AE484

What is a Water Footprint?: An Overview and Applications in Agriculture[1]

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Introduction

A water footprint is a comprehensive measure of freshwater consumption that connects consumptive water use to a certain place, time, and type of water resource. A water footprint can be calculated for a pound of wheat, a jar of pasta sauce, a barrel of oil, a pair of jeans, a person, or a country by following accounting practices that have been standardized by the Water Footprint Network (Hoekstra et al. 2011). The calculation for a water footprint includes the total amount of freshwater consumed along the supply chain of a product. A water footprint differs from the typical measure of water use, water withdrawals, because a water footprint only accounts for consumptive water use, which is water that becomes unavailable locally in the short term due to evaporation or quality decline.

Also, a water footprint accounts separately for three types of freshwater consumption: (1) green water use, which is consumption from rainfall; (2) blue water use, which is consumption from groundwater or surface water; and (3) grey water use, which would be the dilution water required to reduce pollutant concentrations to acceptable values. This distinction among green, blue, and grey water footprints recognizes that the consumptive use of rainfall, groundwater or surface water, and the water quality impacts have different economic costs and ecological impacts.

Agriculture is by far the largest global consumer of freshwater. In this sector, a water footprint measures the volume of evapotranspiration (ET) or water use of a crop per unit mass of yield. Comparing water footprints of different management practices in agriculture can help evaluate drought tolerance, water use efficiency, the effective use of rainfall, and the significance of irrigation. Presently, there is much discussion and research concerning adaptation of agricultural systems to a changing climate, but there are few metrics that can compare the resilience of different systems. Many of the risks agriculture faces from climate change are the result of precipitation changes, which makes the water footprint a useful measure to compare resilience of agricultural systems to droughts and dry spells.

Water Footprint Examples

A water footprint can be calculated for almost anything – a product, a person, or a land area. The following list presents five examples of basic units that can be used to calculate water footprints. These types of water footprints are closely related; for example, the water footprint of a product is the sum of the water footprints of each process step required to make the product. Similarly, a consumer's water footprint consists of the sum of the water footprints of every product used by the consumer. See the section "Calculating a Water Footprint" in this publication for details on how to calculate these water footprints.

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- **Process step:** The water footprint of a process step is the fundamental unit of water footprint accounting. It is used in calculating a product water footprint in order to identify specific processes where reductions in consumptive water use could be made.

- **Product:** The water footprint of a product can be used to give consumers information about the water-related impacts of products they use or to give policy makers an idea of how much water is being "traded" through imports and exports.

- **Consumer:** The water footprint of a consumer (or group of consumers or a business) is useful for illustrating what parts of a lifestyle have the biggest impacts on water use. Typically, calculating the water footprint of a consumer demonstrates that a person's diet has the biggest impact on their water footprint.

- **Land area (county, watershed, or nation):** The water footprint of a land area helps to account for consumptive water use inside and outside of an area. This allows us to account for the "trade" in water through the trade in agricultural products. For example, the United States has the highest per capita total water footprint of any nation (2,480 m^3 water/person/year compared to 700 m^3 water/person/year for China). However, the U.S. is by far the leading exporter of water because of the large amount of agricultural exports.

- **Crop:** The water footprint of a crop can be used to compare consumptive water use among different agricultural systems in different regions, or it can be used at a farm level to compare water use between management practices. A crop water footprint could also be used to evaluate drought tolerance of a management system.

Defining Terms Related to Water Footprints

Consumptive water use describes freshwater that (1) evaporates, (2) is incorporated into a product, (3) is contaminated, or (4) is not returned to the same area where it was withdrawn. All four uses result in water being unavailable for local, short-term reuse. This term recognizes both the renewability of freshwater and its limited availability in a certain time period and location. Evaporation is often the most significant consumptive water use, and it will often be equated with total water use as the other three components are negligibly small by comparison. The term evapotranspiration (ET) is used to describe the combined evaporation of water from soil surfaces and the transpiration from plants. ET represents water use of an agricultural or forestry crop.

Water footprint is the ratio of the volume of consumptive water use (green, blue, and grey) to the quantity of interest (liters/kg for a crop, liters/person/year for a consumer, m^3/year for a land area, or liters/pair of jeans for a product). Ratios do have a tendency to hide information, so in some cases it may be appropriate to present both the numerator and denominator alongside the water footprint.

