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A revised approach to water footprinting to make transparent the impacts of consumption and production on global freshwater scarcity

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ABSTRACT

Through the interconnectedness of global business, the local consumption of products and services is intervening in the hydrological cycle throughout the world to an unprecedented extent. In order to address the unsustainable use of global freshwater resources, indicators are needed which make the impacts of production systems and consumption patterns transparent. In this paper, a revised water footprint calculation method, incorporating water stress characterisation factors, is presented and demonstrated for two case study products, Dolmio® pasta sauce and Peanut M&M's® using primary production data. The method offers a simple, yet meaningful way of making quantitative comparisons between products, production systems and services in terms of their potential to contribute to water scarcity. As such, capacity is created for change through public policy as well as corporate and individual action. This revised method represents an alternative to existing volumetric water footprint calculation methods which combine green and blue water consumption from water scarce and water abundant regions such that they give no clear indication about where the actual potential for harm exists.

1. Introduction

The assessment of product water footprints has raised the awareness of the extent and magnitude that local businesses and consumers are intervening in the hydrological cycle throughout the world (Chapagain and Hoekstra, 2008). This is viewed as a positive development because, in many places, freshwater has become a scarce and overexploited natural resource (UNESCO-WWAP, 2006) leading to a wide range of social and environmental concerns (Falkenmark, 2008). There is an estimated one billion people in developing nations lacking access to safe drinking water and more than two billion people lacking adequate water for sanitation (Bartram, 2008). The demands for freshwater by industry and especially by agriculture are causing groundwater resources to be depleted and surface water resources to be abstracted in ways which compromise freshwater ecosystem health (Smakhtin, 2008). Pressure on freshwater resources is also intensifying rapidly with climate change, population growth, continuing economic development and the expansion of biofuel crops, raising the concern of governmental and non-governmental organisations alike. For all of these reasons, many businesses are seeking to demonstrate good corporate citizenship by measuring, reporting and addressing negative impacts arising from water use in their operations and product life cycles (Chapagain and Orr, 2009).

The water footprint of a product is typically the sum of all water consumed in the various stages of production and therefore the same as its virtual water content (WFN, 2009). This usually includes so-called blue water appropriated from surface and groundwater resources, green water which is rainfall consumed through crop evapotranspiration, and gray (or dilution) water, being the volume of freshwater needed to assimilate emissions to freshwater (Chapagain et al., 2006; Chapagain and Orr, 2009). Milà i Canals et al. (2009) and Ridoutt et al. (2009a) have also extended the concept to include water consumed in the use phase of the product. Water footprints have been calculated for a wide range of products, including cotton (Chapagain et al., 2006), tea and coffee (Chapagain and Hoekstra, 2007), meat products (Galloway et al., 2007) and Spanish tomatoes (Chapagain and Orr, 2009), to name a few. Data from these and other like studies are now being reproduced widely in the popular media to the extent that the term water footprint has become part of the local vernacular in many countries, much like the term carbon footprint. Many companies are also piloting water footprint studies of their supply chains.

However, apart from the similarity in name, product carbon and water footprints share few other characteristics. Considering carbon footprints, they are expressed as a single figure in the units of carbon dioxide equivalents (CO_2-e). This is calculated using characterisation factors, such as those published by the IPCC, which describe the global warming potentials of the various

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greenhouse gases (GHGs). As a result, the carbon footprints of different products and services can be meaningfully compared. In addition, the GHG emissions arising from different forms of consumption are additive, meaning that emissions can be totalled for a nation, a business, an individual or the life cycle of a specific product. Emissions associated with one form of consumption can also be offset by savings elsewhere. Carbon footprints are also comparable with the global warming potential (GWP) midpoint indicator used in life cycle assessment (LCA). As such, carbon footprinting is a streamlined form of LCA, with commonality in approach to life cycle inventory and impact modelling.

Unfortunately, these attributes do not apply to water footprints as they are presently calculated. While there are many examples of water footprints expressed as a single figure (e.g. bread 40 l per slice; beer 75 l per glass; coffee 140 l per cup; milk 1000 l per l; cotton T-shirt 2700 l per shirt; rice 3400 l/kg; cheese 5000 l/kg; beef 15,500 l/kg; www.waterfootprint.org), these are not produced using a normalisation process. Most water footprints are the crude summation of more than one form of water consumption (blue, green and gray water) from locations that differ in terms of water scarcity. As such, water footprints of different products are not comparable. The water footprint concept has also evolved independently from the discipline of life cycle assessment and accordingly there is no clear relationship between a water footprint and potential social and/or environmental harm. 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.

