogramme or tonne without considering the calorific value of food is a rather simplistic argument. As an approach VWC is considering water use rather than the level of water "embedded" in the actual food product. As freshwater is a finite, although ultimately a renewable source, this factor should drive the concept of beneficial use of water for food production. The water considered in the VWC methodology is not "lost" to the environment as a whole, rather it is utilised for a period of time and thus is denied in its use to others until it becomes available again in the water cycle. It is this use of water as a public or private "good" which lies at the heart of water policy for agricultural and non-agricultural purposes. The CV-VWC approach focuses policy directly on the use of water in providing accessible calories and nutrients for humans in the most effective way.

Furthermore Ridoutt and Pfister (2010) argued that most water footprints are "*the crude summation of more than one form of water consumption (blue, green and grey water) from locations that differ in terms of water scarcity. As such, water footprints of different products are not comparable*". This demonstrates that VWC is more complex than a straight calculation as the "source" of the water and the relative environmental impact of its abstraction (in the instance of surface water, ground water or recycled water) should also be considered.

Rainwater that falls on a watershed can be theoretically divided into "green" and "blue" water (Yang *et al.,* 2006). Yang *et al.,* (2006) defined green water as "*the return flow of water to the atmosphere as evapo-transpiration (ET) which includes a productive part as transpiration (T) and a non-productive part as direct evaporation (E) from the surfaces of soils, lakes, ponds, and from water intercepted by canopies or the water stored in the unsaturated soils*". This type of water is the source for rain-fed food production. In contrast the term "blue" water describes "*the water in rivers, lakes, reservoirs, ponds and aquifers*" and this is the main source of water for crop irrigation (Yang *et al.,* 2006). Agriculture already currently consumes 70% of total global 'blue water' withdrawals from rivers and aquifers available to humankind (Foresight, 2011). The report suggests that demand for water for agriculture could rise by over 30% by 2030, while total global water demand could rise by 35–60% between 2000 and 2025, and could double by 2050 owing to pressures from industry, domestic use and the need to maintain environmental flows. The term given to water that is waste, recycled or reprocessed is described in some methodology as “grey” water (EA, 2011). In other methodology grey water is defined to represent the volume of freshwater that is required to assimilate the load of pollutants given natural background concentrations and existing ambient water quality standards (Mekonnen and Hoekstra, 2010).

However, Ridoutt and Pfister (2010) concluded that: “*at present, it is not clear what good would result from choosing a product or production system on the basis of it having a lower water footprint. Indeed, a product with a lower water footprint could be more damaging to the environment than one with a higher water footprint depending upon where the water is sourced*”.

Virtual water content of meat

Cereals are the most important source of total human food consumption as measured in calories (FAO, 2003a). They also provide a food source for livestock, especially intensive livestock production. The report projected that around 50% of cereals will be consumed directly by humans with around 44% being used for animal feed, with the balance going to other uses, such as seed, industrial non-food, and waste. The development of cereals as a precursor of bio-fuel production may well reduce the availability of cereals to humans in the future. Wheat is grown on the biggest area globally, around 225 million hectares (FAOSTAT, 2010). The impact of wheat on human water footprint calculations therefore is both in direct foodstuffs and also as one of the main constituent of animal feeds. Using data for wheat production (Table 3), the crop water requirement varied from 179 – 630 mm/crop period with an average VWC of 1334 m^3/tonne (range of 738 – 1588 m^3/tonne). Research from the Ausgrain (2011) determined the degree of variance from season to season in terms of yields per hectare (Table 4). Whilst one source calculated that the average wheat yield in Australia is 1.9 tonnes/hectare (waterfootprint.org, 2011) the Ausgrain (2011) data for the years 2003 - 2007 proposed an average of 1.5 tonnes/hectare with a range of 0.21 – 1.97 tonnes/hectare.