Water footprint units depend on what is being studied in the water footprint. Volumes of green, blue, and grey water are always in the numerator, but it may be time, mass, people, or units in the denominator. It should be noted that time is always implicitly included in the ratio whether it is shown or not because consumptive water use happens during some specified time. Here is an example from agricultural water footprinting: The yield of a crop is measured over some area (kg/ha), and ET is usually accounted for as a depth (mm). In this example, both yield and ET are based on a set time period (about 120 days for annual row crops), which is not shown in the yield or ET numbers and would cancel out in the combination of yield and ET into the water footprint ratio. Also, the units of area cancel out when ET depth is converted to volume by multiplying by the same area that is in the denominator of the yield value. Handling the units appropriately gives ET in liters/ha or whatever volume unit is preferred. The water footprint is then the ratio of ET volume to crop yield: liters/ha / kg/ha, or simply liters/kg. See the section "Calculating a Water Footprint" for more details on calculation methods.

Green water use describes the evaporation/transpiration ($\text{Evaporation}_{\text{green}}$) or the incorporation into a product of water directly from rainfall before it becomes runoff or drainage ($\text{Incorporation}_{\text{green}}$). A green water footprint is simply the volume of green water used divided by the quantity of interest (mass, number of products, area, etc.). The green water resource is rainfall. The green water footprint of the most basic quantity of interest, a single process step, can be expressed by the following equation:

$$\text{WF}_{\text{process,green}} = \text{Evaporation}_{\text{green}} + \text{Incorporation}_{\text{green}}$$

[volume/time].

The separation of a water footprint into green, blue, and grey portions is significant because the economic and environmental costs can be extremely different among the three water uses. For example, the opportunity cost of blue water use is generally high, meaning that the best foregone alternative water use is of high value. The direct economic cost of consuming blue water is also high when compared to the direct economic cost of consuming green water. Irrigation requires infrastructure and energy that are not necessarily required to use rainfall effectively.

Blue water use describes the evaporation/transpiration ($Evaporation_{blue}$), incorporation into a product ($Incorporation_{blue}$), or return flow discharged to a distant area ($Lost\ Return\ Flow_{blue}$) of blue water resources, which are surface water or groundwater. A blue water footprint is the volume of total blue water use divided by the quantity of interest (mass, number of products, area). The blue water footprint of a single process step can be expressed by the following equation:

$$WF_{process,blue} = Evaporation_{blue} + Incorporation_{blue} + Lost\ Return\ Flow_{blue}$$

[volume/time].

Grey water describes the water required to dilute contaminants from a system to an acceptable concentration (Hoekstra et al. 2009). This can be expressed as the ratio of contaminant load (L: mass during some time) to the difference between the maximum ($c_{maximum}$) and the natural ($c_{natural}$) contaminant concentrations:

$$WF_{process,grey} = L / (c_{maximum} - c_{natural})$$

[volume/time].

The maximum concentration is the highest allowable concentration for the water body of interest, based on water quality regulations or estimated standards. The natural concentration is the expected contaminant concentration of the water body receiving the load if there were no impacts by humans in the basin. A grey water footprint is the volume of total grey water use divided by the quantity of interest (mass, number of products, area).

The grey water footprint is obviously quite different from the evaporative blue and green water footprints. Blue and green water use is the amount of water that is actually used within the system under consideration, while grey water use is a measure of water contamination and should be understood to be a water quality indicator and not a direct measure of water use.

Virtual water, also called embedded or exogenous water, is similar to a water footprint, but it has a somewhat narrower meaning. Virtual water is the aggregated water volume that was consumed in the production of some product, but it

