



**A critical review of  
the water footprint  
concept**

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# Review article: Quantifying the human impact on water resources: a critical review of the water footprint concept

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## Abstract

The water footprint is a consumption-based indicator of water use, referring to the total volume of freshwater used directly and indirectly by a nation or a company, or in the provision of a product or service. Despite widespread enthusiasm for the development and use of water footprints, some concerns have been raised about the concept and its usefulness. A variety of methodologies have been developed for water footprinting which differ with respect to how they deal with different forms of water use. The result is water footprint estimates which vary dramatically, often creating confusion. Despite these methodological qualms, the concept has had notable success in raising awareness about water use in agricultural and industrial supply chains, by providing a previously unavailable and (seemingly) simple numerical indicator of water use. Nevertheless, and even though a range of uses have already been suggested for water footprinting, its policy value remains unclear. Unlike the carbon footprint which provides a universal measure of human impact on the atmosphere's limited absorptive capacity, the water footprint in its conventional form solely quantifies a single production input without any accounting of the impacts of use, which vary spatially and temporally. Following an extensive review of the literature related to water footprints, this paper critically examines the present uses of the concept, focusing on its current strengths, shortcomings and promising research avenues to advance it.

## 1 Introduction

Modern human societies use vast amounts of water, with increasing competition for scarce water resources impacting heavily on present and future human welfare and the state of our natural environment. As part of the search for an effective sustainability indicator for water resource use, the water footprint has grown rapidly in prominence since being proposed a decade ago. Numerous papers have been published, conferences held, and an international Water Footprint Network (WFN) established. Furthermore,

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the water footprint concept has received increasing press coverage, and a growing number of countries<sup>1</sup>, companies (Coca-Cola and Nature Conservancy, 2010; Raisio, 2010; Rep, 2011; Pepsi Co, 2011; Nestlé, 2011; SABMiller et al., 2011; Cooper et al., 2011) and organisations (WWF, 2012) have already begun or are currently moving towards quantifying aspects of their operations related to water, using the water footprint (Water Footprint Network, 2012). In turn, the International Standardization Organisation has considered developing a new international standard for water footprinting in order to complement its existing Life Cycle Assessment (LCA) standard (Raimbault and Humbert, 2011).

The origin of the water footprint stems from the concept of “virtual water” coined by Allan (1997, 2001). Also referred to as “embedded water” or “hidden water”, virtual water is the volume of water required to grow, produce and package agricultural commodities and consumer goods; the term “virtual” was preferred as the final product usually contains only a small fraction of water compared to the total volume of water actually used for its production. Allan noticed that rather than importing huge quantities of water to achieve food self-sufficiency, a significant number of water scarce countries in the Middle East were importing grains instead. Building upon the concept of virtual water, Hoekstra and Hung (2002) sought to quantify these “virtual water” flows related to international food trade and thus developed the water footprint concept.

From a production perspective, the water footprint is numerically equal to the virtual water content of a given product or service (Zhang et al., 2012); what distinguishes the water footprint from virtual water is that it is also applied at a consumer level, thus creating a consumption based indicator of water use (Velasquez et al., 2011)<sup>2</sup>.

<sup>1</sup>Spain (Aldaya et al., 2010b) and Germany (Flachmann et al., 2012) have already begun using estimates of water footprints in policy documents, with the Netherlands (Witmer and Cleij, 2012) currently considering this option.

<sup>2</sup>According to the WFN (2012), although the “virtual water content of a product” is the same as the “water footprint of a product”, the water footprint provides more information with respect to the type of water, as well as where and when that water is being used.

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A water footprint refers to the total volume of freshwater consumed directly and indirectly by a nation or a company, or in the provision of a product or service (Hoekstra and Chapagain, 2006; Hoekstra et al., 2009b). In essence, the additional information provided compared to the traditional, direct water use indicators is that it links human consumption to the space and time of production, accounting for the water use at all the stages along the supply chain of a product. The water footprint concept provides a useful means for estimating flows of water through trade in foodstuffs, and has succeeded in raising public awareness of the already established but somewhat overlooked actuality that the overwhelming majority of global water use takes place in the agricultural sector (Food and Agriculture Organization, 2007). Similarly to virtual water, water footprinting appears to have contributed to moving water issues higher up the political agenda (Wichelns, 2010b).

The water footprint provides a useful means for estimating flows of water through international trade in products and commodities. Trade in foodstuffs has received most attention since it accounts for the bulk of water trade flows and relates to important national policy issues such as food security. It has been calculated that the Netherlands, for example, has an average water footprint of approximately  $37.5 \text{ Gm}^3 \text{ yr}^{-1}$  (or  $2300 \text{ m}^3 \text{ yr}^{-1} \text{ capita}^{-1}$ ), of which  $33.2 \text{ Gm}^3 \text{ yr}^{-1}$  (corresponding to 89% of the total) is imported into the country in the form of “virtual water” (van Oel et al., 2009). This indicates that the Netherlands is a net virtual water importer. This is also true for other EU countries such as the UK, Germany and Italy, all of which import 60–95% of their total water footprint (Yu et al., 2010; Hoekstra and Mekonnen, 2012b; Tamea et al., 2013) despite none of them being water scarce according to the standard indicator of water scarcity proposed by Falkenmark (Falkenmark, 1986; Seckler et al., 1998). Water footprinting also confirms that meat and dairy products are usually associated with much greater water use compared to plant products because of the large amounts of feed crops, drinking water and service water required by the animals (Hoekstra and Hung, 2002). A recent study also shows the enormous variation in water use efficiencies between different animal production systems around the world (Gerbens-Leenes et al.,





adopted regarding the sectoral origins of output products. Feng et al. (2011) for example show that for eight key water consuming economies (Australia, China, Japan, US, Brazil, Germany, Russia and South Africa), the estimated total water footprints between bottom-up and top-down methodologies vary substantially, despite the fact that both methods were compared using the same input dataset. More recently, Chen and Chen (2013) acknowledge the fact that their top-down study obtained significantly smaller global and national water footprints compared to the bottom-up studies of Hoekstra and Chapagain (2006) and Mekonnen and Hoekstra (2011b). Furthermore, the Chen and Chen (2013) study unsurprisingly estimates higher water footprints for processed food, industrial products and services (65 % of total) compared to agricultural products (35 % of total), owing to its input-output (top-down) approach.

## 2.2 Water “colours”

Due to the differing environmental impacts and opportunity costs of the various forms of water use, the total water footprint at a national or product level is broken down into sub-categories of blue, green and grey water. Blue water refers to the amount of surface and groundwater<sup>3</sup> consumed during the production process. The blue water footprint differs from the more traditionally used water withdrawal volume in the sense that it factors in possible return flows, which refer to the volume of water returned to the water body following irrigation. A comprehensive definition of blue WF is that it includes all irrigation water and any direct water use in industry or in homes, minus return flows (Chapagain and Tickner, 2012). Green water resources have been formally defined as the infiltrated rainfall in the unsaturated soil layer (Falkenmark et al., 2009). The green water footprint therefore refers to the precipitation consumed directly by a crop through evapotranspiration of moisture stored in the soil (also known as effective or productive precipitation) (Mekonnen and Hoekstra, 2011a). This is often seen as the rainfed component of the water footprint. The grey component of a water footprint is the amount of

<sup>3</sup>This includes the use of any kind of groundwater irrespective of its recharge rate.

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freshwater required in receiving water bodies for the assimilation of any pollutant resulting from production so that acceptable water quality standards are met (Mekonnen and Hoekstra, 2011a). Thus, the grey water footprint is an estimated measure of the potential water quality impairment caused by the production of a certain good or service. By including all three components, the water footprint aspires to encompass all kinds of direct and indirect consumptive (blue and green) water use and pollution assimilation (through grey water estimates).

While water footprints can be calculated for any individual product, the development of methodologies for doing so has justifiably been focused on agricultural products, since approximately 70 % of global water use is by agriculture (Food and Agriculture Organization, 2007). The first global water footprint assessment quantified the average agricultural production and consumption water footprint of nations for the period 1997–2001, without distinguishing between these water sub-categories (Chapagain and Hoekstra, 2004). In a revised global assessment, Mekonnen and Hoekstra (2011a) developed a grid-based dynamic water balance model to assess crop specific water footprints; the model covered the period 1996–2005 and calculated the average (assumed) consumptive blue and green crop water use and crop yield. This study has formed the basis for what has now been established as the standard WFN methodology (Hoekstra et al., 2011).

The blue and green water footprints are calculated by multiplying the modelled volume of blue and green water use ( $\text{m}^3 \text{outputunit}^{-1}$ ) by the quantity of production (total output). In this way, any rainfall used in-situ by the crop (green water) is distinguished within the water footprint of a product, as well as the volume of irrigation (blue) water assumed to be applied to each crop. The grey water footprint is an estimate of the amount of water needed to assimilate nutrients in agricultural runoff, calculated by assuming that 10 % of all nitrogen fertiliser applied to a crop is lost via leaching, and taking the average nitrogen application rate by crop in the country being assessed; the assumed fraction of nitrogen leachate is then divided by the maximum acceptable concentration of nitrogen in the receiving water body (Mekonnen and Hoekstra, 2011a). The

consideration of grey water is relatively new in water footprinting and was not included in earlier water footprinting studies, such as Chapagain et al. (2006) or Chapagain and Hoekstra (2004).