Table 3: Virtual water content of wheat by country (Source: waterfootprint.org)

Country	Crop water requirement (mm/crop period)	Wheat yield (tonne/ha)	VWC (m^3/tonne)
Argentina	179	2.4	738
Australia	309	1.9	1 588
Canada	339	2.3	1 491
France	630	7.0	895
US	237	2.8	849
Global average (all countries)		2.7	1 334

Table 4: Australian wheat yield 2003 – 2007 (Source: Ausgrain, 2011)

Season	Wheat yield (tonne/ha)						
	NSW	VIC	QLD	WA	SA	TAS	Australia
2003	1.69	2.38	1.46	2.17	1.94	2.5	1.97
2004	1.79	1.43	1.68	1.70	1.30	4.43	1.64
2005	2.26	2.12	1.45	1.82	1.77	2.88	1.93
2006	0.74	0.62	1.31	1.26	0.67	2.86	0.92
2007	0.45	1.23	1.57	1.49	1.16	3.67	1.07
Average							1.52

North *et al.,* (2008) in their research on water usage and wheat yields concluded that wheat in the Australian Murray-Darling basin received median growing season rainfall of 250mm; crops were pre-irrigated in autumn 100 - 150mm; and spring irrigations applied 60 to 75mm i.e. a crop requirement of 410mm – 475mm. The authors further proposed that the total depth of water applied (on top of seasonal rainfall) to each plot varied from 300 to 600 mm and the yield varied between 4.8 and 7.3 tonnes/hectare. This data identified the impact of specific farming practices especially irrigation on the yield and the VWC of wheat and more specifically the colour of the VWC. As over 80 per cent of total agriculture is rain-fed, projections of future precipitation changes and increased evaporative demand due to rising temperatures often influence the magnitude and direction of climate impacts on crop production (Gornall *et al.,* 2010). Therefore whilst averaged data can be used to assess VWC it has to be treated with caution in terms of developing national or organisational policy, or indeed with regard to product labelling, as there is such a range of variants including specific farm practice, intra-national location as well as national location. This wide variation in VWC depending on the region where the wheat is grown is a function of the natural environment, the rate of evapotranspiration and the yield achieved. The impact of annual weather patterns or longer term climatic changes on these crop yields is hard to determine, but will mean that the VWC of the wheat crop will vary from year to year. The rainfall pattern in terms of the crop growth period is also important, because whilst rainfall occurs it may not be at the time of crop need.

Crop rotations are also an important factor that influences VWC including single or double cropping plans, the use of sacrifice crops to aid soil structure and the choice of spring or autumn planting as well as variety variations in terms of predicted yield. Nutrient use, pest damage and disease challenges will also vary from year to year and by location and will influence VWC. The variations demonstrated in this literature review of the VWC of wheat will affect VWC calculations where wheat is either a food ingredient for animal feed supply or a food direct for processing for humans. Ultimately if these factors are not considered this will impact on the accuracy and validity of the VWC calculated.

Zimmer and Renault (2003) argued that in the formulation of virtual water methodologies a number of assumptions are made and different accounting procedures used. They identified five steps that need to be considered namely to categorise food products with regard to processes and their virtual water value; properly map the fluxes of products within and at boundaries of the systems considered; specify the production process for each type of food product; specify the scope of the study; and compute VWC and flows. Hoekstra (2003) stated that it was difficult to assess the VWC of a product because, as previously described in this paper, of the number of influencing factors that affected the amount of water used in a production process. He suggested that the following factors should be considered: the place and period (e.g. which year, which season) of production and the point of measurement. With regard to irrigated crop production, water use at the point of water withdrawal or at the field level should be determined as well as the production method and the associated efficiency of water use. Method of irrigation is also an important consideration as the efficiency of irrigation varies according to method. The inclusion or exclusion of waste water should also be identified in the methodology. The method of attributing water inputs into intermediate products to the virtual water content of the final product should also be defined.

De Fraiture *et al.,* (2004) reviewed whether international cereal trade saves water as a means to determine the impact of virtual water trade on global water use. The authors concluded that whilst virtual water trade has the potential to reduce water use, policy makers should be cautious as to whether it will play a significant role in managing global water resources into the future. They argued that trade does not occur because of water shortages and that most trade occurs between countries with abundant natural resources. Further they stated that "*not all water "savings" can be reallocated to other beneficial uses .... reductions in global water use relate to productivity differences between importers and exporters rather than water scarcity [and] .. political and economic considerations—often outweighing water scarcity concerns [and] .. limit the potential of trade as a policy tool to mitigate water scarcity*". Indeed, Ridoutt and Pfister (2010) have developed a revised water footprint calculation that incorporates a regional water stress factor leading to a "stress-weighted" water footprint. They determined that the incorporation of water stress characterisation factors is essential in order to link global consumption to freshwater scarcity, because freshwater scarcity is primarily a localised concern. It is within this context that the research has been undertaken to determine the VWC of poultry meat.