It is therefore not surprising that many have viewed the popularisation of the water footprint concept with concern because of the potential for misinterpretation and confusion. In order for it to become a useful driver of sustainable consumption and production, the water footprint concept is in need of substantial further development. Our research concerns the incorporation of water stress characterisation factors into a revised water footprint concept. This revised approach, which is demonstrated using two case study food products, represents a solution to many of the abovementioned weaknesses in current water footprint calculation methods.

2. Background

The CSIRO (Commonwealth Scientific and Industrial Research Organisation, Australia) has been working with Mars Australia in the development and application of life cycle-based sustainability indicators for the agri-food sector. In the first stage of this research, a detailed inventory of life cycle water use was conducted for a selection of case study products, including Dolmio® pasta sauce and Peanut M&M's®. What distinguishes this work from other published water footprint studies is its focus at the product brand level rather than the product category level, as well as the complexity and variability of the numerous associated supply chains and the use of primary production data. Rather than basing our analyses on national-level statistics, we have sought to obtain data which is representative of the specific supply chains associated with each product, following a similar approach to that described for carbon footprinting in PAS2050 (BSI, 2008). Product water footprints were subsequently calculated following the approach of Chapagain et al. (2006). Further details are described in Ridoutt et al. (2009a).

For the two case study products, 575 g Dolmio® pasta sauce and 250 g Peanut M&M's®, each manufactured and consumed in Australia, the total water footprints (hereafter termed volumetric water footprints) were 202 and 1153 l, respectively (Table 1, Ridoutt et al., 2009a). However, due to the different proportions of blue, green and gray water, it is not obvious which product water footprint is of more serious concern. This is despite the pasta sauce having a volumetric water footprint less than one fifth of the Peanut M&M's®. This illustrates the point that different kinds of water consumption should not be simply added to produce a water footprint because the opportunity cost and the impacts associated with each form of freshwater consumption differ. For example, in the case of Dolmio® pasta sauce, tomato growing consumes irrigation water. In the absence of production, this water would be fully available for some other productive purpose or could remain in the river system and contribute to the environmental flow. On the other hand, Peanut M&M's® require cocoa derivatives, and the growing of cocoa beans consumes large quantities of green water. However, cocoa beans are typically grown as a tropical rainforest understory crop and it is questionable whether there would be any additional stream flow or groundwater recharge in the absence of production.

Table 1
Volumetric product water footprints for Dolmio® pasta sauce and Peanut M&M's® manufactured and consumed in Australia showing the proportions of blue, green and gray water (Ridoutt et al., 2009a,b). Blue, green and gray water are defined in the text (Section 1).

	Total water footprint (l)	Blue water (%)	Green water (%)	Gray water (%)
Dolmio® pasta sauce (575 g)	202	63.3	10.6	26.1
Peanut M&M's® (250 g)	1153	10.9	85.7	3.4

A further complicating factor is the regional nature of freshwater scarcity (Pfister et al., 2008; Chapagain and Orr, 2009). For carbon footprinting, the normalisation process for different greenhouse gases is simplified by the use of global characterisation factors, i.e. GHG emissions are regarded as making an equivalent contribution to global warming regardless of the location where they are produced (high altitude emissions arising from aviation being a notable exception). However, in the case of water footprinting, regional impact factors are necessary. Naturally, the impact of water consumed in a region of water abundance is in no way comparable to water consumed where scarcity exists. For example, in the case study of the Mars products, the same amount of water consumed in crop production in the Murray Darling Basin of Australia might be much more harmful compared to water consumed in crop production in southern coastal areas of Côte d'Ivoire.

3. Methods

In order to demonstrate an improved water footprint calculation method, incorporating water stress characterisation factors, the abovementioned case studies were revisited. A description of the revised water footprint schema and water stress characterisation factors follows.