There is no doubt that the breakdown of a water footprint into sub-categories provides more information than a footprint consisting of a single number. The aforementioned global average water footprint estimated for wheat ( $1827 \text{ m}^3 \text{ t}^{-1}$ ) breaks down to a green water footprint of  $1277 \text{ m}^3 \text{ t}^{-1}$ , a blue water footprint of  $342 \text{ m}^3 \text{ t}^{-1}$  and a grey water footprint of  $207 \text{ m}^3 \text{ t}^{-1}$ . Crops frequently grown using irrigation will have higher average blue water footprints than crops that are largely rainfed. To illustrate this, 55% of the total average water footprint of dates ( $2277 \text{ m}^3 \text{ t}^{-1}$ ) is blue water, compared to less than 1% of the total average water footprint of raw coffee beans ( $15\,365 \text{ m}^3 \text{ t}^{-1}$ ); these differences are attributed to the crop-specific water requirements – which varies substantially between crops – and the diverse agro-climatic conditions between countries and regions.

Some crops, an example of which is rice, vary significantly between countries in the mix of water types used. In the Philippines green water makes up 63% of the water footprint of rice whereas in Pakistan blue water makes up 82% of the water footprint (Chapagain and Hoekstra, 2011); in this case, the higher blue water component per unit of output in Pakistan can be explained by the greater use of irrigation compared to the Philippines. According to Vanham and Bidoglio (2013), rainfed agriculture is globally the largest green water user (i.e. only a small share of green water is utilised in irrigated crop systems), whereas irrigated agriculture is globally the largest blue water using sector (the others being industry and households). The blue/green/grey distinction can be used in a similar way to disaggregate national water footprints into their component colours (Fig. 2).

The scientific validity of breaking down a water footprint into its three different “colours” or constituents has been questioned, however, on the grounds that blue and green water are not necessarily discrete categories (Wichelns, 2011a), while grey water is essentially a fictional measure of water pollution that does not reflect either

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a consumptive use of water or pollution treatment costs (Gawel and Bernsen, 2011b). Furthermore, the inclusion of green water creates inconsistencies between water content figures for agricultural products compared to non-agricultural products (Zhang et al., 2011). With regards to grey water, the consensus among water experts and policymakers is that it is the least meaningful of the three water types as it is a theoretical rather than an actual measured volume (Morrison et al., 2010). It is extremely difficult to determine how much freshwater will be contaminated by polluted water, with the actual extent being dependent upon local hydrology and water quality standards (Nazer et al., 2008). In the global water footprint assessments, grey water quantification is only associated with nitrogen leaching but in many areas other leached nutrients can be the major pollution threat for water quality (Juntunen et al., 2002; Johnston and Dawson, 2005). However, these nutrients are not usually considered in water footprint assessments. Furthermore, the grey water concept does not provide any information with respect to the impact of polluted water on downstream ecosystem service delivery (Launiainen et al., 2013). In the absence of a standardized method for the quantification of dilution volumes required for assimilation (Thaler et al., 2012), grey water becomes a largely subjective estimate (Jeswani and Azapagic, 2011).

### 2.3 Attempts to estimate impacts of water use – stand-alone impact-oriented approaches

Within the bottom-up family of approaches, and in addition to the original method proposed by the WFN, there are currently several published methods. Some of these simply elaborate the WFN method whereas others critically argue for omitting or adding certain elements in order to enhance its potential as an impact indicator. Furthermore, some of these methods are proposed as stand-alone procedures (even though some use LCA software) whereas others are designed to be part of a broader and more comprehensive LCA (Berger and Finkbeiner, 2012). This sub-section reviews several of the most important stand-alone alternatives whereas the next sub-section examines full-blown LCA-oriented approaches.

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Sausse (2011) notes that certain studies (e.g. Gerbens-Leenes et al., 2009) define the three water footprint components, but omit this distinction in the quantification process, which limits the clarity and usefulness of the concept. Ridoutt and Pfister (2010a) argue that green water should not be included in water footprints since green water use does not contribute to water scarcity from a water management perspective – green water neither contributes to environmental flows nor is accessible for other productive uses. Rather, since green water is only accessible through the occupation of land it is better considered as a land use impact within an environmental LCA rather than through a water footprint. On the contrary, many authors still argue that green water resources are also limited, scarce and highly variable, and can be substituted by blue water as well as, in the case of agriculture, act as a substitute for blue water (Jefferies et al., 2012), especially in areas where blue water resources are scarce. According to Berger and Finkbeiner (2012), the actual question to be addressed is how the green water footprint affects blue water availability<sup>4</sup>. Similarly, since grey water is not a consumptive use, water quality aspects may be better considered through other means such as water quality modelling (Thomann and Mueller, 1987) or LCA (reviewed in the following section).

The revised water footprint methodology developed by Ridoutt et al. (2012a) and Pfister and Hellweg (2009) considers only consumptive water use, using a stress-weighted blue water footprint calculated by multiplying the blue water footprint at each point of a product's life cycle by a geographically-specific indicator of water stress. Using this methodology for six different beef production systems in Australia, Ridoutt et al. (2012a) estimate water footprints ranging from 3.3 to 221 m<sup>3</sup> t<sup>-1</sup> of beef. This compares to the global weighted average water footprint calculated by Mekonnen and Hoekstra (2012b) of 15 415 m<sup>3</sup> t<sup>-1</sup>, with the difference largely due to Ridoutt

<sup>4</sup>In the case of managed forests in Fennoscandian forests, Launiainen et al. (2013) have shown that there is no evidence of forest management having had any effects on evapotranspiration or blue water availability. Nevertheless, this is a context- and climatically-specific finding which may differ in other environments.



soil moisture availability as well as more blue water in the form of surface runoff to rivers and aquifer recharge (Ruprecht and Schofield, 1989).

Herath et al. (2011) compare three methods of calculating the water footprint of hydroelectricity: (a) consumptive water use whereby the volume of water evaporated from a reservoir is divided by the energy produced by its hydropower plant, (b) net consumptive use whereby land use changes resulting from the construction of the dam are considered and thus evapotranspiration that would have occurred from the vegetation which the dam replaced is subtracted from the evaporative water losses, and (c) net water balance whereby both water inputs and outputs from the reservoir are considered and thus the volume of precipitation occurring over the reservoir is subtracted from the evaporative water losses from the reservoir. Approach (a) is the approach suggested by Mekonnen and Hoekstra (2012a). Approaches (b) and (c) are alternative variants of the “net green” approach. The results demonstrate the considerable range in water footprint values depending on the method: (a) produces an average water footprint for New Zealand hydro-electric reservoirs of  $6.05 \text{ m}^3 \text{ GJ}^{-1}$ , method (b)  $2.72 \text{ m}^3 \text{ GJ}^{-1}$  and method (c)  $1.55 \text{ m}^3 \text{ GJ}^{-1}$ . Deurer et al. (2011) similarly estimate the “net blue water” footprint of kiwi fruit production by calculating the net aquifer recharge occurring beneath kiwi orchards. They subsequently compare this with the water footprinting methodology proposed by Hoekstra et al. (2009b), which estimates total water consumed during production. The net blue water footprint averaged  $-500 \text{ L tray}^{-1}$ <sup>5</sup> of kiwi fruit whereas the blue water footprint using the Hoekstra et al. (2009b) methodology was  $100 \text{ L tray}^{-1}$ . Deurer et al. (2011) found that kiwi fruit production had no impact on freshwater scarcity in soils and thus questioned the usefulness of the green water footprint concept.

As the methodological possibilities for stand-alone measures are numerous depending on the context, there is yet no established method that stands out as a gold standard. To a certain extent, the appropriate methodology for a water footprint study should

<sup>5</sup>A tray is defined by the authors as 3.6 kg of fresh produce, and is the standard functional unit of productivity in the New Zealand kiwifruit industry (Deurer et al., 2011).

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depend on what goal is trying to be achieved (Chapagain and Tickner, 2012; Jefferies et al., 2012). However, the diversity of approaches, with their dramatically different results, means that the outcomes of studies performed by different researchers or organisations may not be compatible. In some cases there may even be a risk of biased outcomes since researchers are more likely to choose the methodology which best gives the desired result.

## 2.4 Attempts to estimate impacts of water use – full-blown LCA approaches

Despite the primary aim of this review being to concentrate on the usefulness of stand-alone procedures, the voluminous LCA literature also demands some attention. In an attempt to provide water footprint methods with an improved ability to quantify environmental impact and to complement existing LCA methodologies, several studies have been published in recent years proposing various ways to integrate water footprints into LCA inventories (Pfister et al., 2009; Bayart et al., 2010; Boulay et al., 2011a; Milà i Canals et al., 2009; Berger and Finkbeiner, 2010). LCA, a technique which originates from the field of industrial ecology, is a tool capable of measuring the combined effect of several environmental impacts of products across their supply chain (from cradle to grave) (Finnveden et al., 2009). LCA did not traditionally include water consumption (freshwater use) as an impact (Milà i Canals et al., 2009), hence the process of integrating water footprinting into LCA is still relatively new and the procedures far from clear-cut, which is, perhaps, a reflection of the state of the concept in general.

Several comprehensive reviews of methodological alternatives and developments by different working groups are available in the LCA literature (Berger and Finkbeiner, 2010, 2012; Kounina et al., 2013). According to Kounina et al. (2013) there is no single method which comprehensively describes all potential impacts derived from freshwater use. Approaches differ significantly in terms of considered water types, whether or not they account for local water scarcity and differentiation between watercourses and quality aspects (Berger and Finkbeiner, 2010). Some LCA applications also explicitly quantify potential health impacts (Boulay et al., 2011b; Motoshita et al., 2011),

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community-level land use data for the period 1995–2009. The results of this model were compared with previous global water use assessments of Siebert and Döll (2010) and Mekonnen and Hoekstra (2010b, 2011a) for Cyprus, to reveal the large discrepancies among estimates. In particular, the Siebert and Döll (2010) estimates for Cyprus were 72 % lower for total green water use and 41 % higher for blue water use, for the period 1998–2002, while Mekonnen and Hoekstra (2011a) average estimates for the period 1996–2005 were 43 % higher for blue water use and almost identical for green water use. These differences in modeling outcomes are attributed both to different climate and land use datasets, but also to different modeling parameters, such as planting and harvesting dates, soil and other parameters.