The VWC of poultry meat

Global meat production has increased from 70 million tonnes in 1961 to 273 million tonnes in 2006 (Deckers, 2010 citing FAO, 2008). There has been a significant global growth in poultry meat production over the last forty years (Table 5) and by continent (Table 6). The data shows that poultry meat production continues to grow in all continents but with only a small increase in Europe of 2%.

Table 5: Development of global meat production between 1970 and 2005 (in million tonnes) Source: Daghir *et al.,* 2008

Year	Beef and veal	Pig meat	Poultry meat
1970	38.3	35.8	15.1
2005	60.4	102.5	81.0
Increase (%)	57.6	186.4	436.5

Table 6: Global production of poultry meat between 1990 and 2005 (in million tonnes) Source: Daghir *et al.,* 2008

Continent	Chicken meat		
	1990	2005	% change
Africa	1.8	3.2	+78
North and Central America	12.8	22.7	+77
South America	3.8	13.7	+256
Asia	9.4	22.0	+134
Europe including former USSR	11.5	11.8	+2
Oceania	0.48	0.94	+96
World	39.9	74.3	+86

To demonstrate this further the changing contribution of individual continents towards global meat production between 1970 and 2005 has been assessed (Table 7). The analysis shows that the influence of US and European production within the global production total is waning by -7.8% and -11.7% respectively with growth being seen in the proportion of global production in South America (9.9%) and Asia (16.1%). The contribution of African production has stayed fairly constant at around 4%. The volume of the poultry meat production is predicted to meat reach 143 million tonnes by 2030 (Table 8).

Table 7: Changing contribution to global poultry meat production between 1970 and 2005 (%) Source: Daghir *et al.,* 2008

Continent	1970	1990	2005	Overall Change (%)
Africa	4.0	5.0	4.2	0.2
North and Central America	36.2	31.3	28.4	-7.8
South America	5.8	9.5	15.7	9.9
Asia	17.9	24.4	34.0	16.1
Europe	28.1	20.6	16.4	-11.7
USSR	7.1	8.0	-	-
Oceania	0.9	1.2	1.2	0.3
World	100	100	100	-

Table 8: Poultry meat production past and projected

Year	1967/69[1]	1987/89[1]	1997/99[1]	Average[2] (2002-06)	2015[1] (projected)	2015[2] (projected)	2030[1] (projected)
Poultry production - liveweight (million tonnes)	12.9	37.2	61.8	79.9	100.6	101.7	143.3
Poultry trade (million tonnes)	-	-	-	7.6	-	10.5	-

(Source: [1]FAO, 2003b and [2]OEDC/FAO, 2008)

Ridoutt and Pfister (2010) argued that despite animal products being defined as having a much higher VWC compared to cereal-based products (Table 2) the extent to which transitions diets have caused increased water scarcity is questionable. They proposed that the VWC of meat is dependent on the type of meat production system and the extent to which the cereals grown for animal feed have come from irrigated sources. They suggested that the “colour” of the VWC is important as many livestock production systems especially those produced on a grass based system will have a very low stress-weighted VWC as the system is based largely on rainfall (green water). However, livestock production systems that are feedlot based will have a different VWC footprint. It could therefore be argued that VWC calculations, in an effort to determine the environmental impact of foodstuffs, are actually a form of environmental benchmarking or a tool that can be used to compare the ecological footprint of different production systems. Manning *et al.,* (2008b) contended that the key to effective benchmarking is to determine whether the tool will be utilised at a strategic management level or at an activity or enterprise level i.e. either as a whole supply chain or at individual stages within the supply chain. However, in supply chains with multiple suppliers, manufacturers, distributors and retailers, that can interact on either a global, national or local basis, performance measurement is "challenging" because it can be difficult to attribute performance results to one particular unit within the supply chain (Hervani *et al.,* 2005).

