Commentary: On the water footprint as an indicator of water use in food production

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The water footprint (WF), defined as the volume of water used per unit food produced, is becoming a popular indicator in a variety of assessments that relate food production to water use. The complexities underlying the phrase “water used” already point to the difficulties in computing an indicator with robust and general meaning. The Water Footprint organization defines three components of water use¹:

Green water footprint is water from precipitation that is stored in the root zone of the soil and evaporated, transpired or incorporated by plants.

Blue water footprint is water that has been sourced from surface or groundwater resources and is either evaporated, incorporated into a product or taken from one body of water and returned to another, or returned at a different time. Irrigated agriculture, industry and domestic water use can each have a blue water footprint.

Grey water footprint is the amount of fresh water required to assimilate pollutants to meet specific water quality standards.

These definitions embody many uncertainties:

- If the baseline is the water use of the natural ecosystem, the so-called “green” footprint of a crop may actually be less than the water consumption of native vegetation. In this case, downstream water availability is actually increased by rainfed agriculture.
- The water consumed by an irrigated crop is often a complex mix of residual soil moisture from previous “green” rainfall events or “blue” irrigation deliveries. Rainfall that occurs just after an irrigation event will tend to cause runoff or deep percolation; irrigation after rainfall will have similar effects. Is the water consumed by the crop green or blue? Hydropower dams are massive consumers of “blue” water, because water delivery downstream is at a “different time”. Water delivered through a canal head powerhouse to irrigated areas would be counted as “blue” as it went through the generators, and “blue” again when consumed by the crop.
- The total water consumption of a crop (“blue” plus “green”) is computed as the maximum potential crop ET, which is often significantly higher than actual crop ET. This error may be particularly serious in rainfed systems of low productivity which, when attributed a consumption equivalent to maximum ET, would have huge WFs.
- Where pollution is severe, the “grey” footprint may exceed the water available in the basin for dilution—yet be reduced to zero if a suitable treatment plant is installed.

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¹ <http://waterfootprint.org/en/water-footprint/what-is-water-footprint/> viewed December 30, 2016.

Despite these difficulties, the WF metaphor continues to generate a vast body of journal articles covering many different aspects of the relations between water and food, often focused on the role of humans in various aspects of life in the Planet and its implications for sustainability. Criticisms about the limitations of the WF were voiced ever since the formulation of the WF idea in 2002 (Hoekstra and Hung 2002). Two recent papers by Perry (2014) and Wichelns (2015) have clearly outlined compelling arguments against using the WF to compare production systems or to derive policy implications regarding water allocation and use. Perry's comments focus on the technical difficulties in deriving robust WF indicators, while Wichelns focuses on the absence of any concept of the local opportunity cost of water in the formulation of WFs.

Notwithstanding their criticisms, a section in the scientific community continues to use the WF as a preferred indicator in a number of recently published exercises. The assessments are quite diverse, from agricultural production to the formulation of diets, from local to regional and global, and are more and more oriented towards trade, sustainability analyses and to influence consumers' behavior and government policy. As stated in the preface to The Water Footprint Assessment Manual (see Footnote 1): "A shared standard on definitions and calculation methods is crucial given the rapidly growing interest in companies and governments to use water footprint accounts as a basis for formulating sustainable water strategies and policies". In times of water scarcity, it is easy to capture the imagination of the public with large figures such as the one ton of water used in the production of one kilogram of wheat, but by no means such figure tells the whole story.

The objective of this commentary is to highlight some important limitations of the WF as an indicator of water use in food production and to suggest alternative views regarding the assessment of water use in irrigated agriculture.

Irrelevant assessments The WF is sometimes seen as paralleling the carbon footprint, but a crucial distinction between the two indicators is overlooked by the WF proponents. *Local* CO₂ emissions contribute to the *global* stock of CO₂ regardless of where or how the emissions are produced, but the evaporation of water has only a local effect, affecting the basin where evaporation occurs. In the water cycle, there are differences about the disposition of water to various sinks. As Perry (2014) described, hydrologists and others make the distinction between water use (contributing to various dispositions, i.e., evaporation, transpiration, changes in storage, runoff, drainage) and water consumption (evaporation losses to the atmosphere, ET). At the basin scale, losses to runoff and drainage may be recovered, at least in part, while consumption through ET is largely uncontrollable and constitutes a 'true' water loss to the basin. Therefore, without accounting for the various

dispositions of water and their local significance, the WF ratio has no general meaning.

A look at WF values implies that huge amounts of water are being used to produce food. However, the ET process is passive—a direct consequence of the exposure of wet surfaces (plant canopies and soil surfaces) to drier environments. The rate of ET cannot be controlled or modified for most field crops as it depends on the evaporative power of the atmosphere which varies in space and time, a characteristic of the environment which farmers are unable to control. Thus, comparing the WF of different locations or for different seasons has the same meaning as comparing geographical features of environments not manageable in food production processes. If the WF would be used for the certification of agricultural production in different environments it would lead to normative which is highly questionable. Imagine for example the negative impact on the textile industry of arid countries if the WF of cotton, naturally much higher than that of humid environments, would be used as a standard of environmental sustainability.