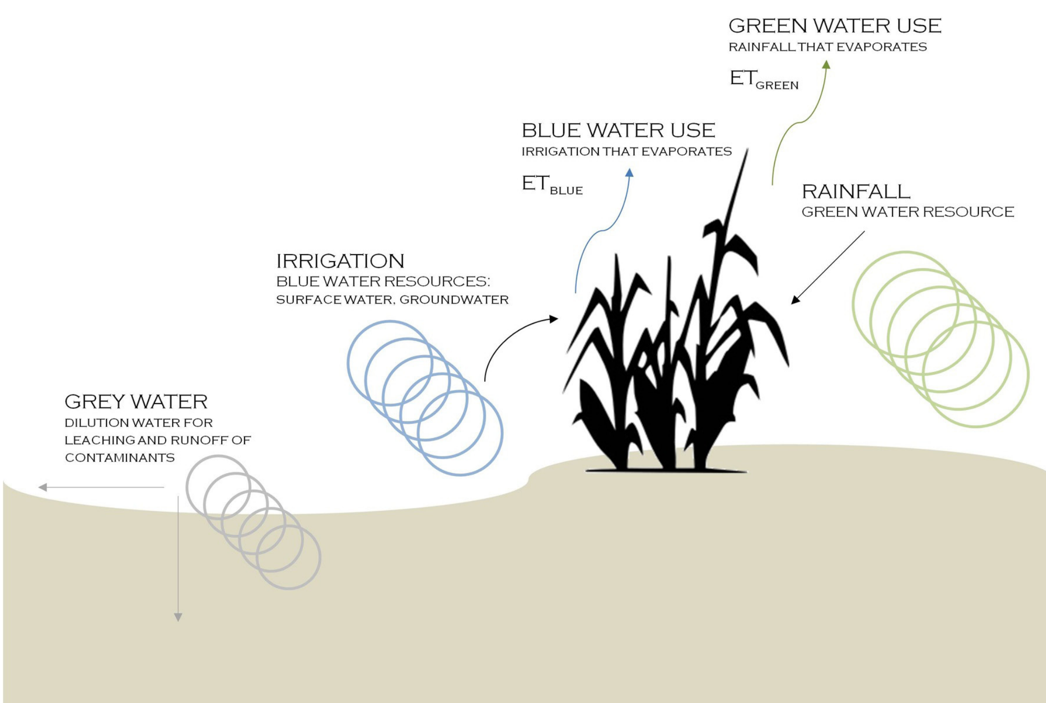

Figure 1. Green, blue, and grey water flows in an agricultural system.

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does not include the distinction between green, blue, and grey water.

History of Water Footprints

John Anthony Allan, of King's College London, first expressed the concept of virtual water in the early 1990s in the context of the water-scarce Middle East and North African countries' export of citrus to the European Union. These irrigated exports were important economically, but the virtual water accounting helped accomplish a careful evaluation of the water that was being virtually exported in the citrus. The term "virtual" is used because the total consumptive water used in citrus production is very large compared to the actual water content of the fruit.

Arjen Hoekstra expanded the virtual water concept to develop the water footprint, which adds the important distinction between consumption of surface water and groundwater (blue water use) and consumption of rainfall (green water use). Including a grey water footprint also allows for water quality impacts to be taken into account. A water footprint can be defined much like an ecological footprint. While an ecological footprint is the bioproductive area required to support a population, a water footprint is the volume of consumptive water used to support a population. Calculating water footprints helps communicate the global nature of freshwater. Water scarcity can only be measured locally, but accounting for the water footprints of products means that the amounts of water being "traded" can be monitored (for example, we can look at the trade in agricultural products and the water footprint of those products for the water being "traded"). The Water Footprint Network (www.waterfootprint.org) is an international organization with the goal of promoting and standardizing the accounting of direct and indirect water use of producers and consumers. The organization has published the only manual to standardize water footprint accounting (Hoekstra et al. 2011).

Calculating a Water Footprint

A water footprint assessment in its most complete form will follow four separate steps:

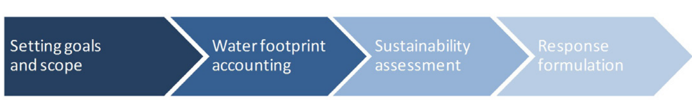

Figure 2. The four steps of water footprinting.

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Following the methods standardized by the Water Footprint Network (Hoekstra et al. 2011), the procedures for water footprint accounting of a process step, an agricultural crop, a product, a consumer, and a land area are summarized here.

Process Step Water Footprint

A process step water footprint is a fundamental unit of water footprint accounting. The higher level water footprints such as that of a product (a bag of potato chips, for example) consist of the total of numerous process step water footprints. The aggregated total water footprint of a process step is simply the sum of the green, blue, and grey water uses (as defined in the above terminology section) that result from the process:

$$WF_{process} = WF_{process,green} + WF_{process,blue} + WF_{process,grey}$$

[volume/time].

While the aggregate water footprint gives a single number for easy comparisons, it is recommended that the separate green, blue, and grey water footprints be presented because they have different economic and environmental costs.