The differences between global and local model estimates indicate one of the key issues regarding the credibility and usefulness of the water footprint as environmental impact indicator. Finger (2013) has recently argued that the mean global crop water footprint values that are most frequently cited are not informative enough. This mainly relates to the fact that the spatial heterogeneity in terms of both climate parameters and production systems is poorly captured and reported. Furthermore, although the limitations of global water footprint assessments are usually included in academic reports, they are not stressed to the same extent when these mean global values are reported in the media or forwarded to policy makers. A recent example is the attempt by the Federal Statistical Office of Germany to establish water footprint accounts of food products in the country, for the period 2000–2010 (Flachmann et al., 2012). Although the input statistics are directly derived from the national food-related accounts of Germany, the water footprint values per crop and per country are from the global water footprint assessment of Mekonnen and Hoekstra (2011a).

Similarly, global estimates have been recently employed to assess the sustainability of consumption in France (Ercin et al., 2013), and to quantify the impact of the cut flower trade in Lake Naivasha Basin (Kenya) (Mekonnen et al., 2012); the latter is going one step further and proposes a water sustainability premium to fund water use efficiency measures, even though the limitations of global water footprint estimates is



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acknowledged. In the absence of temporally explicit analysis using location specific data, such studies can potentially result in false estimates and provide the wrong indication both to policy-makers and the general public regarding the internal and external water footprint, and the blue and green water footprint components of production, consumption within a country or region. The same limitation also applies for product-specific water footprint assessments that rely on global water use model estimates (Mekonnen and Hoekstra, 2010a; Van Oel and Hoekstra, 2012; Erzin et al., 2011).

Ultimately, the choice of spatiotemporal scale should depend on what the study is trying to achieve. Using global averages taken from the WFN for a locally specific application is certainly not advisable and is likely to result in erroneous estimations of local water use impacts. This is particularly relevant to businesses wishing to engage in transparent water use estimates across product supply chains, with potential benefits to both their own interests (saving water and reducing costs) as well as for better informing customers. Many companies and corporations have already embraced water footprinting of their operations (Unilever, 2012; Coca-Cola and Nature Conservancy, 2010; Raisio, 2010; Rep, 2011; Pepsi Co, 2011; Nestlé, 2011; SABMiller et al., 2011; Cooper et al., 2011; Ruini et al., 2013; Francke and Castro, 2013). Nevertheless, it would appear that most studies do not use their own spatially and temporally explicit water footprint values and are potentially basing the analysis of their own operations on previously published global values.

It could also be argued that, despite the aforementioned limitations, using readily available tools such as the WaterStat<sup>6</sup> database is an acceptable first attempt for companies and consumers to become more aware of water use at different stages of production as well as across different sites. Nevertheless, they have to realise that they must, in due course, also engage in their own data collection (or work with national or regional environmental agencies where resources or expertise are an issue), in order to obtain improved and trustworthy water footprint estimates. This should eventually allow businesses to have an acceptable understanding of their own direct and operational

<sup>6</sup>This is freely available online at <http://www.waterfootprint.org/?page=files/WaterStat>.

water use, and proceed to the next step that is often proposed, i.e. product labeling (Hoekstra, 2009; Rockström et al., 2009; Ridoutt et al., 2010). However, in the absence of a universally accepted methodology, we are still some way from being able to consistently compare water impacts of different products made by different companies.

### 3 Uses of water footprints

Despite the growing interest in water footprinting and the continuing refinements and comparisons of alternative methodologies, there has been relatively little critical discussion about the purpose of water footprinting or the uses of water footprints, with only a handful of papers questioning its purpose. Uses of water footprinting suggested by those developing the water footprinting methodologies can be grouped under three broad themes: (i) a tool for assisting water resources management and dealing with water scarcity; (ii) a means of consumer empowerment; and (iii) a way of promoting equity in the use of global water resources.

#### 3.1 A tool for assisting water resources management and managing water scarcity at national/regional level

Water footprinting is put forward as a tool for assisting policy development in the water sector by showing the extent of interdependence of individual countries on the water resources of other countries (Chapagain et al., 2006) and thus allowing countries to assess their national food security and develop environmental policy (Hoekstra and Mekonnen, 2012b). Water footprinting can help governments understand the extent to which the size of their national water footprint is due to consumption patterns or inefficient production and thus to prioritise policy actions such as changing consumption patterns or improving the water efficiency of production (Hoekstra and Mekonnen, 2012b; Hoekstra and Chapagain, 2007; Aldaya et al., 2010a; Flachmann et al., 2012).

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Water footprinting has been suggested as a way for exploring whether production sites are suitable for producing crops for export (Chapagain and Orr, 2009; Mekonnen et al., 2012). However, by adopting an entirely water-centric basis of analysis, the livelihoods of those working in agriculture is largely ignored (Mostert and Raadgever, 2008). It has been argued, for instance, that the main purpose of trade worldwide is not necessarily to reduce the demand for scarce production inputs but to enhance incomes and well-being, especially when the net benefit of such a policy to the local environment or society is uncertain or poorly justified (Wichelns, 2010a). While water is clearly an input to production, it cannot be the sole criterion for judging the rationality of trading patterns, as trade between countries is determined by a variety of factors such as land, labour, technology, trade agreements and other factors (Aldaya et al., 2010b). Considering gross value added to the economy per litre of water used, and thus bringing in a socio-economic dimension, is one idea for widening the criteria considered as part of a water footprint analysis (Aldaya et al., 2010b).

Some water footprinting researchers have suggested in a policy context that water footprinting can be used to show countries how to externalise their water demands and thus save water (Hoekstra, 2009; Hoekstra et al., 2009a; Aldaya et al., 2010b; Biewald, 2011; Biewald and Rolinski, 2012), with the dominant argument being that water scarce countries should aim at importing water-intensive products from humid countries with abundant water resources. Conceptually, however, it is difficult to see how a water scarce country can save through international trade something which it never had, as some countries are shown to have saved through food imports more water than they have available locally (Wichelns, 2010a, 2011b). Antonelli et al. (2012) strongly criticize the concept of “savings”, particularly in the case of green water, which is trapped in the soil and cannot possibly be diverted to non-agricultural uses.

Suggesting that a country “loses” water by exporting goods from employment and wealth generating industries is also conceptually problematic. While countries need to ensure that water is allocated in ways that reflect its scarcity and its opportunity cost, water footprinting does not assess the opportunity cost of water (Wichelns, 2010a).

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Furthermore, there is no consideration of the important concept of water productivity in a basic water footprint (Gleick, 2003). However, water footprints do allow comparisons of water productivity if results are linked to the gross value added per unit of water used in addition to just product yields per unit of water (Aldaya et al., 2010b). Water productivity (usually measured in dollars per unit of water), implies that any comparisons of volumes of water used in the making of agricultural or industrial products must also account for (at least) the economic yield of the water used.

Dividing water footprints into blue, green and grey water footprints has been suggested by Mekonnen and Hoekstra (2010a) as a means to identify ways of saving blue water, which is seen as having a higher opportunity cost than green water. However, the opportunity cost of water use is location-specific: high value rain-fed agricultural land may be scarce in a region where blue water is not scarce, thus blue water will not always have a higher opportunity cost than green water. For example, in the Netherlands 8.7 % of total renewable (blue) water resources are withdrawn each year, suggesting that blue water is not particularly scarce, but arable land is obviously a limited resource (Food and Agriculture Organization, 2009). This comes back to the argument with respect to the usefulness of the green water concept. Where there is no apparent impact of any green water use on surface or aquifer waters (blue water), its use impact is essentially a land use impact.

Water footprints have been suggested as a means to encourage improved agricultural water efficiency throughout the world. Nevertheless, improving irrigation efficiency does not necessarily save water at the basin-scale as it may reduce valuable return flows and limit aquifer recharge (Ward and Pulido-Velasquez, 2008). Watersheds differ with respect to their physical and institutional characteristics, meaning that decisions to achieve more efficient water use are best taken at the water-basin scale, as advocated by more traditional water resources management perspectives (Mitchell, 1990; Bach et al., 2011; Gooch and Stalnacke, 2010). It is along these lines that some of the recent developments in water footprints have occurred whereby monthly climatic data have been combined with crop production to produce location and time specific water

footprints (Aldaya et al., 2010b), and daily climatic data combined with community-level land-use data has been used to produce highly location and time specific water footprints (Zoumides et al., 2012).

While such developments of the water footprint concept make the results more accurate (rather than just being global averages), policy makers and the media are attracted to the big simple numbers derived from global studies which have little relevance for local water resources management or policy making. As the methodology and results of water footprint analysis becomes more spatially and temporally specific and thus sophisticated, it loses its major strength – an indicator that simplifies complicated data down to a form which is conceptually simple and readily understood. The further water footprints move in this direction, the further they get from their starting point of quantifying the volumes of “virtual water” being traded between countries and their role as a consumer indicator, thus becoming simply another form of local hydrological assessment.

### 3.2 A means of consumer empowerment

Water footprinting at the product level has been suggested as a means of empowering consumers by providing information to allow them to take responsibility for the impact of their consumption (Ridoutt and Pfister, 2010b; Hoekstra and Mekonnen, 2012b; Feng et al., 2012). According to its proponents, by empowering the final consumers of products, a tool like water footprinting can extend water management beyond single catchments or countries (Chapagain et al., 2006), thus providing a means to overcome the inadequacies of water governance found in some countries (Ridoutt and Pfister, 2010b).