With specific focus on poultry meat production, the VWC of an animal at the end of its life span has been defined "*as the total volume of water that was used to grow and process its feed, to provide its drinking water, and the water used during the production cycle*" (Chapagain and Hoekstra, 2004). It will vary according to the type and breed of the animal, the farming system used, water consumption, feed consumption, feed conversion rate, the water used in producing the feed, and the climatic conditions of the place where the feed is grown. Chapagain and Hoekstra (2004) defined three components to the VWC V_a of a live animal *a*:

$$V_a = V_{a,feed} + V_{a,drink} + V_{a,serv}$$

where $V_{a,feed} + V_{a,drink} + V_{a,serv}$ represent the VWC of an animal *a* related to feed, drinking water and service water consumption respectively, expressed in cubic metres (m^3) per live animal. The VWC of a crop *c* (m^3/tonne) has calculated as the ratio of the total volume of water used for crop production, U_c (m^3) to the volume of crop produced Y_c (tonne).

$$V_c = \frac{U_c}{Y_c}$$

The average VWC of a crop c in a country, $V_{c,n}$ (m^3/tonne) is calculated as the ratio of the total volume of water used for the production of crop *c* (U_c) to the total volume of crop produced in that country. The total volume of water used for the production of crop $U_{c,}$ is calculated as:

$$U_c = R_c \times A_c$$

where A_c is the total harvest area (ha) of a crop *c* in a country and R_c is the crop water requirement (m^3/ha) for the entire growth period of a crop c. It is usually assumed in these calculations that the crop water requirement is fully met either by irrigation or by rainfall.

Having developed these equations, Chapagain and Hoekstra (2004) determined that the VWC of a processed product relates to the VWC of the primary crop or live animal from which it is derived. The VWC of the primary crop or live animal is distributed over the different products from that specific crop or animal. This makes the calculations more complex. The products derived from a primary crop or live animal are called primary products e.g. poultry primary products are meat or eggs. Some of these primary products are further processed into secondary products. The VWC of a processed product from a primary crop or a live animal includes the element of the VWC of the primary crop or live animal plus the processing water needed. The processing water requirement is calculated as follows:

$$R_{proc} = \frac{Q_{proc}}{X_{proc}}$$

where R_{proc} is the processing water requirement per ton of primary crop *c* or live animal *a* for processing primary products (m^3/tonne). Q_{proc} is the volume of processing water required (m^3) to process crop *c* or animal *a*. X_{proc} is the total weight of the primary crop or live animal processed. It is important to ensure that the VWC attributed to the final product takes into account the actual yield of the product at the end of processing compared to the live weight or gross weight of the crop or animal prior to processing. In order to determine the VWC of poultry meat it is important to consider the different production methods of poultry meat production; namely intensive known as broiler production, and more extensive systems such as free range or organic. As has been previously described the methodology of determining VWC is based on averaged figures which can be misleading in benchmarking a specific type of food product or method of production. This is a limiting factor because material origin will not only impact on VWC, stress weighted water footprint, but also the CV-VWC. Therefore in the following analysis as these factors cannot be assessed they are worthy of future research.

Water consumption

The volume of water consumed by birds is influenced by a number of differing and even cumulative factors as shown in Table 9 (Manning *et al.,* 2007a). Manning *et al,* (2007b) determined the mean water consumption for broilers and this data has been collated with other sources (Table 10).

Table 9: Factors that affect water consumption (Source: Manning *et al.,* 2007a)

Bird issues	Water quality issues	Feed quality issues	House environmental issues
Genetics	Hardness;	Feed composition and suitability	Water temperature;
Sex	Nitrate levels	Feed type	Water pressure
Age	Total dissolved solids	Feed intake	Poorly installed regulators on drinker lines;
Health or disease challenge	Bacterial contamination	Mycotoxin contamination	Type of drinker and bird to drinker (nipple) ratio
Body temperature control			Spillage by birds especially after long dark period if there is jostling at the drinkers;
			Drinker height (including impact of floor slope);
			Leakage from drinker system
			House temperature
			Air velocity and humidity

Table 10: Benchmarking data for poultry water consumption

	Defra (2006)	IPPC BREF (2003)	AUS (2000)	Chapagain and Hoekstra (2003)	Manning *et al.,* (2007b)
Water consumption (L/head per day/1000)	15 –30		180 – 320	280	152 - 166
Water consumption (L/head per cycle) 42 days	0.63 – 1.26	4.5 – 11	7.6 – 13.4	19.6	6.39
Water consumption (L/head per cycle) 52 days	0.78 – 1.56	4.5 – 11	9.4 - 16.6		8.68