Product Water Footprint

Examples of product water footprints for selected beverages are given in Figure 3. A product water footprint is calculated by adding all the process step water footprints of a product (Hoekstra et al. 2011):

$$WF_{product} = \frac{\sum_{i=1}^{n} WF_{process,i}}{P\ [quantity]}$$

[volume/product unit],

where $WF_{process,i}$ is the water footprint of an individual process in the production chain of some product, P. Most production systems have multiple product outputs; therefore, to avoid double counting using the simple $WF_{process,i}$ summation, a broader and more realistic approach is needed. To calculate the water footprint of output product(s) $p = 1$ to m, being dependent on $k = 1$ to n input products, the following expression is used (Hoekstra et al. 2011):

$$WF_{product} = WF_{process} + \frac{\sum_{k=1}^{n} WF_{product,p}}{f_p[p,k]} * f_v[p]$$

[volume/product unit],

where $WF_{product}$ is the output product water footprint, $WF_{process}$ is the water footprint of the process required to transform the input product, $WF_{product,p}$ into the m output products, $f_p[p,k]$ is the quantity of output product q[p] per unit input product q[k], and $f_v[p]$ is the ratio of the market value of an output product price[p] to the total market value of all the *m* output products made from the n input products.The product fraction, $f_p[p,k]$, and the value fraction, $f_v[p]$, are expressed as follows:

$$f_p[p,k] = \frac{q[p]}{q[k]}$$

and

$$f_v[p] = \frac{price[p]*q[p]}{\sum_{i=1}^{z}(price[p]*q[p])} .$$

Data on process-step water use and the product and value fractions for a specific product can usually be found in the scientific and marketing literature. The available data on water use of process steps will often be total water withdrawals; some adjustment will be required to estimate consumptive water use based on withdrawals. The examples of packaged beverages in Figure 3 reflect U.S. averages; the water footprints of a bottle of milk, orange juice, or soft drink will vary widely. Most of the variability results from differences in the location and management of the agricultural systems that produce the major inputs of the products.

Alternative uses of the agricultural residues from the major inputs can result in small reductions in water footprints as some portion of the consumptive water use from crop growth is attributed to another product. For example, orange peels are not used in juice production, and there are culinary uses of orange peel that would be assigned an economic value relative to the value of the juice from the fruit. This value would be used to assign some portion of the total water footprint of orange production to the alternative use of orange peel. In any case in which an input product is used for more than one output product, the relative economic values, based on output products, are used to assign the appropriate consumptive water use to various products.

Consumer Water Footprint

The water footprint of a consumer consists of the total direct and indirect consumptive water uses. Examples of direct use include drinking, washing, household irrigation, and others. Examples of indirect water use, which is the large majority of a consumer water footprint, include the water used to produce the food, energy, clothing, paper, and other products used by a consumer. A consumer water footprint can be expressed by the following equation:

Figure 3. Example of product water footprints, with relative green, blue, and grey proportions, including crop growth, processing, and packaging for milk, orange juice, and soft drinks. The value for milk production is a weighted U.S. average of grazed, industrial, and mixed dairies; the value for orange juice is a U.S. average; and the value for soft drinks includes the average water use of sugarcane grown in the U.S. (Mekonnen and Hoekstra 2010b).

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$$WF_{consumer} = WF_{direct} + WF_{indirect}$$

[volume/time].

There are numerous web-based water footprint calculators that consumers can use to calculate their water footprint. One good example is provided by National Geographic at http://environment.nationalgeographic.com/environment/freshwater/water-footprint-calculator/.

Land Area Water Footprint

The water footprint of a land area, which may be a county, state, country, or river basin, is calculated as the sum of all the process water footprints (i = 1 to n) in the area:

$$WF_{area} = \sum_{i=1}^{n} WF_{process,i} .$$

Land area water footprints are often used in the accounting of national or regional “trade” in water. This trade in virtual water is the exchange of products that are represented by the consumptive water volumes required to produce them. For example, the United States exports about 26 million metric tons of wheat each year, and the aggregate water footprint required to produce that much wheat is about 570 billion cubic meters (Mekonnen and Hoekstra 2010a). The virtual water balance of an area can be calculated as the difference between gross virtual water imports and gross virtual water exports. This approach should be used in land area water footprinting to reduce the water footprint of an area based on exports and increase the water footprint of an area based on imports of products or water. The national water footprints of several countries are shown in Figure 4.

Crop Water Footprint

Agriculture is responsible for about 85% of all global, consumptive freshwater use (Hoekstra and Chapagain 2007). The water footprints of specific management systems can be important tools for considering water conservation impacts from a variety of farm management options. For example, changes in irrigation management, tillage, crop selection, and rotations can all have meaningful impacts on farm-level water footprints. The water footprint of a crop is a special case of a process water footprint, and it is similarly calculated as:

$$WF_{crop} = WF_{crop,green} + WF_{crop,blue} + WF_{crop,grey}$$

[volume/mass],

where

$$WF_{crop,green} = \frac{ET_{green}[\text{volume/area}]}{\text{Yield [mass/area]}};$$

$$WF_{crop,blue} = \frac{ET_{blue}[\text{volume/area}]}{\text{Yield [mass/area]}};$$

and

$$WF_{crop,grey} = \frac{\frac{L}{c_{maximum} - c_{natural}}[\text{volume/area}]}{\text{Yield [mass/area]}}.$$