The extent to which consumer choices in one country can modify water policy decisions elsewhere in the world is debatable. More fundamentally, it is unclear how water footprinting can empower consumers. A water footprint alone only indicates the volume of water required to produce a product, not the impact of that water use on the local environment, the opportunity costs of the water used, nor the degree of water scarcity in

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the producer region. Informing consumers of the environmental impact of the products they consume may potentially be useful, but it is not clear how water footprinting can do this as the information provided, at present, is too aggregated and limited. This may even become misleading, when, for the sake of simplicity, only total water footprints of products are reported, with no elaboration on what the figure includes and where it was taken from.

Breaking the footprint down into its constitute components of blue, green and grey waters at the global or national level still does not provide consumers with real information on the environmental impact of production, besides the fact that the agricultural stages of production are always shown to account for the majority of water use for all three components (Fig. 3). It also means that consumers are no longer being provided with a single indicator but a set of indicators. It instead becomes another composite sustainability indicator complete with value judgements upon which the weighting is based. It is clear that there are trade-offs between precision and applicability but also between scientific validity and consumer relevance, with water footprinting techniques yet to strike a balance with respect to either of these trade-offs.

A host of different kind of companies have already made attempts to calculate water footprints of their activities (Unilever, 2012; Coca-Cola and Nature Conservancy, 2010; Raisio, 2010; Rep, 2011; Pepsi Co, 2011; Nestlé, 2011; SABMiller et al., 2011; Cooper et al., 2011). Most of these companies have embraced the concept of water footprints, seeing them as a natural follow-up to carbon footprints and offering an additional way to render the environmental impact of their supply chains more transparent. While the credibility of such corporate water footprints can be questioned, as previously discussed, they do appear to force companies to directly consider their use of water in their supply chain and the broader impacts on the aquatic environment.

### 3.3 A way of promoting equity of water use and “virtual water” trade

By quantifying direct and indirect water use, water footprinting allows the comparison of total per capita water use in different countries where previously it was only possible

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to compare direct water use and only within national boundaries. The inclusion of indirect and external water use allows consideration of the equity and sustainability of consumption (Chapagain et al., 2006). Under current production efficiencies, it is not possible for everyone in the world to develop water footprints equal to those currently achieved in countries with very high water footprints, such as the US (Hoekstra, 2011). Based upon this concept of inequitable water use, Ridoutt and Pfister (2010b) argue that developed countries, through their supply chains, take a disproportionate share of the world's water resources, and therefore just as greenhouse gas reduction targets have been set, water footprint reduction targets need to be set. Mekonnen and Hoestra (2010a) suggest that a water scarcity rent on traded products would be another means of tackling the inequality of water resources use and allow externalities to be passed on to the consumers of products. Hoekstra (2011) advocates for water footprint quotas to be allocated to countries on a per capita basis to ensure that their citizens consume a fair proportion of the world's water resources and thus increase equity in total water use.

Conversely, it has been argued that the discussion on the equity of water use ignores the fact that water scarcity is a largely local or regional problem where demands on water resources exceed local supplies; if people in one location cut their consumption of water intensive products it will have little impact on water scarcity in other regions (Wichelns, 2011a). Farmers in the exporting regions would likely adapt by switching to other crops or export markets while carrying on using the water, while water intensive products being consumed may not originate from water scarce regions in the first place. Suggesting that people in one location are consuming an unfair amount of water because they consume more than people in another region is unhelpful. People living in humid areas are likely to consume more water than people living in arid areas simply because people tend to make use of the available resources in the area where they live (Wichelns, 2011a). Countries with high total water footprints tend to consume water available from their own territories (Fader et al., 2011), while many of those countries with high external water footprints (such as the Netherlands, van Oel

et al., 2009) import goods due to a scarcity of arable land not local water resources (Wichelns, 2010a). To this end, water is just one of factor influencing a country's comparative advantage when it comes to trade.

Gawel and Bernsen (2013) argue that nearly all “virtual water” trades can be condemned from a certain moral standpoint due to the potential negative consequences for developing countries, and thus attaching moral judgements to water footprints is not helpful. A developed country importing food from a developing country can be accused of externalising the environmental consequences of its water footprint and unfairly taking the water resources of developing countries. A developed country exporting food to a developing country can be accused of creating an unacceptable state of dependency in the importing country, however, a developed country which does not export can be accused of hoarding its water resources or consuming internally more than its “fair share” of global water resources. A developing country importing food can be accused of neglecting its rural economy and allowing itself to become dependent upon others. Lastly, a developing country exporting food can be accused of allowing itself to be exploited by developed countries seeking to externalise their water footprints and associated environmental damage (Gawel and Bernsen, 2013). Applying normative criteria to water footprints and associated “virtual water” trading is problematic and suggests that water related problems need to be tackled according to the specifics of their location.

#### 4 Water footprinting compared to other “footprint” indicators

In a globalised world, production and consumption are frequently geographically distant, allowing the outsourcing of high environmental impact activities to less developed countries (Galli et al., 2012b). As such, indicators are needed to link consumers to the demands they place on the environment. Water footprinting has been suggested as a complementary indicator to the ecological footprint as both concepts convert

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consumption into different measures of natural resource use (Hoekstra, 2009; Ge et al., 2011).

The ecological footprint was introduced by Rees (1992) to measure human consumption in terms of land use, with all consumption being converted into a common metric, global-hectares – the land area needed to sustainably supply the resources used or assimilate the wastes produced. Whereas the ecological footprint considers the land use implications of consumption, the water footprint considers the water use implications of consumption (Hoekstra, 2009).

Water footprinting has also been compared to carbon footprinting, which measures the total amount of greenhouse gas emissions which are directly or indirectly caused by a product over its life cycle, with carbon footprints expressed in the common metric of kg of CO<sub>2</sub> equivalent (Galli et al., 2012b). Carbon footprinting thus tries to show the impact of consumption decisions for climate change. Ridoutt and Pfister (2010b) argue that, just like carbon footprinting, water footprinting can create pressure for change. They do, though, point out that, unlike in the case of the carbon footprint where several companies and countries have set themselves arbitrary targets, it remains unclear how much reduction in water consumption needs to be achieved at present.

Water footprints, however, are not analogous to either carbon or ecological footprints as carbon footprints describe impacts in terms of the limited absorptive capacity of the earth's atmosphere and ecological footprints in terms of scarce land resources (Wichelns, 2011a; Gawel and Bernsen, 2013). Water footprints in their conventional form are simply calculations of a single important input used for production or consumption without any accounting of the impacts of use. In the same way that methane and carbon dioxide emissions cannot be compared on a kilogram level (because of their very different global warming potential), water consumption in places with different water scarcity levels are not comparable (Berger and Finkbeiner, 2012). Products often have complex, spatially disconnected production chains. This means that simply aggregating all local water consumption determined at catchment or river basin level into one figure is physically incorrect (Launiainen et al., 2013). Although with

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methodological developments like the inclusion of pollution impacts through grey water accounting there have been attempts to incorporate impacts of use, such innovations move water footprints away from being an actual measure of water used in production. Furthermore, within LCA, there are still several possible characterization models available for water consumption whereas an internationally agreed characterization model for carbon footprinting already exists (Berger and Finkbeiner, 2012).

While water may be scarce in some locations, in many regions it is not. The impacts of water use vary spatially and thus water saved in a water abundant region will have no effect on abundance in water scarce regions. Water availability is also subject to significant seasonal variation in certain places, meaning that the impact of water use can vary markedly from one month to the next. A kilogram of carbon-dioxide emitted to the atmosphere has the same impact regardless of where or when the emission occurs but the impact on the environment of a litre of water use will vary dramatically.

Contrasting a hypothetical energy footprint with that of a carbon footprint illustrates what is, perhaps, the key shortcoming of water footprints. An energy footprint which involves calculating the total energy required for producing and supplying a consumer product, would be a poor substitute for the carbon footprint since it would not provide information on the environmental impacts of the energy used. As such, it would provide little useful information to consumers or policy makers. Breaking down energy footprints into subcategories, such as a product's renewable energy and non-renewable energy footprints, along similar lines to which water footprints have been broken down to green, blue and grey water footprints, would still not provide sufficient information to allow useful comparisons of the environmental impact of two products. A carbon footprint, however, while only assessing a single environmental impact – the climate change impact – does theoretically provide a metric for direct comparison of two products for the impact on the atmosphere will be the same where ever the carbon emission occurs (Gawel and Bernsen, 2013).

## 5 Conclusions: present options and future directions

In this review we have shown that there is still no consensus with regards to both the methodological standard to be employed for water footprinting as well as the actual purpose behind water footprinting. We believe that these two types of uncertainty (methodological and purpose-related) may be reinforcing each other as part of a vicious cycle. Exhaustive debates with respect to the methodological procedures actually detract from the fact that there are numerous proposed uses of the concept, with no universally defined and agreed purpose. On the other hand, the exact purpose may be difficult to pinpoint while there are so many different frameworks developed to achieve diverse objectives. This is not necessarily bad as it is to be expected that different academic groups and practitioners may want to apply the concept in different contexts. Nevertheless, it does make it harder to move towards a gold standard for quantifying water use impacts. As seen in this text, the commendable attempts by academic groups worldwide to develop different methodologies have not converged mainly because, unlike in the case of carbon, the physical properties of water such as its spatial and temporal availability, along with its many different sources and types or “colours” make it exceptionally difficult to value across varying contexts or locations. To conclude this review, we would like to summarise some recent developments and directions (both positive and negative in our view) as well as offer present options for researchers, corporations and consumers.