3.1. Revised water footprint schema

As already mentioned (Section 1), current water footprint calculation methods have evolved independently of LCA and a weakness is their lack of correspondence with any defined social or environmental impact category. Therefore, in order to progress the water footprint concept it has been necessary to consider the major impacts associated with water appropriated into product life cycles. This endeavour has much in common with the UNEP/SETAC Life Cycle Initiative project which is developing a framework for assessing freshwater use in LCA (Koehler, 2008; Koehler et al., 2008). As discussed above, a feature of carbon footprinting is its compatibility with LCA and it is desirable that the same occurs for water footprinting as this will provide a basis for comparing the relative importance of product water footprints against carbon footprints and other environmental burdens.

3.1.1. Green water consumption

Agri-food product life cycles appropriate green water through land occupation and there are three major impact pathways. First, occupation of land limits the availability of that land and thereby access to the green water for other social purposes. For example, if land in Australia is being used to produce wheat, that same land and its associated green water is not available for other kinds of agricultural enterprise. Secondly, land use influences the partitioning between green and blue water and thereby the availability of blue water for other social purposes and the environment. Of particular concern in the Australian context is the transformation of pasture into industrial forestry with deep-rooted tree species which, in certain circumstances, may increase evapotranspiration and reduce stream flow (Benyon et al., 2007). Thirdly, additional green water for food and fibre production can be accessed by conversion of natural ecosystems into agricultural land. In this case, the impact is loss of natural ecosystems and habitat.

3.1.2. Blue water consumption

Blue water is surface or groundwater and it is mainly appropriated into agri-food product life cycles as irrigation water in farming and process water in factories. Water for irrigation and industry competes with water for domestic use. However, as noted by Rijsberman (2006), the appropriation of blue water into agri-food product life cycles is generally not the reason why people lack safe water for drinking and adequate water for sanitation. Such people are generally not affected by water scarcity in the physical sense but by a lack of access to adequate water services. Alternatively, they may be victims of extraordinary events such as extreme drought or war (Pfister et al., 2009). Malnutrition is a more likely impact of blue water consumption, in particular in developing nations where shortage of irrigation water may limit subsistence food production. That said, where blue water resources are consumed at a rate that exceeds the short-term replacement, and where non-renewable blue water resources are consumed (e.g. fossil groundwater resources), this is a form of resource depletion that limits availability to future users. On the other hand, water for irrigation and industry competes with water for the environment with the potential to negatively impact aquatic biodiversity and the health of riparian, floodplain and estuarine ecosystems. Indeed, there is mounting evidence that this is a serious global concern (Falkenmark and Molden, 2008).

3.1.3. Proposed calculation method

Based on the preceding discussion, we propose that the main concern relating to water consumption in agri-food product life cycles is the potential to contribute to water scarcity and thereby limit the availability of freshwater for human uses and for the environment (Fig. 1). In this way, the direct consumption of blue water resources is important, as well as the changes in blue water availability associated with land use. In regards to the latter, most agricultural systems intercept less precipitation than the natural ecosystems they replace (Scanlon et al., 2007). Indeed, simulations using the LPJmL dynamic global vegetation and water balance model suggest that globally, river discharges have increased by 6.6% as a result of transformation of natural ecosystems to crop and grazing land (Rost et al., 2008). An alternative approach to categorising land use effects on stream flow has been offered by Milà i Canals et al. (2009) involving a distinction between sealed and unsealed land use types and assumptions about the value of runoff from heavy rainfall to ecosystem health. In this study, we have taken a conservative approach and not sought to include the additional blue water resources arising from agricultural land use.

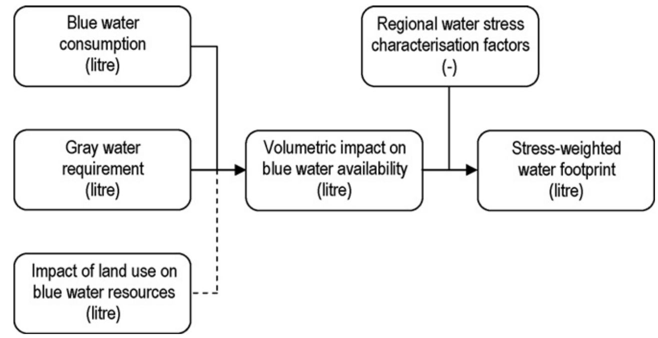

Fig. 1. Revised method of calculating product water footprints incorporating water stress characterisation factors. As a conservative approach, most agricultural production systems can be assumed to have no negative impact on blue water resource availability as a result of land occupation.