A noticeable difference between process and crop water footprints is the units expressed in volume per unit mass (often liters/kg or, equivalently, m^3/ton). Both time and area are included implicitly in the calculation of a crop water footprint. The yield of a system is usually measured in mass per unit area, and the yield is produced during some time (typically around 4–6 months for most annual crops). Yield may be simulated using a crop growth model, or it may be input based on recorded data at the appropriate location. Also, green and blue evapotranspiration (ET) are measured in units of depth (mm), and converting these units of depth requires multiplication of ET depth by the area used to measure yield (hectare or acre), giving ET in units of volume/area. The crop under consideration could be any agricultural or forestry product from either annual or perennial systems.

Another difference between process and crop water footprints is the absence of water incorporated into the crop for the crop water footprint. This would be included in the numerator of the green and blue crop water footprint calculations, but it is safe to assume the incorporated

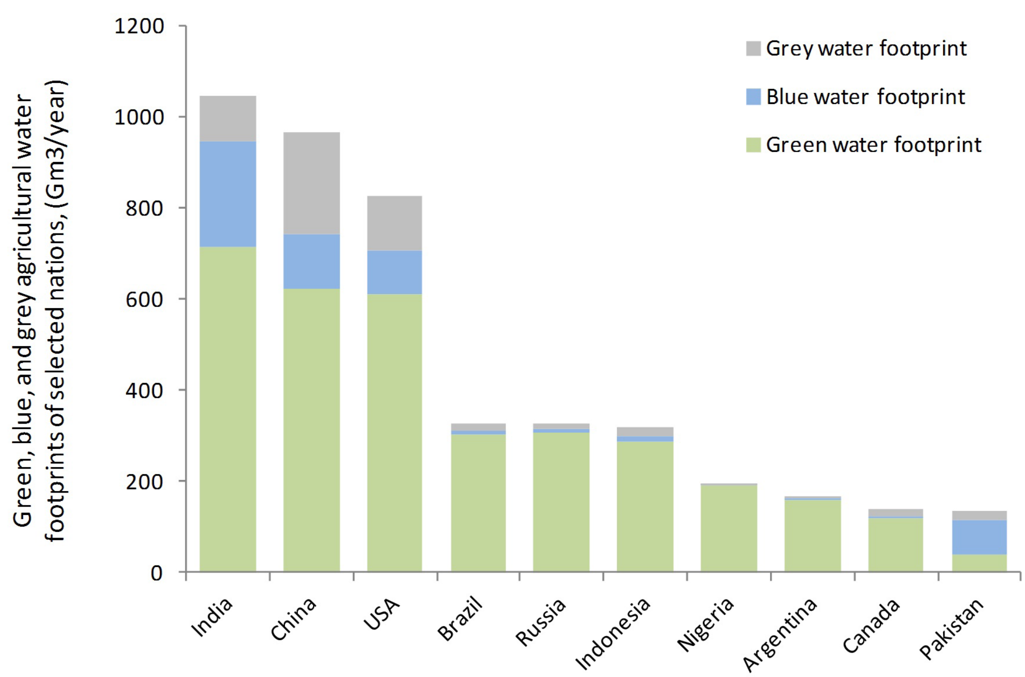

Figure 4. Agricultural production water footprints of selected countries (Gm^3/year) from 1996-2005 data (Mekonnen and Hoekstra 2010b).

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water is negligible when compared with the amount of ET. Even for fruits and vegetables having a harvested moisture content of 80%–95%, the amount of water incorporated into the crop is less than 1% of total ET (Hoekstra et al. 2011). However, the moisture content of crops is included implicitly in the denominator.

The yield in the denominator of the water footprint components is the yield at standard, marketable moisture content. Therefore, if a yield is measured in a field based on a grain that was harvested above marketable moisture content, the yield value should be adjusted downward to account for the grain drying needed prior to marketing the crop. The different moisture contents and yields of grains, legumes, fruits and vegetables, stimulants, and others mean that comparisons of water footprints among different types of crops are sometimes inappropriate or misleading because of the differences in moisture contents among groups of crops.