We believe that certain recent studies show some encouraging signs with respect to where the concept may be heading towards. Hoekstra et al. (2012) make an attempt to address some of the shortcomings of previous global water footprint studies by including environmental flows and monthly variations in water availability. Nevertheless, despite their valid argument that blue water (consumption) is more relevant in water scarcity considerations compared to total water use, it is unclear whether their approach offers more insight on water-stressed areas compared to worldwide water assessments that do not employ a water footprinting approach (Vörösmarty et al.,

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2000, 2010; Oki and Kanae, 2006; Döll et al., 2003; Alcamo et al., 2007; Hanasaki et al., 2008). Furthermore, the aforementioned worldwide assessment studies, despite their limitations (low spatial and temporal resolution compared to locally-specific studies, climate input and population projection uncertainties), offer the advantage of using dynamic models which can incorporate future climate, population and economic projections. This is not the case for the majority of water footprint studies, although there have been some recent attempts to address this by including climate projections (Ercin and Hoekstra, 2012; Bocchiola et al., 2013). Another recent study suggests that complementary indicators may be required with regards to estimating groundwater use impacts (Gleeson et al., 2012), thus highlighting one of the main arguments made here – the fact that, at present, water footprint methodologies and proposed applications still remain too broad and diverse.

From an academic perspective, recent studies (Galli et al., 2012a, b; Steen-Olsen et al., 2012) may provide an option in terms of a possible way to develop the water footprint and acknowledge its limitations by combining it with established indicators such as the carbon or ecological footprints. The main idea is that by focusing on many indicators simultaneously prevents potential trade-offs in other environmental impacts which would otherwise arise if water footprints are considered in isolation (Hadjikakou et al., 2013; Francke and Castro, 2013). In addition to the multi-indicator approach, the aforementioned studies also employ a hybrid modelling framework (Ewing et al., 2012) which combines input-output analysis (top-down) with product-level data (bottom-up), thus addressing the first of the methodological dilemmas identified in this review. The Steen-Olsen et al. (Steen-Olsen et al., 2012) study also strongly argues for the use of only the blue water footprint, by leaving out the more controversial green and grey parts. This is in agreement with Antonelli et al. (2012) who conclude that it is blue water which matters in most circumstances. Besides, blue water is water in the most conventional sense (considered in traditional water resources assessments) and the form with the greatest opportunity cost (Ridoutt et al., 2009).

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Therefore, approaches that consider only blue water, that make use of hybrid models and do not look at water use in isolation, should, in principle, offer more insightful results. The challenge, however, rests in interpreting these results critically and with caution, whilst acknowledging the shortcomings of estimated water footprints as a policy-changing tool. This point needs to be highlighted, given that some countries have already included the water footprint concept in national statistical reports (Flachmann et al., 2012) and legal frameworks (Spanish Ministry of the Environment and Rural and Marine Affairs, 2008), while others are currently examining its potentials to formulate sustainable strategies to minimise their seemingly high external water footprints (Witmer and Cleij, 2012).

Despite its methodological limitations, the water footprint has succeeded in stimulating the discussion on the inter-linkages between water use, food security and consumption (both in terms of different diet types as well as the increasing quantities of food produced and consumed worldwide) (Vanham et al., 2013; Cazcarro et al., 2012). The concept has also stimulated increasing attention at the corporate level (Mason, 2013), facilitating companies to begin to consider the environmental impact of their water use, which may be seen as an important first step. At the present stage of its methodological development, corporate water footprinting is best carried out through incorporating water use into LCA, a more comprehensive tool which does not focus on a single environmental parameter or production input. There are also some emerging stand-alone procedures (Ridoutt and Pfister, 2013a) that make use of LCA methodologies. These potentially offer an additional option for a nontechnical audience likely to be more responsive to simplified footprint indicators (Ridoutt and Pfister, 2013b).

Ultimately, companies are not merely interested in becoming more water-efficient, but they also want to demonstrate more transparency in terms of their operations through marketing tools such as environmental labelling. Labelling also allows them to publicise their progress against any predetermined objectives. In the absence of standardised procedures and regulatory authorities, the message to the consumer can be misleading. For consumers in water scarce regions, the current lack of a standardised

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and comparable water use impact indicator could mean that at present, a direct water consumption footprint which simply measures per capita household water consumption may still remain more meaningful. Such an indicator can provide information on how personal choices impact directly on a locally scarce resource and thus potentially bring about immediate improvement in water use efficiency and savings for the local population. This will hopefully change as progress is made towards a standardised water footprint and subsequent labelling. Overall, through such progress, the usefulness and relevance of the water footprint concept can potentially be enhanced and become much more than its current status of producing headline grabbing estimates that are, sadly, often of limited use to policy-makers and consumers alike.

## References

- Alcamo, J., Florke, M., and Marker, M.: Future long-term changes in global water resources driven by socio-economic and climatic changes, *Hydrolog. Sci. J.*, 52, 247–275, 2007.
- Aldaya, M. M., Garrido, A., Llamas, M. R., Varela-Ortega, C., Novo, P., and Casado, R. R.: Water footprint and virtual water trade in Spain, in: *Water Policy in Spain*, edited by: Garrido, A. and Llamas, M. R., CRC Press, Leiden, 49–59, 2010a.
- Aldaya, M. M., Martinez-Santos, P., and Llamas, M. R.: Incorporating the water footprint and virtual water into policy: reflections from the Mancha Occidental Region, Spain, *Water Resour. Manag.*, 24, 941–958, 2010b.
- Allan, T.: “Virtual Water”: a Long Term Solution for Water Short Middle Eastern Economies?, British Association Festival of Science, Water and Development Session – TUE.51, 14.45, University of Leeds, 9 September 1997, 1997.
- Allan, T.: *The Middle East Water Question: Hydropolitics and the Global Economy*, I. B. Tauris, London, 2001.
- Antonelli, M., Roson, R., and Sartori, M.: Systemic input-output computation of green and blue virtual water “flows” with an illustration for the Mediterranean region, *Water Resour. Manag.*, 26, 4133–4146, 2012.
- Bach, H., Clausen, T. J., Trang, D. T., Emerton, L., Facon, T., Hofer, T., Lazarus, K., Muziol, C., Noble, A., Schill, P., Sisouvanh, A., Wensley, C., and Whiting, L.: From Local Watershed

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Bayart, J.-B., Bulle, C., Deschênes, L., Margni, M., Pfister, S., Vince, F., and Koehler, A.: A framework for assessing off-stream freshwater use in LCA, *Int. J. Life Cycle Ass.*, 15, 439–453, 2010.

Berger, M. and Finkbeiner, M.: Water footprinting: how to address water use in life cycle assessment?, *Sustainability*, 2, 919–944, 2010.

Berger, M. and Finkbeiner, M.: Methodological challenges in volumetric and impact: oriented water footprints, *J. Ind. Ecol.*, 17, 79–89, 2012.

Biewald, A.: Give virtual water a chance! An attempt to rehabilitate the concept, *GAIA*, 20, 168–170, 2011.

Biewald, A. and Rolinski, S.: The theory of virtual water: why it can help to understand local water scarcity, *GAIA*, 21, 88–90, 2012.

Bocchiola, D., Nana, E., and Soncini, A.: Impact of climate change scenarios on crop yield and water footprint of maize in the Po valley of Italy, *Agric. Water Manage.*, 116, 50–61, 2013.

Boulay, A.-M., Bouchard, C., Bulle, C., Deschênes, L., and Margni, M.: Categorizing water for LCA inventory, *Int. J. Life Cycle Ass.*, 16, 639–651, 2011a.

Boulay, A.-M., Bulle, C. C., Bayart, J.-B., Deschênes, L., and Margni, M.: Regional characterization of freshwater use in LCA: modeling direct impacts on human health, *Environ. Sci. Technol.*, 45, 8948–8957, 2011b.

Buckley, C., Friedrich, E., and von Blottnitz, H.: Life-cycle assessment in the South African water sector: a review and future challenges, *Water SA*, 37, 719–726, 2011.

Cazcarro, I., Duarte, R., and Sánchez-Chóliz, J.: Water flows in the Spanish economy: agri-food sectors, trade and households diets in an input-output framework, *Environ. Sci. Technol.*, 46, 6530–6538, 2012.

Chapagain, A. and Hoekstra, A.: Water Footprints of Nations: Volume 1: Main Report, UNESCO-IHE Delft, Delft, 2004.

Chapagain, A. and Hoekstra, A. Y.: The blue, green and grey water footprint of rice from production and consumption perspectives, *Ecol. Econ.*, 70, 749–758, 2011.

Chapagain, A. K. and Orr, S.: An improved water footprint methodology linking global consumption to local water resources: a case of Spanish tomatoes, *J. Environ. Manage.*, 90, 1219–1228, 2009.