It is argued that the consumption of green water *per se* does not contribute to water scarcity. Until it becomes blue water, green water does not contribute to environmental flows which are needed for the health of freshwater ecosystems nor is it accessible for other human uses. Green water is only accessible through access to and occupation of land. Indeed, green water is only one of the many resources acquired through land occupation: access to solar radiation, wind and soil are others. This is not to downplay the importance of green water as a vital natural resource. Indeed, green water dominates in current global food production and will become more important if food security for a growing world population is to be met (Rockström et al., 2009). However, due to the inseparability of green water and land (except via the impacts of land use on flow, as mentioned above), the consumption of green water in agri-food product life cycles is better considered in the context of the land use impact category. For example, the issue of using agricultural land to produce biofuels concerns the ethical use of arable land rather than water, even though green water is consumed in the process. This is because biofuel crops, if they are rain-fed, do not contribute to water scarcity. However, they do consume land which might otherwise be used for food production.

The third element is gray water (Chapagain et al., 2006; Chapagain and Orr, 2009). The rationale is to include in the water footprint calculation a measure of the impact on water resource availability of emissions to freshwater from a product system. The gray water calculation method is admittedly imperfect as a litre of water extracted directly from a resource is not physically or conceptually the same as a litre of water assimilating an emission. Nevertheless, it is considered beneficial to include the gray water calculation rather than lose from the water footprint any consideration of the impacts of water quality degradation on usable water quantity. However, in the context of LCA, emissions to freshwater would normally be considered under other impact categories such as eutrophication or freshwater eco-toxicity, applying complex fate and effect models.

This proposed water footprinting schema represents a substantial departure from existing water footprinting approaches. Importantly, what is being proposed now has a clearly defined goal, being the avoidance of water scarcity. It is also noted that this water footprint schema is broadly consistent with the water deprivation midpoint indicator being proposed for LCA by Pfister et al. (2009).

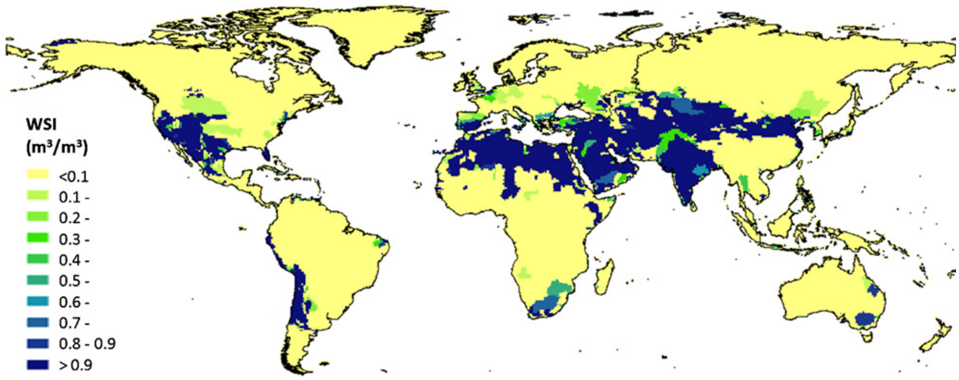

Fig. 2. Global representation of the water stress index (Pfister et al., 2009).

3.2. *Water stress characterisation factors*

To obtain water stress characterisation factors relevant to each location where water was consumed, the water stress index (WSI) developed by Pfister et al. (2009) was used. Briefly, the WSI is based on the WaterGAP 2 global hydrological and global water use models (Alcamo et al., 2003) with modifications to account for monthly and annual variability of precipitation and corrections to account for watersheds with strongly regulated flows. The index follows a logistic function ranging from 0.01 to 1. It is tuned to result in a WSI of 0.5 for a withdrawal-to-availability ratio of 0.4, which is commonly referred to as the threshold between moderate and severe water stress (Vorosmarty et al., 2000; Alcamo et al., 2000). The WSI has a spatial resolution of 0.5 degrees (Fig. 2), which is more relevant to describing water stress at a local watershed level than indicators which are based on national or per capita statistics (Rijsberman, 2006). Especially for large, heterogeneous countries like Australia, China, India and the US, national statistics provide little insight into local water scarcity.