SIMULATING EVAPOTRANSPIRATION

Both the estimation of ET and the separation into ET_{green} and ET_{blue} generally require the use of water and energy balance models. ET can be measured, but the instrumentation required to measure ET is expensive and the measurement is only valid for a small area under specific management. ET estimates for a variety of climate regimes, seasons, crops, and management require the use of mathematical models that account for the environmental demand of the atmosphere. These models are based on the physics of heat transfer, measured weather variables, and the physical properties of the crop and management system, based on crop type, growth stage, irrigation, and tillage management. Crop ET (ET_c) is often estimated by multiplying a growth-stage-dependent crop coefficient (K_c) by a measure of reference evapotranspiration (ET_o), giving $ET_c = K_c * ET_o$ (Allen et al. 1998).

SEPARATING BLUE AND GREEN ET

As with estimating ET, the separation of ET into blue (from irrigation) and green (from rainfall) components requires the use of mathematical models because the required instrumentation to observe the separation is too expensive to be practical in most situations. ET_{green} is the depth of rainfall that stays in the plant root zone that is available for use by the plant. It can be referred to as effective rainfall $P_{effective}$, and it is expressed by the following equation:

$$P_{effective} = P - RO - DP$$

[depth/time],

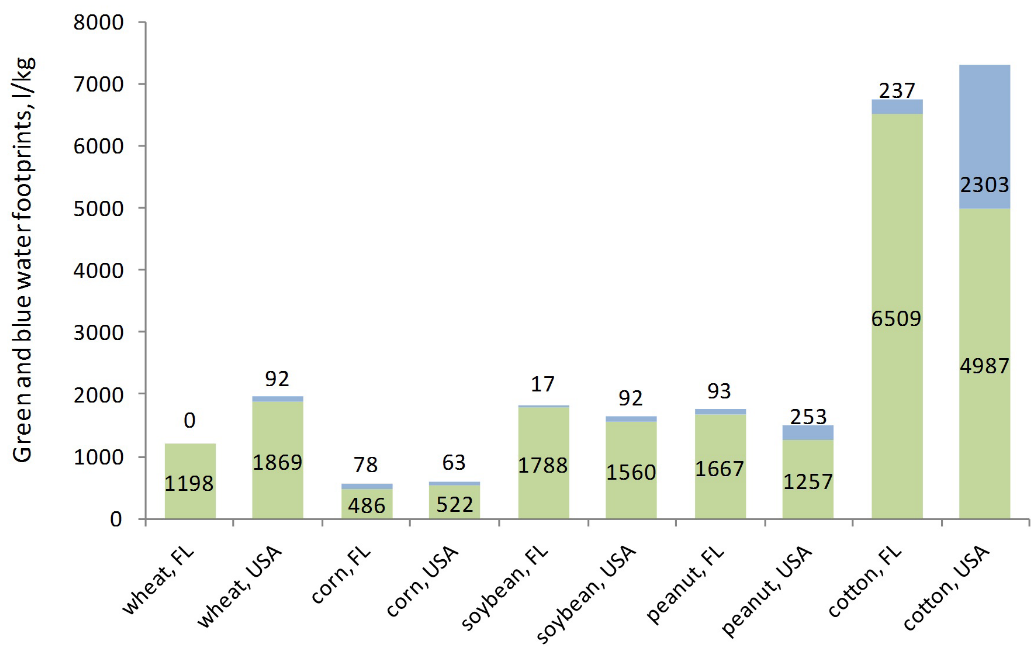

Figure 5. Green and blue water footprint averages of selected crops in Florida and the whole U.S. (Mekonnen and Hoekstra 2010b) during 1996-2005.

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where P is total rainfall, RO is runoff of excess rainfall, and DP is deep percolation or drainage below the root zone of excess soil water. $P_{effective}$ can be estimated using a variety of models. Two examples are the empirical USDA SCS method (United States Department of Agriculture, Soil Conservation Service; USDA, SCS 1967) or a physically based soil-water balance model, like that of a hydrology (SWAT; Arnold et al. 1998) or crop model (EPIC; Williams et al. 1989). Having an estimation of effective rainfall, green and blue ET can be calculated as follows (Hoekstra et al. 2011):

$$ET_{green} = \min(ET_c, P_{effective})$$

[depth/time]

and

$$ET_{blue} = ET_c - ET_{green}$$

[depth/time].

As in the calculation for the process step water footprint, it is suggested that the three water footprint components be presented separately and not only as an aggregated sum.

Figure 5 shows the Florida and U.S. national average blue and green water footprints for wheat, corn, soybean, peanut, and cotton (Mekonnen and Hoekstra 2010b). The figure illustrates the importance of green water use and ET of rainfall, which is not accounted for in traditional water use measures. The global water footprint of crop production is 7,404 billion m^3/year (Mekonnen and Hoekstra 2011), of which 78% is from rainfall (green water), 12% is from freshwater resources (blue water), and 10% is grey water.