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- Chapagain, A. K., Hoekstra, A. Y., Savenije, H. H. G., and Gautam, R.: The water footprint of cotton consumption: as assessment of the impact of worldwide consumption of cotton products on the water resources in the cotton producing countries, *Ecol. Econ.*, 60, 186–203, 2006.
- Chen, Z. M. and Chen, G. Q.: Virtual water accounting for the globalized world economy: national water footprint and international virtual water trade, *Ecol. Indic.*, 28, 142–149, 2013.
- Coca-Cola, and Nature Conservancy: Product Water Footprint Assessments: Practical Application in Corporate Water Stewardship, The Coca-Cola Company, Atlanta, 2010.
- Cooper, T., Fallender, S., Pafumi, J., Dettling, J., Humbert, S., and Lessard, L.: A semiconductor company's examination of its water footprint approach, in: ISSST 2011: IEEE International Symposium on Sustainable Systems and Technology, Chicago, doi:10.1109/ISSST.2011.5936865, 16–18 May 2011.
- Deurer, M., Green, S. R., Clothier, B. E., and Mowatt, A.: Can product water footprints indicate the hydrological impact of primary production? – a case study of New Zealand kiwifruit, *J. Hydrol.*, 408, 246–256, 2011.
- Döll, P., Kaspar, F., and Lehner, B.: A global hydrological model for deriving water availability indicators: model tuning and validation, *J. Hydrol.*, 270, 105–134, 2003.
- Ercin, A. E. and Hoekstra, A. Y.: Water Footprint Scenarios for 2050, UNESCO-IHE Institute for Water Education, Delft, 2012.
- Ercin, A. E., Aldaya, M. M., and Hoekstra, A. Y.: Corporate water footprint accounting and impact assessment: the case of the water footprint of a sugar-containing carbonated beverage, *Water Resour. Manag.*, 25, 721–741, 2011.
- Ercin, A. E., Mekonnen, M. M., and Hoekstra, A. Y.: Sustainability of national consumption from a water resources perspective: the case study for France, *Ecol. Econ.*, 88, 133–147, 2013.
- Ewing, B. R., Hawkins, T. R., Wiedmann, T. O., Galli, A., Ertug Ercin, A., Weinzettel, J., and Steen-Olsen, K.: Integrating ecological and water footprint accounting in a multi-regional input–output framework, *Ecol. Indic.*, 23, 1–8, 2012.
- Fader, M., Gerten, D., Thammer, M., Heinke, J., Lotze-Campen, H., Lucht, W., and Cramer, W.: Internal and external green-blue agricultural water footprints of nations, and related water and land savings through trade, *Hydrol. Earth Syst. Sci.*, 15, 1641–1660, doi:10.5194/hess-15-1641-2011, 2011.

# HESSD

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## A critical review of the water footprint concept

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Falkenmark, M.: Fresh water – time for a modified approach, *Ambio*, 15, 192–200, 1986.

Falkenmark, M., Rockström, J., and Karlberg, L.: Present and future water requirements for feeding humanity, *Food Security*, 1, 59–69, 2009.

Feng, K., Chapagain, A. K., Suh, S., Pfister, S., and Hubacek, K.: Comparison of bottom-up and top-down approaches to calculating the water footprints of nations, *Econ. Systems Res.*, 23, 371–385, 2011.

Feng, K., Siu, Y. L., Guan, D., and Hubacek, K.: Assessing regional virtual water flows and water footprints in the Yellow River Basin, China: a consumption based approach, *Appl. Geogr.*, 32, 691–701, 2012.

Finger, R.: More than the mean – a note on heterogeneity aspects in the assessment of water footprints, *Ecol. Indic.*, 29, 145–147, 2013.

Finnveden, G., Hauschild, M. Z., Ekvall, T., Guinée, J., Heijungs, R., Hellweg, S., Köhler, A., Pennington, D., and Sangwon, S.: Recent developments in life cycle assessment, *J. Environ. Manage.*, 91, 1–21, 2009.

Flachmann, C., Mayer, H., and Manzel, K.: Water Footprint of Food Products in Germany, Statistisches Bundesamt (Federal Statistical Office of Germany), Wiesbaden, 2012.

Aquastat: FAO's Information System on Water and Agriculture: available at: <http://www.fao.org/ag/agl/aglw/aquastat/main/index.stm> (last access: 8 May 2007), 2007.

FAO Statistical Yearbook 2009: available at: <http://www.fao.org/economic/the-statistics-division-ess/publications-studies/statistical-yearbook/fao-statistical-yearbook-2009/en/> (last access: 17 July 2013), 2009.

Francke, I. C. M. and Castro, J. F. W.: Carbon and water footprint analysis of a soapbar produced in Brazil by Natura Cosmetics, *Water Resour. Ind.*, online first, doi:10.1016/j.wri.2013.03.003, 2013.

Galli, A., Weinzettel, J., Cranston, G., and Ercin, E.: A footprint family extended MRIO model to support Europe's transition to a one planet economy, *Sci. Total Environ.*, 26, 1504–1505, 2012a.

Galli, A., Wiedmann, T., Ercin, E., Knoblauch, D., Ewing, B., and Giljum, S.: Integrated ecological, carbon and water footprint into a “footprint family” of indicators: definition and role in tracking human pressure on the planet, *Ecol. Indic.*, 16, 100–112, 2012b.

Gawel, E. and Bernsen, K.: Do we really need a water footprint? Global trade, water scarcity and the limited role of virtual water, *GAIA*, 20, 162–167, 2011a.

## A critical review of the water footprint concept

J. Chenoweth et al.

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- Gawel, E. and Bernsen, K.: The colour of water: what does it tell us about scarcity? Reaction to two articles regarding the virtual water concept, *GAIA*, 20, 224–228, 2011b.
- Gawel, E. and Bernsen, K.: What is wrong with virtual water trading? On the limitations of the virtual water concept, *Environ. Plann. C*, 31, 168–181, 2013.
- 5 Ge, L., Xie, G., Zhang, C., Li, S., Qi, Y., Cao, S., and He, T.: An evaluation of China's water footprint, *Water Resour. Manag.*, 25, 2633–2647, 2011.
- Gerbens-Leenes, P. W., Hoekstra, A. Y., and van der Meer, T.: The water footprint of energy from biomass: a quantitative assessment and consequences of an increasing share of bio-energy in energy supply, *Ecol. Econ.*, 68, 1052–1060, 2009.
- 10 Gerbens-Leenes, P. W., Mekonnen, M. M., and Hoekstra, A. Y.: The water footprint of poultry, pork and beef: a comparative study in different countries and production systems, *Water Resources and Industry*, online first, doi:10.1016/j.wri.2013.03.001, 2013.
- Gleeson, T., Wada, Y., Bierkens, M. F., and van Beek, L. P.: Water balance of global aquifers revealed by groundwater footprint, *Nature*, 488, 197–200, 2012.
- 15 Gleick, P. H.: Water use, *Annu. Rev. Env. Resour.*, 28, 275–314, 2003.
- Gooch, G. and Stalnacke, P.: *Science, Policy and Stakeholders in Water Management: an Integrated Approach to River Basin Management*, Earthscan, London, 2010.
- Guieysse, B., Bechet, Q., and Stilton, A.: Variability and uncertainty in water demand and water footprint assessments of fresh algae cultivation based on case studies from five climatic regions, *Bioresource Technol.*, 128, 317–323, 2013.
- 20 Hadjikakou, M., Chenoweth, J., and Miller, G.: Estimating the direct and indirect water use of tourism in the eastern Mediterranean, *J. Environ. Manage.*, 114, 548–556, 2013.
- Hanasaki, N., Kanae, S., Oki, T., Masuda, K., Motoya, K., Shirakawa, N., Shen, Y., and Tanaka, K.: An integrated model for the assessment of global water resources – Part 2: Applications and assessments, *Hydrol. Earth Syst. Sci.*, 12, 1027–1037, doi:10.5194/hess-12-1027-2008, 2008.
- 25 Herath, I., Deurer, M., Horne, D., Singh, R., and Clothier, B.: The water footprint of hydroelectricity: a methodological comparison from a case study in New Zealand, *J. Clean. Prod.*, 19, 1582–1589, 2011.
- 30 Hoekstra, A. Y.: Human appropriation of natural capital: a comparison of ecological footprint and water footprint analysis, *Ecol. Econ.*, 68, 1963–1974, 2009.

## A critical review of the water footprint concept

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Hoekstra, A. Y.: The global dimension of water governance: why the river basin approach is no longer sufficient and why cooperative action at global level is needed, *Water*, 2011, 21–46, 2011.

Hoekstra, A. Y. and Chapagain, A. K.: Water footprints of nations: water use by people as a function of their consumption pattern, *Water Resour. Manag.*, 21, 35–48, 2006.

Hoekstra, A. Y. and Chapagain, A. K.: The water footprints of Morocco and the Netherlands: global water use as a result of domestic consumption of agricultural commodities, *Ecol. Econ.*, 64, 143–151, 2007.

Hoekstra, A. Y. and Chapagain, A. K.: *Globalization of Water: Sharing the Planet's Freshwater Resources*, Blackwell Publishing, Oxford, 2008.

Hoekstra, A. Y. and Hung, P. Q.: *Virtual Water Trade: a Quantification of Virtual Water Flows Between Nations in Relation to International Crop Trade*, IHE Delft, Delft, 2002.

Hoekstra, A. Y. and Mekonnen, M. M.: Reply to Ridoutt and Huang: from water footprint assessment to policy, *P. Natl. Acad. Sci. USA*, 109, E1425, doi:10.1073/pnas.1205186109, 2012a.

Hoekstra, A. Y. and Mekonnen, M. M.: The water footprint of humanity, *P. Natl. Acad. Sci. USA*, 109, 3232–3237, 2012b.

Hoekstra, A. Y., Chapagain, A. K., Aldaya, M. M., and Mekonnen, M. M.: *Water Footprint Manual: State of the Art 2009*, Water Footprint Network, Enschede, 2009a.

Hoekstra, A. Y., Chapagain, A. K., Aldaya, M. M., and Mekonnen, M. M.: *Water Footprint Manual: State of the Art 2009*, Water Footprint Network, Enschede, 2009b.

Hoekstra, A. Y., Gerbens-Leenes, W., and van der Meer, T. H.: Reply to Pfister and Hellweg: water footprint accounting, impact assessment, and life-cycle assessment, *P. Natl. Acad. Sci. USA*, 106, E114, doi:10.1073/pnas.0909948106, 2009c.

Hoekstra, A. Y., Chapagain, A. K., Aldaya, M. M., and Mekonnen, M. M.: *The Water Footprint Assessment Manual: Setting the Global Standard*, Earthscan, London, 224 pp., 2011.