For the two case study products, Dolmio® pasta sauce and Peanut M&M's® produced in Australia, the location of water consumption at each point in the product life cycle was defined as precisely as possible. In some cases, such as for particular factories, the specific coordinates were able to be identified. In other cases, such as for commodity agricultural ingredients, only a region within a country was able to be described, and not the specific farms, therefore a range of WSI values were averaged to produce a representative characterisation factor. For the water consumed in the product use phase, an average WSI value for Australia was applied, as the case study products are distributed nationally. To calculate the stress-weighted water footprint, water consumption at each point in the product life cycle (as defined in Section 3.1.3) was multiplied by the relevant characterisation factor (e.g. 0.011 for sugar processing in the Clarence River Catchment of northern NSW, Australia; 0.996 for tomato cultivation in the San Joaquin Valley of California). These results were then summed to enable reporting at the product level, with scaling used to account for minor ingredients, such as herbs and spices. Separate calculations were performed including and excluding gray water to enable a comparison to be made.

4. Results

The stress-weighted water footprints of Dolmio® pasta sauce and Peanut M&M's® were 141 and 13 l respectively when gray water was included and 98 and 5 l respectively when gray water was omitted (Table 2). For these two products, the gray water requirement made a substantial contribution to the overall stress-weighted water footprint (30% and 62%), suggesting that the impacts of water quality degradation were important, and this may well be typical of agri-food products generally. What is also immediately apparent are the differences compared to Table 1 where the volumetric water footprints for these two products were 202 and 1153 l. Whereas the volumetric water footprint of Dolmio® pasta sauce was less than one fifth that of Peanut M&M's®, the stress-weighted water footprint of Dolmio® pasta sauce was over 10 times greater.

Regardless of the absolute differences in the stress-weighted water footprints of these two case study products, in both cases it was the agricultural stage of production which, by far, made the greatest contribution (97% in each case, Table 2). For Dolmio® pasta sauce, the use phase contributed slightly over 1% of the stress-weighted water footprint. Other parts of the value chain (primary processing of agricultural ingredients, Mars' operations and packaging) contributed less than 1% each (Table 2). For Peanut M&M's®, there was no water used in the product use phase. The next most important contribution to the stress-weighted water footprint came from the Mars's operations (2.6%) followed by the primary processing of agricultural ingredients (0.7%) and packaging (<0.1%, Table 2). Minor differences were observed when gray

Table 2
Stress-weighted water footprints (excluding and including the gray water component) for Dolmio® pasta sauce and Peanut M&M's® manufactured and consumed in Australia. Also shown is the distribution across the value chain.

	Dolmio® pasta sauce		Peanut M&M's®	
	Excluding gray water	Including gray water	Excluding gray water	Including gray water
Stress-weighted water footprint (l)	98	141	5	13
Distribution across value chain (%)				
Agricultural production	96	97	92	97
Ingredient processing	1.3	0.9	1.7	0.7
Mars' operations	0.3	0.2	6.3	2.6
Packaging	0.9	0.6	<0.1	<0.1
Use phase	1.6	1.1	0	0

Table 3
Major agricultural ingredients contributing to the volumetric and stress-weighted water footprints (including gray water) of Dolmio® pasta sauce and Peanut M&M's® manufactured and consumed in Australia. Volumetric water footprint data: Ridoutt et al. (2009a,b).

Ingredient	Volumetric water footprint (l)	Stress-weighted water footprint (l)
Dolmio® pasta sauce		
Tomato products	149.9	133.9
Sugar	22.9	<0.1
Onion	12.0	1.8
Garlic	5.9	0.1
Minor ingredients	3.3	1.9
Peanut M&M's®		
Cocoa derivatives	690.1	4.1
Peanuts	140.2	1.1
Sugar	135.1	0.9
Milk derivatives	133.6	5.3
Palm oil derivatives	27.3	<0.1
Minor ingredients	17.8	0.2
Tapioca starch	7.9	0.5

water was excluded from the stress-weighted water footprint calculation; however, the agricultural stage of production remained dominant (Table 2).