Note Chapagain and Hoekstra is based on a 70 day age

In research reported in Manning (2007) the water consumption varied between a sexed programme with a mean bird weight of 2.74 Kg with a mean water consumption of 8.68 L/bird per cycle (SD 0.50, IQR 8.47-8.75) and an as-hatched programme with a mean bird weight of 2.18 Kg and mean water consumption of 6.39 L/bird per cycle (SD 0.55, IQR 6.11-6.56). The two groups were compared using sem and there was a statistically significant difference between the two groups (Manning *et al.,* 2007b). Therefore, when determining bird water consumption, and its impact on VWC of the meat the type of production system must be taken into consideration. The two production systems are an as hatched and a sexed system, birds are grown to weight bands and the size will influence the total water consumed in terms of litres/bird but also in terms of litres/kg liveweight. The analysis of total water consumption by Manning (2007) demonstrated variance by site, by group and by season and each site (n = 12) had a different water consumption profile in terms of l/bird per cycle. This will be due to a variance by site in the factors highlighted in Table 9. The data from the Chapagain and Hoekstra (2003) study was based on a 70 day production cycle. This is not indicative of a commercial intensive poultry meat production operation or a free range or organic type system as the production cycle length is different in all cases.

Water used for terminal hygiene

The IPPC BREF (2003) for water used for terminal hygiene in intensive broiler production has been compared with Chapagain and Hoekstra (2003) see Table 11. The IPPC BREF (2003) figure is a factor of ten lower but this difference has very little impact on the overall VWC of poultry meat. The water used for terminal hygiene per kg live weight will relate to stocking density in terms of kg/m^2 however the stocking density was not defined in the Chapagain and Hoekstra study so a comparison could not be made.

Table 11: Benchmarking data for water for servicing (cleaning)

	IPPC BREF (2003)	Chapagain and Hoekstra (2003)
Water usage (m^3/m^2)	0.002 – 0.020	
Water usage m^3/bird (*Based on 18 birds/m^2)	1.1×10^{-4} – 1.1×10^{-3}	9.8×10^{-3}

Commercial data (Manning, 2007) was comparable with the IPPC BREF benchmark.

Feed conversion rate (FCR)

FCR is a measure of feed efficiency. Feed efficiency of broilers is affected by bird age, sex, health and environmental temperature although the major factor is usually dietary energy concentration (Leeson, 2002). Ross Breeders (2007) defined both FCR and average weight benchmarking figures for the Ross 308 (Table 12).

Table 12: Ross 308 performance figures for FCR and average weight

	Ross 308 42 day as hatched[1]	Ross 308 38 day female[1]	Ross 308 52 day male[1]	Manning (2007) 42 day	Manning (2007) 52 day	Chapagain and Hoekstra (2003)
Feed consumed (kg/bird)	4.64	4.41	7.19	3.94	4.96	6.97
FCR	1.75	1.72	1.89	1.81	1.76	3.18
Average Weight (kg)	2.65	2.11	3.82	2.18	2.74	2.20

(Source: Ross Breeders, 2007[1])

The FCR on commercial site (Manning, 2007) and that suggested by Ross Breeders (2007) was much lower than the FCR proposed by the Chapagain and Hoekstra (2003) study (FCR =3.18) and that suggested by Mekonnen and Hoestra (2010) namely an FCR of 2.8. the FCR for the commercial system being 1.76; and 1.81 depending on the bird age and production system. Mekonnen and Hoestra (2010) identified a variance in FCR between industrial (intensive) production 2.8, mixed 4.9 and grazing 9.0. As the FCR is a major element of the VWC calculation variance will have a major impact on the final calculations (Table 13).

Table 13: Comparison of the VWC of poultry meat

	Manning (2007) 52 day	Manning (2007) 42 day	Chapagain and Hoekstra (2003)
Live weight	2.74	2.18	2.20
Product fraction (0.73)	2.00	1.59	1.60
Water from drinking (m^3/tonne)	3.13	2.75	9
Water from servicing (m^3/tonne)	0.19	0.25	4
Water from feed (m^3/tonne)	771	968	1344
VWC of live weight (m^3/tonne)	774	971	1357
VWC of poultry meat (m^3/tonne)	1059	1330	1867