Hoekstra, A. Y., Mekonnen, M. M., Chapagain, A. K., Mathews, R. E., and Richter, B. D.: Global monthly water scarcity: blue water footprints versus blue water availability, *PLoS ONE*, 7, e32688, doi:10.1371/journal.pone.0032688, 2012.

Jefferies, D., Muñoz, I., Hodges, J., King, V. J., Aldaya, M., Erwin, A. E., Milà i Canals, L., and Hoekstra, A. Y.: 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, *J. Clean. Prod.*, 33, 155–166, 2012.



# HESSD

10, 9389–9433, 2013

## A critical review of the water footprint concept

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- Milà i Canals, L., Chenoweth, J., Chapagain, A., Orr, S., Antón, A., and Clift, R.: Assessing freshwater use impacts in LCA: Part I – Inventory modelling and characterisation factors for the main impact pathways, *Int. J. Life Cycle Ass.*, 14, 28–42, 2009.
- Mitchell, B.: Integrated water management, in: *Integrated Water Management: International Experiences and Perspectives*, edited by: Mitchell, B., Belhaven Press, London, 1–21, 1990.
- Morrison, J., Schulte, P., and Schenck, R.: *Corporate Water Accounting: an Analysis of Methods and Tools for Measuring Water Use and Its Impact*, UNEP/Pacific Institute, Oakland, 2010.
- Mostert, E. and Raadgever, G. T.: Seven rules for researchers to increase their impact on the policy process, *Hydrol. Earth Syst. Sci.*, 12, 1087–1096, doi:10.5194/hess-12-1087-2008, 2008.
- Motoshita, M., Itsubo, N., and Inaba, A.: Development of impact factors on damage to health by infectious diseases caused by domestic water scarcity, *Int. J. Life Cycle Ass.*, 16, 65–73, 2011.
- Munksgaard, J., Wier, M., Lenzen, M., and Dey, C.: Using input-output analysis to measure the environmental pressure of consumption at different spatial levels, *J. Ind. Ecol.*, 9, 169–185, 2005.
- Nazer, D. W., Siebel, M. A., van der Zaag, P., Mimi, Z., and Gijzen, H. J.: Water footprint of the Palestinians in the West Bank, *J. Am. Water Resour. As.*, 44, 449–458, 2008.
- Nestlé: *Meeting the Global Water Challenge: Creating Shared Value Summary Report 2011*, Nestlé, Vevey, 2011.
- Núñez, M., Pfister, S., Antón, A., Muñoz, P., Hellweg, S., Koehler, A., and Rieradevall, J.: Assessing the environmental impact of water consumption by energy crops grown in Spain, *J. Ind. Ecol.*, 17, 90–102, 2012.
- Oki, T. and Kanae, S.: Global hydrological cycles and world water resources, *Science*, 313, 1068–1072, 2006.
- Pepsi Co: *Environmental Sustainability Report 2009/10: Path to Zero*, Pepsi Co UK & Ireland, London, 2011.
- Pfister, S. and Hellweg, S.: The water “shoesize” vs. footprint of bioenergy, *P. Natl. Acad. Sci. USA*, 106, E93–94, 2009.
- Pfister, S., Koehler, A., and Hellweg, S.: Assessing the environmental impacts of freshwater consumption in LCA, *Environ. Sci. Technol.*, 43, 4098–4104, 2009.
- ISO Considers Potential Standard on Water Footprint: available at: [http://www.iso.org/iso/isofocusplus\\_bonus\\_water-footprint](http://www.iso.org/iso/isofocusplus_bonus_water-footprint) (last access: 21 June 2012), 2011.

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Raisio's H<sub>2</sub>O Label: available at: <http://www.raisio.com/www/page/4397> (last access: 21 February 2010), 2010.

Rees, W. E.: Ecological footprints and appropriated carrying capacity: what urban economics leaves out, *Environ. Urban.*, 4, 121–130, 1992.

5 Rep, J.: From Forest to Paper, the Story of Our Water Footprint, UPM-Kymmene, Helsinki, 2011.

Ridoutt, B. G. and Huang, J.: Environmental relevance – the key to understanding water footprints, *P. Natl. Acad. Sci. USA*, 109, E1424, doi:10.1073/pnas.1203809109, 2012.

10 Ridoutt, B. G. and Pfister, S.: A revised approach to water footprinting to make transparent the impacts of consumption and production on global freshwater scarcity, *Global Environ. Chang.*, 20, 113–120, 2010a.

Ridoutt, B. G. and Pfister, S.: Reducing humanity's water footprint, *Environ. Sci. Technol.*, 44, 6019–6021, doi:10.1021/es101907z, 2010b.

15 Ridoutt, B. G. and Pfister, S.: A new water footprint calculation method integrating consumptive and degradative water use into a single stand-alone weighted indicator, *Int. J. Life Cycle Ass.*, 18, 204–207, 2013a.

Ridoutt, B. G. and Pfister, S.: Towards an integrated family of footprint indicators, *J. Ind. Ecol.*, 17, 337–339, 2013b.

20 Ridoutt, B. G., Eady, S. J., Sellahewa, J., Simons, L., and Bektash, R.: Water footprinting at the product brand level: case study and future challenges, *J. Clean. Prod.*, 17, 1228–1235, 2009.

Ridoutt, B. G., Williams, S. R. O., Baud, S., Fraval, S., and Marks, N.: The water footprint of dairy products: case study involving skim milk powder, *J. Dairy Sci.*, 93, 5114–5117, 2010.

25 Ridoutt, B. G., Sanguansri, P., Freer, M., and Harper, G. S.: Water footprint of livestock: comparison of six geographically defined beef production systems, *Int. J. Life Cycle Ass.*, 17, 165–175, 2012a.

Ridoutt, B. G., Sanguansri, P., Nolan, M., and Marks, N.: Meat consumption and water scarcity: beware of generalizations, *J. Clean. Prod.*, 28, 127–133, 2012b.

30 Rockström, J., Steffen, W., Noone, K., Persson, Å., Chapin, F. S., Lambin, E. F., Lenton, T. M., Scheffer, M., Folke, C., and Schellnhuber, H. J.: A safe operating space for humanity, *Nature*, 461, 472–475, 2009.

## A critical review of the water footprint concept

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Ruini, L., Marino, M., Pignatelli, S., Laio, F., and Ridolfi, L.: Water footprint of a large-sized food company: the case of Barilla pasta production, *Water Resources and Industry*, online first, doi:10.1016/j.wri.2013.04.002, 2013.

Ruprecht, J. K. and Schofield, N. J.: Analysis of streamflow generation following deforestation in southwest Western Australia, *J. Hydrol.*, 105, 1–17, 1989.

SABMiller and WWF-UK: *Water Footprinting: Identifying & Addressing Water Risks in the Value Chain*, SABMiller and WWF, Woking, 2009.

SABMiller, WWF-UK, and GIZ: *Water Futures: Addressing Shared Water Challenges Through Collective Action*, SAB Miller, Woking, Surrey, 2011.

Sausse, C.: On the water footprint of energy from biomass: a comment, *Ecol. Econ.*, 71, 1–3, 2011.

Seckler, D., Amarasinghe, U., Molden, D., de Silva, R., and Barker, R.: *World Water Demand and Supply, 1990 to 2025: Scenarios and Issues*, Research Report 19, International Water Management Institute, Colombo, 1998.

Siebert, S. and Döll, P.: Quantifying blue and green virtual water contents in global crop production as well as potential production losses without irrigation, *J. Hydrol.*, 384, 198–217, 2010.

Spanish Ministry of the Environment and Rural and Marine Affairs: *Approval of the Water Planning Instruction: Official State Gazette 229*, Government of Spain, Madrid, 2008.

Steen-Olsen, K., Weinzettel, J., Cranston, G., Ericin, A. E., and Hertwich, G.: Carbon, land, and water footprint accounts for the European Union: consumption, production, and displacements through international trade, *Environ. Sci. Technol.*, 46, 10883–10891, 2012.

Tamea, S., Allamano, P., Carr, J. A., Claps, P., Laio, F., and Ridolfi, L.: Local and global perspectives on the virtual water trade, *Hydrol. Earth Syst. Sci.*, 17, 1205–1215, doi:10.5194/hess-17-1205-2013, 2013.

Thaler, S., Zessner, M., de Lis, F. B., Kreuzinger, N., and Fehring, R.: Considerations on methodological challenges for water footprint calculations, *Water Sci. Technol.*, 65, 1258–1264, 2012.

Thomann, R. V. and Mueller, J. A.: *Principles of Surface Water Quality Modeling and Control*, Harper & Row Publishers, 1987.

Unilever: *Our Water Footprint*, available at: <http://www.unilever.com/sustainable-living/water/footprint/> (last access: 21 June 2012), 2012.