When considered on an ingredients basis, important differences were observed between the volumetric and stress-weighted water footprints (Table 3). Whereas the volumetric water footprint method directed attention to cocoa derivatives as the ingredient of greatest concern, the stress-weighting method highlighted tomato products. The results obtained using the latter approach were deemed to make the most intuitive sense. Tomatoes are typically grown under irrigation in hot and dry climatic regions. As such, tomato production has the potential to contribute significantly to local water scarcity, limiting the availability of freshwater for environmental flows and alternative human uses. On the contrary, cocoa beans are predominantly grown as a tropical rainforest understory crop without irrigation and with little or no use of fertilizers and other agro-chemicals. As such, the potential of cocoa production to contribute to water scarcity is very small.

For Dolmio® pasta sauce, tomato products contributed more than 95% of the stress-weighted water footprint (Table 3). The locations where the tomatoes were sourced, northern Victoria in the Murray Darling Basin and the San Joaquin Valley in California, had local water stress characterisation factors of 0.815 and 0.996 respectively (on a scale of 0.01–1). In contrast, sugar, which was the ingredient making the second highest contribution to the volumetric water footprint of Dolmio® pasta sauce, made almost no contribution to the stress-weighted water footprint because the local water stress characterisation factor for the production region was 0.011. Although being less important in the Dolmio® pasta sauce recipe, onion products were sourced from regions having water stress characterisation factors that ranged from 0.025 to 0.998, suggesting that there is scope to reduce impacts on water scarcity through selective procurement.

For Peanut M&M's®, dairy products contributed most to the stress-weighted water footprint, with ingredients sourced from the San Joaquin Valley in California being of more concern than ingredients sourced from the South Island of New Zealand (local water stress characterisation factor: 0.017). Cocoa derivatives and peanuts were the next most important ingredients (4.1 and 1.1 l, respectively, Table 3). However, none of the ingredients in a 250-g bag of Peanut M&M's® had a stress-weighted water footprint that was comparable in magnitude to the tomato products in a 575-g jar of Dolmio® pasta sauce.

Finally, it is of interest to note that for Dolmio® pasta sauce and Peanut M&M's®, manufactured and consumed in Australia, much of the stress-weighted water footprint occurred outside Australia (48% and 81%, respectively), highlighting the extent to which producers and consumers intervene in the water cycle in locations far from their local environment.

5. Discussion

In order to address the unsustainable use of global freshwater resources, indicators are needed which make the impacts of production systems and consumption patterns transparent. In this study, a revised water footprint calculation method was introduced, which incorporates water stress characterisation factors. Using two case study products, Dolmio® pasta sauce and Peanut M&M's®, we demonstrate this revised calculation method and show that stress-weighted water footprints can differ substantially from water footprints calculated using existing methods on a simple volumetric basis. Indeed, the two sets of results obtained in this study suggested completely different priorities for corporate action.

5.1. Advantages of the revised water footprint calculation method

One of the most important features of the revised water footprint calculation method is that it enables meaningful comparison both between different products and between the different stages of a particular product's life cycle. For example, a 575-g jar of Dolmio® pasta sauce has a potential to contribute to water scarcity that is more than 10 times that of a 250-g bag of Peanut M&M's® (Table 2). Furthermore, within the life cycle of Dolmio® pasta sauce, 97% of the potential to contribute to water scarcity occurs in the production of agricultural ingredients (Table 2), with tomato cultivation being by far the greatest concern (Table 3). Therefore, for companies wanting to exercise good water stewardship, the revised water footprint calculation method provides a quantitative means of identifying priorities and directing actions. This provides an alternative to volumetric water footprinting methods which combine green and blue water consumption from water scarce and water abundant regions such that they give no clear indication about where the actual potential for harm exists.

The revised water footprint calculation method can also provide a meaningful basis for corporate sustainability reporting. Many businesses in the food industry are already reporting on direct water use and setting targets for reduction (e.g. CIAA, 2007; AFGC, 2005). However, as demonstrated in this study, for many, if not most agri-food products, the majority of the impacts from life cycle water use occur in the agricultural stage of production. As a rule of thumb, in the food and grocery supply chain, the relative water intensity of the primary production, manufacturing and use phases are 100:1:10 (AFGC, 2003). As such, many businesses are now embracing the life cycle concept (UNEP, 2007) and reporting of sourcing and supply chain issues is increasing in the food industry (GRI, 2008). A few companies, such as Coca Cola (Liu, 2008), have even made declarations about becoming water neutral, which in most cases will inevitably require some degree of water offsetting. However, a constraining factor to date has been the lack of methodology enabling water consumption in one location to be compared with a water saving or improvement in another (Hoekstra, 2008). Again, the revised water footprint calculation methodology introduced in this paper may represent a way forward.