A surprising result of separating green and blue water footprints is that the total water footprints of many irrigated crops are actually less than that of rainfed crops (Table 1). This can happen because the yields of irrigated crops increase more than the associated ET increase, and the water footprint as a ratio of ET volume to yield mass can show similar or lower total water footprints for irrigated crops compared to rainfed crops. However, the blue water footprint of rainfed crops is zero, and it is consumption of blue water that typically has more important environmental impacts and greater competition for its use.

TOOLS FOR ESTIMATING CROP WATER FOOTPRINT

As mentioned earlier, simulating ET is usually a requirement for water footprint accounting in agriculture. The mostly commonly used tools for simulating crop yield and ET at a variety of spatial scales are EPIC (Williams et al. 1989), GEPIC (Liu et al. 2007), CROPWAT (FAO 2010a), and AQUACROP (FAO 2010b). These crop growth models require some additional programming to separate green, blue, and grey water and to do the unit conversion and ET/yield ratios required for a water footprint.

Table 1. Water footprints of irrigated and rainfed systems for selected crops based on averages from 1996-2005 climate data. Wheat, corn, and rice are the three leading contributors to the global agricultural water footprint. Sugar crops have one of the lowest water footprints in agriculture.

Crop	Farming system	Yield (ton/ha)	Annual total water footprint (Gm^3/year)				Water footprint (liters/kg)			
			Green	Blue	Grey	Total	Green	Blue	Grey	Total
Wheat	Rainfed	2.48	610	0	65	675	1629	0	175	1804
	Irrigated	3.31	150	204	58	412	679	926	263	1868
	Global	2.74	760	204	123	1087	1278	342	208	1828
Corn	Rainfed	4.07	493	0	85	578	1082	0	187	1269
	Irrigated	6.01	104	51	37	192	595	294	212	1101
	Global	4.47	597	51	122	770	947	81	194	1222
Rice	Rainfed	2.69	301	0	30	331	1912	0	190	2102
	Irrigated	4.67	378	202	81	661	869	464	185	1518
	Global	3.90	679	202	111	992	1146	341	187	1674
Sugarcane	Rainfed	58.70	95	0	7	102	164	0	13	177
	Irrigated	71.17	85	74	10	169	120	104	14	238
	Global	64.96	180	74	17	271	139	57	13	209

Data adapted from Mekonnen and Hoekstra (2010b).

What's the Purpose of a Water Footprint?

All the above water footprint calculation summaries focus on step two (water footprint accounting) in the four steps of a water footprint. This section focuses on the steps after the actual water footprint accounting, which involves assessing sustainability and formulating a response after the water footprint is calculated. To begin, let's get back to the basics of why freshwater use is measured at all. We monitor freshwater use because, despite its renewability, its availability is limited in space and time. In order to sustain human populations, a certain amount of consumptive water use is needed, estimated at about 1,300 m^3/year/person (Rockström et al. 2009). Water footprinting provides a way to account for what types of freshwater resources are used (rainfall, surface water, or groundwater) and where they are used.

Blue water resources, including lakes, rivers, and groundwater resources, are replenished at a rate determined by atmospheric and landscape characteristics. The available green water resource (or the amount of rainfall that is consumptively used) depends on rainfall during some time period and the partitioning of that rainfall into green and blue flows, which is determined by land management and landscape characteristics. Sustainability of blue water use can be evaluated by comparing a blue water footprint of some area [volume/time] with the estimated renewal rate of the blue water resource(s). This has been done on a global scale, and it was estimated that up to 25% of consumptive uses of irrigation water are unsustainable (Rost et al. 2008), meaning they exceed local renewal rates.

The complementary nature of blue water use and green water use has important management implications. For example, if the blue water footprint of some agricultural system is found to be substantially larger than the renewal rate of blue water resources, then an expansion of green water use may be evaluated as a way to satisfy crop water requirements while reducing the blue water footprint.

Green water use in global agriculture is important because making rainfall more productive – that is, increasing the green water use – shows great potential for providing the increased consumptive water use required to increase agricultural production (Rockström et al. 2009). The following table (Table 2) summarizes some options for reducing the blue water footprint by increasing productive use of rainfall. It is important to note that in rainfed systems there is no complementary blue water use decrease to accompany an increase in green water flow. Also, the expected changes in water footprints [volume/mass yield] resulting from management changes should be evaluated based on observed or modeled data; an increase in green water use (ET_{green}) might actually result in a lowered green water footprint if there are sufficient yield increases accompanying the increased ET.