Commercial data (Manning, 2007) for the 52 day programme showed an average bird weight of 2.74 kg, (SD = 0.10, IQR = 2.68 – 2.79) and 42 day programme with an average bird weight of 2.18 kg, (SD = 0.04, IQR = 2.11 – 2.17). Ross Breeders (2007) defined further average weight benchmarking figures for the Ross 308 between 2.11 and 3.82 Kg (Table 12). The determination of the virtual water attributed to the feed has been undertaken using the Chapagain and Hoekstra methodology because the exact specification of the feeds used on the farms involved in the commercial research was confidential and not released as part of the study. The results for the VWC of the meat produced by the 42 day and 52 day programme have been collated (Table 13). This demonstrates that the 52 day programme results are on a par with those obtained by Chapagain and Hoekstra (2003) for the intensive programme (Table 14) at 1059 and 1028 m^3/tonne respectively. The difference in ten days of the growing programme alone has an impact on the virtual water content of the meat at 1330 m^3/tonne but both show a considerably lower water footprint than the 1867 m^3/tonne identified by Chapagain and Hoekstra (2003) in Table 13.

Mortality

Defra (2006) define an average mortality rate of 10%; Heier *et al.,* (2002) 4.42% at 42 days; Sheppard and Edge (2006) 4.1%; and in the study undertaken by Dawkins *et al.,* (2004) the mean total mortality was 4.1% with a range of 1.4 – 14.7. Heier *et al.,* (2002) in their research on mortality in Norwegian broiler flocks concluded that the average weekly cumulative mortality was 1.54% during the 1st week and 0.48% per week during the rest of the crop. The mean total mortality for all sites in the commercial study was 3.00% (Manning, 2007). Mortality has not been included in the Chapagain and Hoekstra model and should be included in a future refinement of the methodology as it has the potential to greatly impact on the VWC of poultry meat as is demonstrated by the range identified by Dawkins *et al.,* (2004).

Production system

The standard calculation on which much of the current water footprint literature is based i.e. 3900 m^3/tonne of poultry meat (waterfootprint, 2011). However, Chapagain and Hoekstra (2003) determined that this figure is influenced by growing system. The more intensive the production systems the lower the virtual water content of the live animal and the resultant meat produced (Table 14).

Table 14: Comparison of the virtual water content of live poultry birds from different production systems Source: Chapagain and Hoekstra (2003)

System	Virtual water content of live poultry birds (m^3/tonne) Chapagain and Hoekstra (2003)
Grazing system	7702
Mixed system	2695
Intensive system	1028
World average	1498
Water footprint stated	3900

The research undertaken highlighted the range of variables that can have an impact at a production level for both crop and livestock production. This makes the determination of VWC both process and production system specific. Therefore the methodology required is more complex than has previously been suggested, for example, the methodology should include the volume of water used in processing the carcase. Literature suggests that this will be between 8 and 15 litres per bird which at 2.2 kg and 11.5 litres would equate to an additional 5 m^3/tonne (EA, 2009). This would only make a minor contribution to VWC but should be included. Mortality and factory rejects should also be included as losses at this stage will also have an impact on VWC. Indeed, the health and welfare of the animals themselves plays a key role in influencing the ecological footprint of livestock production.

Conclusion

The VWC of intensively reared poultry meat is suggested to be around 1028 m^3/tonne with a CV:VWC of 0.55. Extensification of poultry meat production will increase VWC and therefore reduce the CV:VWC ratio of the meat as the FCR increases with the degree of intensity of livestock production systems. Therefore in this instance extensification will have a detrimental impact on the VWC of the final meat product. The ethics of sustainable agricultural intensification have been discussed (FAO, 2004) where it was argued that: "*Intensification that takes the form of increased production is most critical when there is a need to expand the food supply, for example during periods of rapid population growth."* Further, the report determined that intensification that makes more efficient use of inputs may be more critical when environmental problems or social issues are involved. However, these ethical and social issues are neither mutually exclusive nor mutually cohesive and this creates issues for society in general on how the "*benefits and burdens of intensification are distributed*" (FAO, 2004). This is especially the case with intensive livestock production. Garnett (2011) proposed that the ultimate goal is 'sustainable intensification' where yields are improved without damage to ecosystems. However, the author determined that "*the concept of 'sustainable intensification' and the routes to achieving it can be the subject of much debate and may raise a number of environmental and ethical concerns*". This paper has analysed current methodology used in the determination of VWC of poultry meat and the conclusions that can be drawn with regard to different methods of food production. The research has assessed the VWC of poultry meat and the impact of intensification of livestock production on the VWC of the meat produced. Furthermore, the paper suggests that VWC cannot be assessed as an ecological benchmark in isolation. Instead VWC should be determined together with the calorific value (CV) of food and this factor CV-VWC should be used to propose effective water use for human food production in the future.

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