Like carbon footprints, water footprints also have the potential to enable consumers to become more aware of the impacts of their purchasing decisions and thereby take greater responsibility for their consumption patterns. As already mentioned, existing volumetric water footprints are misleading and confusing because

Table 4
Stress-weighted and Australian-equivalent water footprints for Dolmio® pasta sauce and Peanut M&M's® manufactured and consumed in Australia. The Australian-equivalent water footprints were calculated using the national average water stress index (WSI, Pfister et al., 2009) for Australia. Normalised product water footprints such as these could enable consumers to compare the potential to contribute to water scarcity through consumption of a product with the direct consumption of the same volume of water in their home country.

Country	WSI	Stress-weighted water footprint (l)		Australian-equivalent water footprint (l)	
		Dolmio® pasta sauce	Peanut M&M's®	Dolmio® pasta sauce	Peanut M&M's®
Australia	0.402	141	13	350	31

consumers have no means of interpreting a number which is an aggregation of blue, green and dilution water, especially when the water use has occurred in locations of undeclared water stress. In this regard, the stress-weighted water footprints calculated using the revised method have the potential to be expressed in units which are normalised according to the local water stress in the country of consumption (e.g. Australian-equivalent water footprint, Table 4). In this way, a consumer can compare the product water footprint with the direct consumption of water in their home country, which is simple and should make intuitive sense for that consumer. Therefore, the consumption of a 575-g jar of Dolmio® pasta sauce in Australia has the same potential to contribute to water scarcity as the direct consumption of 350 l of water in Australia (Table 4). Similarly, the consumption of a 250-g bag of Peanut M&M's® in Australia has the same potential to contribute to water scarcity as the direct consumption of 31 l of water in Australia. As a point of comparison, the Australian-equivalent water footprint of mango consumed in Australia is 217 l/kg (Ridoutt et al., 2009b). For a consumer, this kind of information is thought to be meaningful. As another point of reference, householders in Melbourne are currently being encouraged by the government to limit domestic water use to 155 l per person per day. We are not however suggesting that avoiding the use of 31 l of water in Melbourne is a direct substitute for the water use associated with the consumption of a bag of Peanut M&M's®, since 81% of the stress-weighted water footprint of Peanut M&M's® occurs outside Australia.

In the global context, one of the greatest challenges is to meet future food demands within the constraints of sustainable freshwater consumption. Already there is an estimated 963 million undernourished people in the world (FAO, 2008a) and demand for food is forecast to double by 2050 based on projected population and socio-economic growth (FAO, 2008b). At a practical level, the impact of food consumption patterns on global freshwater resources must become less intense. Traditionally, water resources management has focussed on increasing supply and where supply has become limited demand management has become necessary, typically in relation to direct water consumption by the domestic, industrial and agricultural sectors. However, demand for water by the industrial and agricultural sectors derives from demand for goods and services by consumers. At the consumer level, indirect water use through the consumption of goods and services far exceeds direct water consumption, perhaps by an order of magnitude (Molden et al., 2007). Governments are therefore encouraged to complement demand management strategies for water with strategies which take into consideration indirect (or virtual) water use though consumption of goods and services. The revised water footprint calculation method may contribute to making such interventions possible.

5.2. *Drivers created by the revised water footprint calculation method*

The revised approach to product water footprinting described in this study is designed to encourage food product manufacturers and retailers to reduce the negative impacts arising from water use in the life cycles of the products they develop and sell. A range of practical interventions is highlighted. First, due to the importance of water consumed in primary production, the sourcing of agricultural ingredients from locations of high water stress will be discouraged. Also discouraged will be the sourcing of agricultural ingredients from regions where there is a high irrigation water demand. For example, Chapagain and Orr (2009) assessed the blue water requirements of fresh tomato production in Spain and reported a range of 14.2–117 m^3/t, a range of over 8-fold. Similarly, Chapagain et al. (2006) describe a range of blue water requirements for cotton ranging from 46 m^3/t (Brazil) to 5602 m^3/t (Turkmenistan), a range of over 120-fold. While these are volumetric water footprints and not stress-weighted water footprints, they still illustrate the enormous variability that exists and therefore the great potential to alleviate water scarcity through selective procurement of agricultural commodities.