Evaluating Sustainability

Deciding whether green water use in some basin is sustainable should start by assessing how much green water is available, which can be estimated by this equation (Hoekstra et al. 2011):

$$WA_{green}[x,t] = ET_{green}[x,t] - ET_{environmental}[x,t] - ET_{unproductive}[x,t]$$

[volume/time],

where $WA_{green}[x,t]$ is the total available green water in some basin x during some time t, $ET_{green}[x,t]$ is the total evapotranspiration of rainfall in the basin, $ET_{environmental}[x,t]$ is the evaporative flow of rainfall reserved for natural ecosystems, and $ET_{unproductive}[x,t]$ is the evaporative flow of rainfall in the areas of the basin unsuitable for agriculture. Similarly, blue water availability can be estimated as follows:

$$WA_{blue}[x,t] = Rainfall\ [x,t] - ET_{green}[x,t] - EFR[x,t]$$

[volume/time],

Table 2. Examples of management for increasing green water use in order to reduce blue water use.

Management options	Green water use	Blue water use
Water harvesting: tillage or reservoirs/ponds	↑	↓
Reduced or zero tillage	↑	↓
Contour planting	↑	↓
Terracing	↑	↓
High residue cover crops	↑	↓
Rotations with perennials	↑	↓
Variable-rate irrigation application		↓
Soil-moisture or ET-based irrigation controllers		↓

where $WA_{blue}[x,t]$ is the total available blue water in some basin *x* during some time *t*, Rainfall [x,t] is the amount of precipitation, $ET_{green}[x,t]$ is the total evapotranspiration of rainfall in the basin, and EFR[x,t] is the environmental flow requirement, which is the surface runoff and groundwater recharge required to maintain the ecosystems that depend on those flows. These water balances can give rough estimates of how much green and blue water can be used sustainably.

Example Applications

The following list summarizes some applications of water footprint accounting:

- Making comparisons of consumptive water use among different agricultural management systems: For example, converting a rainfed system to no-tillage may decrease the water footprint as there may be an increase in infiltration of rainfall and a reduction in non-beneficial soil evaporation. However, in some soil types, compaction problems could increase the water footprint because of reduced crop yields. Adding a high-residue cover crop that slowly increases soil organic matter may increase ET while actually lowering the water footprint because of yield increases.

- Evaluating drought tolerance of agricultural management systems: When comparing different management strategies, a lower water footprint in a low-rainfall or a highly variable rainfall situation suggests higher water use efficiency (WUE), which is the ratio of yield or biomass to volume of ET.

- Comparing management systems in different regions/climates: Regional comparisons of water footprints of some crops may suggest that production should be shifted to an area where production would have a lower water footprint.

- Building resilience to climate change: Estimating the impacts on agriculture resulting from predicted and observed changes in climate can be made using water footprints, which include information about yield and water use connected to place and time. For example, increasing rainfall variability in rainfed systems may result in an increased water footprint due to reduced yields unless management changes are able to reduce the impacts of dry spells.

- Analyzing public policies that may affect water use: One example is evaluating industrial and agricultural policies using water footprints and some measure of water scarcity. Water footprinting has shown that an estimated 350 billion m^3/year are saved as an unintended result of international food trade (Chapagain, Hoekstra, and Savenije 2006).

- Evaluating basin-level sustainability: Water footprinting provides more complete information (both green and blue consumptive use) in comparison to considering only total water withdrawals.

- Connecting consumption to place: The water footprint of a cotton T-shirt in the U.S. may be based on consumptive water use in China and Malaysia.

- Labeling products to increase awareness of water use: Providing a water footprint label on food products could give consumers more information about the size and location of a product's water footprint.

Conclusion

The strength of water footprint accounting is that it measures consumptive water use of different types, including green, blue, and grey water, and then it connects those water uses to a specific place and time. This recognizes the renewability of freshwater, but also emphasizes the need to use it efficiently because of its limited availability in an area during some time. Water footprinting can provide even more information when it is used alongside some measure of water scarcity. For example, consider cotton grown in Arizona compared with that grown in north Florida. Total water footprints are about the same, but the per capita renewable freshwater is much lower in Arizona. That is an important consideration when using water footprints to evaluate the hydrologic sustainability of a system. Finally, it is suggested to always make the distinction between consumptive use of rainfall (green water use) and of groundwater or surface water (blue water use) because this separation between water of different value is an important part of water footprinting.

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