ET is part of the water cycle, proceeding regardless of the type of vegetative surfaces that cover the land. Thus, the ET of a crop surface in a location where the only supply of water is rainfall would be similar to the ET of the natural vegetation that would take place in the absence of the crop. Therefore, to compute the WF of rainfed crops is meaningless, as the water 'losses' to ET would take place in any case, and might even be reduced when forest is replaced by seasonal agriculture, so that the WF of the crop is actually negative!

Taking the WF indicator to the absurd, one may compute the WF of fish. The global footprint of fish from marine ecosystems may be estimated as the ratio of the mean global evaporation from oceans (413 km³/year) and the global fish catch (126 Mt/year) resulting in 3.3 m³ of water per kg of fish. But if one takes into account the inedible parts of fish (e.g. 50%) and the water content of fish flesh (assumed 35%) the WF value becomes 10 m³ per kg of dry edible fish. Are consumers going to stop eating fish given the very high WF? Evaporation from the oceans would proceed regardless of the capture of fish, thus the WF just calculated is meaningless. Similarly, computing the WF of meat when the animals are fed only from pastures and/or rainfed crops is a futile exercise, as the ET from those ecosystems would be about the same whether they are cropped or not.

Producing figures to capture the public attention is easy if we know where to look at. Take for instance a British citizen eating a sandwich with 75 g of white bread, which has required 73 g of wheat grain for its production. An average wheat field in the UK produces 0.8 kg/m² of grain, covering a field for 10 months which receives a total solar radiation load of 3200 MJ/m². A kg of wheat is associated with

4000 MJ of solar energy and thus the sandwich would have required a solar energy input of 292 MJ, the same energy that is contained in 6.3 liters of gasoline! Isn't this an outrageous 'energy footprint' for a sandwich? Should we blame agriculture for having such a low radiation use efficiency? The answer is no. In fact agriculture has increased the efficiency of primary production by the management of inputs and the control of biotic factors.

Irrigated Agriculture So, if computing the WF of rainfed systems is for the most part meaningless, what about irrigated systems?

Here, additional water to that of rainfall is supplied artificially, so that the seasonal ET from irrigated agriculture exceeds that of the natural ecosystems that the crop had replaced. But what is the contribution of irrigated agriculture to global evaporation? As a first approximation, assume that rainfed agriculture has the same evaporation as the average land areas (490 mm/year) and that evaporation from irrigated areas is equal to the rate of evaporation from the oceans (1144 mm/year). Taking into account that the areas of oceans, total land and irrigated areas are 361, 149 and 3.0 million km², respectively, the relative contribution of irrigation to enhancing *global* evaporation would be only about 0.4%. By contrast, its contribution to food production cannot be overemphasized, as only 17% of the cropped lands are irrigated globally producing more than 40% of our food. Locally, of course, the impact of irrigation on water demand may be substantial, but this just emphasizes the irrelevance of WFs in any global, international or even trans-regional context.

In irrigated agriculture another indicator, water productivity (WP), defined as the ratio of production to ET, is quite popular as it reflects the objectives of producing more and consuming less water. Usually, an improvement in WP reflects some positive advance in the search for productivity. The WF is essentially the inverse of WP, so that a higher WF has negative connotations, as the higher the WF the higher the water consumption. Both indicators are too simplistic to characterize the quality of irrigation services and thus may be misleading depending of their interpretation. Looking at the WP of irrigated crops, its overall improvement in recent decades should be mostly attributed to an increase in the numerator (production), while very little may be attributed to a decrease in the rate of ET. In fact, if biomass has increased for a given crop, the ET would have increased during that period too, given the tight relationship between transpiration and biomass production. The point here is that a simple ratio such as WP or WF cannot offer sufficient information to guide policy decisions or to make meaningful

comparisons that have implications for sustainability. Furthermore, comparing production systems that differ in ET makes little sense unless a procedure for normalization by Reference ET (ET_o) is introduced, as the arid and semi-arid climates would always exhibit higher WF values than humid climates, given their higher ET_o.

The success of indicators such as the WF reflects society concerns regarding the use of water in food production in general, and in irrigation, in particular. The scrutiny of irrigation is justified because of the large amounts of water derived for use and of all the environmental issues associated with its practice. Much has been done in recent decades to improve irrigation practices although the perception that irrigation is wasteful remains in many urban circles. It is therefore imperative to develop meaningful assessments to provide unbiased information on the quality of current practices and to provide recommendations for improvement. All assessments must be based on proper accounting of the water applied (AW) and its disposition, i.e., by quantifying the water balance. The fate of AW varies widely even in the same farm as part drains below the crop root zone, runs off fields or is lost to evaporation. At the higher scales, up to the basin and beyond, AW losses are often reused and constitute part of the downstream water supply, or recharge to aquifers. All of these features must be considered when assessing the use of water in irrigated food production. We now have many tools to develop robust procedures to evaluate irrigation practices by determining the fate and disposition of the AW. Such knowledge would be invaluable to provide technical recommendations for improvement that would have to be integrated into the socio-economic and institutional environments. Irrigation is complex and is not amenable to be characterized by a single indicator. In the case of the WF, which claims to integrate consumption of rainfall, irrigation water, changes in timing of downstream flows, and pollution impacts on a globally standardized basis, this could be particularly misleading.

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