Even within a particular region, opportunities exist to source from farms which are most efficient in their irrigation water use. For example, in the case of tomato production, farms employing drip irrigation systems are much more efficient than those using furrow systems. As such, the revised water footprint calculation method will encourage investments in farming systems which increase the efficiency of irrigation water use, decrease runoff and leaching of fertilizers and other agri-chemicals, and increase the productivity of rain-fed production systems. For food manufacturers, the revised water footprint calculation method will also encourage investments in factories to improve water use efficiency, water reuse and recycling as well as wastewater reduction and treatment. It will also encourage new factories to be located in regions of freshwater abundance rather then scarcity. Reducing waste is another obvious way of reducing water consumption (Lundqvist et al., 2008).

This approach to product water footprinting is not intended to address other valid concerns which are less directly related to water scarcity. One example is the loss of natural ecosystems through agricultural expansion. Another is the goal of increasing the calorific or nutritive value of food per unit of water consumed, which has been described as an important strategy in meeting future food production requirements (Liu and Savenije, 2008; Rockström, 2003). For the same reasons that product carbon footprints are not expressed on a calorific or nutritive basis (PAS2050, 2008), we do not see the potential for this kind of reporting as a useful everyday indicator of sustainable consumption and production. Product water footprinting is also not expected to effectively address local issues pertaining to watershed management. For a particular freshwater ecosystem, the natural variability in flows can be great and the relationship to ecosystem health extremely complex (Arthington et al., 2006; King and Brown, 2006; Richter et al., 2006; Acreman et al., 2008). As such, sourcing products from a region of greater water abundance does not ensure that the specific environmental flow requirements of river systems are necessarily being met. Environmental flow requirements encompass not only a volume, but also timing and duration (Smakhtin, 2008). Therefore, although product water footprinting promises to be a useful driver of sustainable consumption and production, with potential to encourage global-scale change with respect to freshwater resource consumption, other approaches to environmental protection and management will also be required.

6. Conclusion

The most significant way that humans intervene in the global hydrological cycle is in the production of agri-food products (Rost et al., 2007) and oftentimes, as demonstrated in this study, these impacts occur far from where the consumption of food takes place. By making transparent the relationship between the production and consumption of these and other products and the unsustainable use of global freshwater resources, a capacity will be created for change through public policy and through corporate and individual action. The revised water footprint calculation method, introduced and demonstrated in this report, provides a way of making simple, yet meaningful comparisons between products and production systems in terms of their potential to contribute to water scarcity. The incorporation of water stress characterisation factors is deemed essential in linking global consumption to freshwater scarcity, since freshwater scarcity is largely a local and regional concern.

Two priorities for further research have also been identified. First, there is a need for targets for reducing pressure on global freshwater resources that decision makers can respond to. In terms of climate change, carbon dioxide concentrations in the atmosphere have been a key scientific indicator that has been used to underpin the setting of GHG pollution reduction targets, e.g. 20% by 2020; 80% by 2050. However, at present there is no equivalent basis for deriving water footprint reduction targets. As already mentioned, an increasing number of companies are piloting water footprint studies of their operations and supply chains. This is occurring with the notion that water footprints need to be reduced. Other companies have set the aspiration of becoming water neutral, but without a clear understanding as to how this can be determined. The setting of water footprint reduction targets would provide a benchmark for policy makers in both the public and corporate sectors.

Finally, our research points to land use as another important sustainability indicator. The revised water footprint calculation method introduced in this report does not specifically account for green water consumption. This is because green water consumption does not contribute directly to water scarcity. However, the availability of green water is one factor that determines the productive capacity of land, and productive land is itself a scarce resource. Animal products have been reported to have much higher volumetric water footprints compared to cereal-based products (www.waterfootprint.org), leading to claims that changing food consumption patterns (i.e. toward greater meat consumption) are a major cause of worsening water scarcity (Nellemann et al., 2009; Liu et al., 2008). This may not be the case, depending upon the extent to which cereals grown for animal feed consume irrigation water. Many livestock production systems, especially those which are rangeland-based, would be expected to have very low stress-weighted water footprints, and contribute little to water scarcity. However, livestock production systems, rangeland or feedlot-based, have substantial land resource requirements. We intend to pursue this line of investigation in future research.

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