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- Van Oel, P. R. and Hoekstra, A. Y.: Towards quantification of the water footprint of paper: a first estimate of its consumptive component, *Water Resour. Manag.*, 26, 733–749, 2012.
- van Oel, P. R., Mekonnen, M. M., and Hoekstra, A. Y.: The external water footprint of the Netherlands: geographically-explicit quantification and impact assessment, *Ecol. Econ.*, 69, 82–92, 2009.
- 5 Vanham, D. and Bidoglio, G.: A review on the indicator water footprint for the EU 28, *Ecol. Indic.*, 26, 61–75, 2013.
- Vanham, D., Mekonnen, M. M., and Hoekstra, A. Y.: The water footprint of the EU for different diets, *Ecol. Indic.*, 32, 1–8, 2013.
- 10 Velasquez, E., Madrid, C., and Beltran, M. J.: Rethinking the concepts of virtual water and water footprint in relation to the production-consumption binomial and the water-energy nexus, *Water Resour. Manag.*, 25, 743–761, 2011.
- Vörösmarty, C., Green, P., Salisbury, J., and Lammers, R.: Global water resources: vulnerability from climate change and population growth, *Science*, 289, 284–288, 2000.
- 15 Vörösmarty, C. J., McIntyre, P. B., Gessner, M. O., Dudgeon, D., Prusevich, A., Green, P., Glidden, S., Bunn, S. E., Sullivan, C. A., Reidy Liermann, C., and Davies, P. M.: Global threats to human water security and river biodiversity, *Nature*, 467, 555–561, 2010.
- Wang, Y., Xiao, H., and Lu, M.: Analysis of water consumption using a regional input-output model: model development and application to Zhangye city, northwestern China, *J. Arid Environ.*, 73, 894–900, 2009.
- 20 Ward, F. A. and Pulido-Velasquez, M.: Water conservation in irrigation can increase water use, *P. Natl. Acad. Sci. USA*, 105, 18215–18220, 2008.
- Water Footprint Network: available at: <http://www.waterfootprint.org> (last access: 21 June 2012), 2012.
- 25 Wichelns, D.: Virtual water and water footprints offer limited insight regarding important policy questions, *Int. J. Water Resour. D.*, 26, 639–651, 2010a.
- Wichelns, D.: Virtual water: a helpful perspective, but not a sufficient policy criterion, *Water Resour. Manag.*, 24, 2203–2219, 2010b.
- Wichelns, D.: Virtual water and water footprints: compelling notions, but notably flawed: reaction to two articles regard the virtual water concept, *GAIA*, 20, 171–175, 2011a.
- 30 Wichelns, D.: Do the virtual water and water footprint perspectives enhance policy discussions?, *Int. J. Water Resour. D.*, 27, 633–645, 2011b.



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Witmer, M. C. H. and Cleij, P.: Water Footprint: Useful for Sustainability Policies?, PBL Netherlands Environmental Assessment Agency, The Hague, 2012.

WWF: Living Planet Report 2012, WWF International, Gland, Switzerland, 2012.

5 Yu, Y., Hubacek, K., Feng, K., and Guan, D.: Assessing the regional and global water footprints for the UK, *Ecol. Econ.*, 69, 1140–1147, 2010.

Zhang, Z., Yang, H., and Shi, M.: Analyses of water footprint of Beijing in an interregional input-output framework, *Ecol. Econ.*, 70, 2494–2502, 2011.

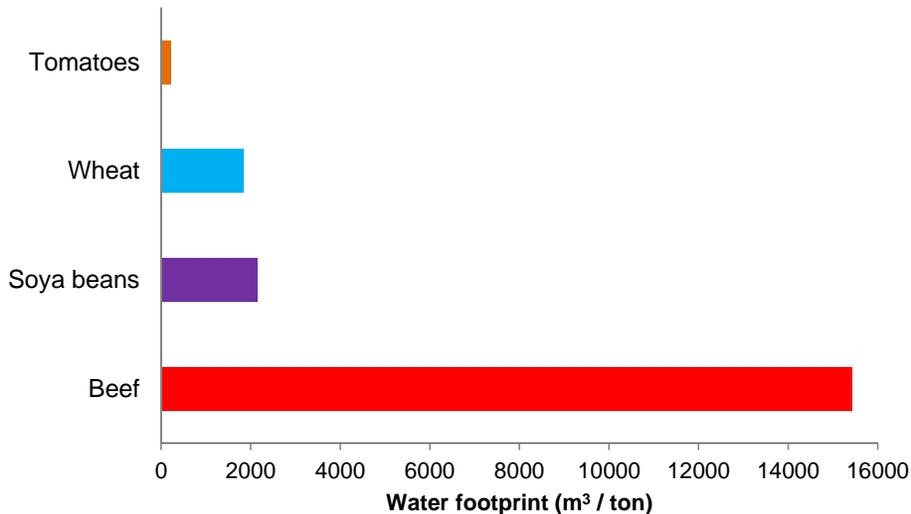
10 Zhang, Z., Shi, M., and Yang, H.: Understanding Beijing's water challenge: a decomposition analysis of changes in Beijing's water footprint between 1997 and 2007, *Environ. Sci. Technol.*, 46, 1273–12380, 2012.

Zhao, X., Chen, B., and Yang, Z. F.: National water footprint in an input-output framework – a case study of China 2002, *Ecol. Model.*, 220, 245–253, 2009.

15 Zhao, X., Yang, H., Yang, Z., Chen, B., and Qin, Y.: Applying the input-output method to account for water footprint and virtual water trade in the Haihe River Basin in China, *Environ. Sci. Technol.*, 44, 9150–9156, 2010.

Zoumidis, C., Bruggeman, A., and Zachariadis, T.: Global versus local crop water footprints: the case of Cyprus, in: Proceedings of the Session “Solving the Water Crisis: Common Action Toward a Sustainable Water Footprint”, Planet under Pressure Conference, London, 26 March 2012, 7–27, 2012.

20 Zoumidis, C., Bruggeman, A., Zachariadis, T., and Pashiardis, S.: Quantifying the poorly known role of groundwater in agriculture: the case of Cyprus, *Water Resour. Manag.*, 27, 2501–2514, 2013.



**Fig. 1.** The water footprint of selected agricultural products. Data source: Mekonnen and Hoekstra (2012b). Note that these are average global values which show considerable variability from place to place depending on climate and agricultural efficiency (Hoekstra and Chapagain, 2008).

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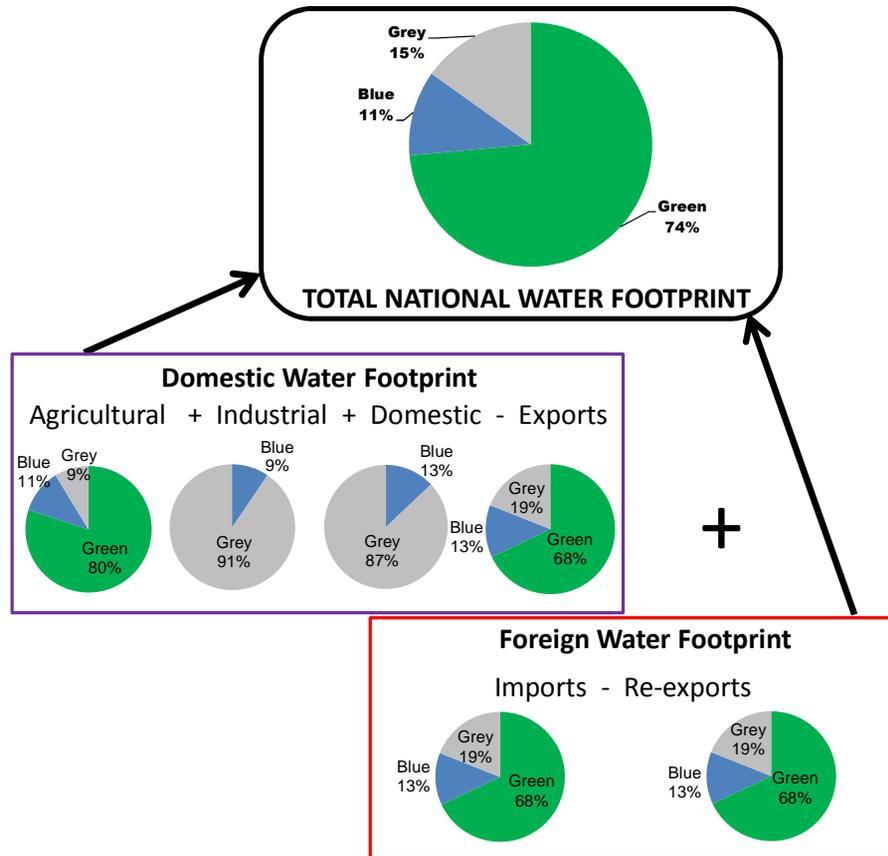
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**Fig. 2.** The composition of a national water footprint. It is composed of domestic goods and services plus imports (incoming water) minus exports (outgoing water). Each of these has green/blue/grey components. Data are from Hoekstra and Mekonnen (2012b) and show global averages to illustrate differences in water composition.

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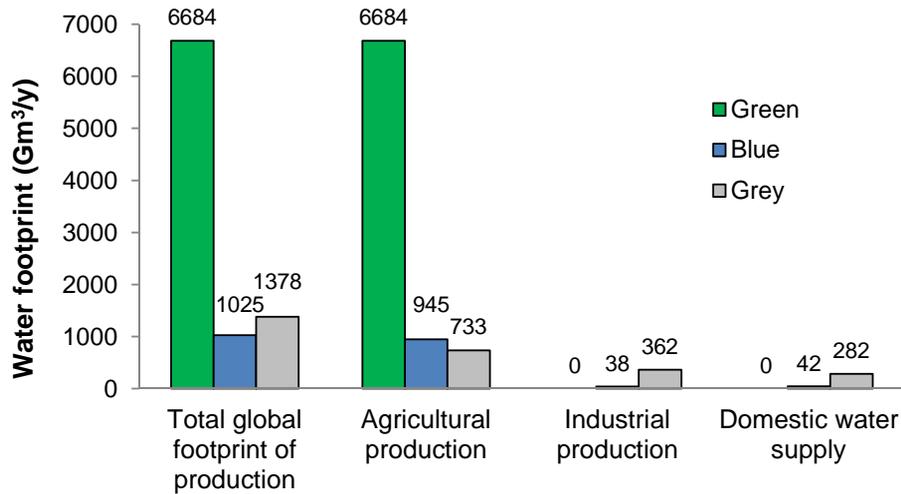
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**Fig. 3.** The composition of the global water footprint for 1996–2005. (Data are from Hoekstra and Mekonnen, 2012b.) Regardless of how these diagrams are drawn they highlight the well-known fact that agriculture dominates global water consumption.

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