The Wide World of Water Metrics

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Abstract. *There is growing public awareness of the world's limited water resources and most sustainability organizations include some type of water metric when evaluating the environmental impact of consumer products. Commonly used approaches typically fall into three categories: 1) water scarcity models; 2) water footprints; and 3) life cycle assessment (LCA) techniques. Measures established by the irrigation community are typically not utilized although irrigation is most always listed as the largest water use component in the water footprint of any agricultural-based product. This is because these metrics focus solely on water consumption (removal of water from the watershed) and ignore total water withdrawn (water removed including that returned to the watershed, as in power generation, for example). Results based on water metrics that do not take into account the critical nexus between water and power generation tell an incomplete story and could underestimate the water risks for companies whose products are based on energy intensive processes. Some newer approaches, usually coupled with LCAs, are starting to broaden the water dialogue. For instance, some metrics attempt to estimate the impact of water use on human health by attributing loss of water to malnutrition, thus acknowledging the importance of irrigation for food production. Because purchasing and product design decisions of brands and retailers are starting to be driven by the metrics adopted or developed by sustainability initiatives, accuracy and inclusion of context around agricultural water use is critical. There is a pressing need for those with expertise in agriculture and irrigation to become engaged in the evaluation and development of these metrics. The irrigation community is well-positioned to ensure that the complexity of agricultural systems is captured by those developing water metrics and that these same entities are informed about solutions for managing this increasingly limited resource.*

Keywords. Sustainability, life cycle assessment, water footprint

Introduction

It is clear fresh water will become scarcer in many parts of the world as the population grows over the next 40 years. The pressure on water resources is already evident in the decline of many aquifers across the United States as recently summarized by Konikow (2013). Very few environmental impacts are as complex and emotional as water resources. Water is a human necessity, a commoditized resource, an ecosystem matrix, a geochemical cycle, and of cultural/spiritual value, all at the same time. Water scarcity threatens the safety and stability of consumer supply chains, especially food, fiber, feed, and fuel. This has led a number of companies to evaluate water use across their supply chain and a corresponding increase in methods to quantify, either on an absolute or relative basis, the water associated with raw materials and processes throughout the life of a product. Some approaches only consider water consumption (water removed from it source watershed either by evaporation or embedded in the product) and may not consider site-specific water availability. Essentially all of the approaches identify irrigation water as a major contributor for any agriculturally-based product. Without the benefit of additional context, this can be misinterpreted to mean that water use for irrigation is wasteful and therefore undesirable.

The objectives of this paper are to: 1) review current sustainability efforts and metrics as they pertain to agricultural water; and 2) to inform the irrigation community of these efforts so we can enter into a constructive dialog on how irrigation water use should be assessed. The first section of this paper reviews several water metrics with special emphasis on those applied in sustainability discussions and then provides an overview the major sustainability organizations that are using water metrics in their programs. The last section will focus on many of the complexities related to irrigation water use that are not addressed by these metrics.

Water Metrics

Developing metrics for the critical dimensions of water requires agreement on what those dimensions are. There is general agreement that scarcity and water quality are metrics of concern. Both of these metrics are dependent on geospatial and temporal resolution. Water scarcity may be chronic or seasonal, regional or local, depending on the characteristics of each place. This section will briefly review irrigation performance measures and then follow with water metrics applied to product evaluation and sustainability discussions in three categories: 1) indices used to more generically rank levels of water scarcity; 2) the concept of a “water footprint”; and 3) water metrics used in life cycle assessments (LCA). Each category has different strengths and weaknesses, and all are constantly being refined and improved.

Established Irrigation Water Metrics

Over the last 50 years or more many measures to assess the performance of irrigation systems at different scales have been developed. An effort to standardize these measures, reported by Burt et al. (1997), was in part motivated by water rights and regulatory discussions. The hope was to standardize the definition for many key irrigation performance indicators including: irrigation efficiency; distribution uniformity; and application efficiency. The authors also made the point that some measures can be applied across different spatial scales and may encompass different time intervals, while others may only apply to a specific irrigation event in one field. For example, a key measure used in evaluating agricultural water use is irrigation efficiency (IE), defined by Burt et al. (1997) as:

$$IE = \frac{Volume\ Irrigation\ Water\ Beneficial\ ly\ Used}{Volume\ Irrigation\ Water\ \ Applied\ - Change\ in\ Storage\ of\ \ Irrigation\ \ Water}\ X100\% .$$

To illustrate the relevance of spatial scale for IE, consider the case when tail water leaves a field, it may not be considered beneficially used at the field scale; however, if that tail water is diverted to another field it would be considered beneficial at the farm and district scales. Jenson (2007) provides a detailed discussion of irrigation efficiency, including misinterpretations of the term, especially the incorrect concept that improving irrigation efficiency at the field scale *must* result in increased water availability at the watershed scale.

To overcome some of the limitations of the term irrigation efficiency, Solomon and Burt (1999) discuss the term "irrigation sagacity" (IS) in an attempt to describe not only beneficial water use, but also "reasonable" water use. Mathematically it is similar to equation 1, but adds "or reasonably" following "beneficially" in the numerator. Figure 1 illustrates the difference between IE and IS.

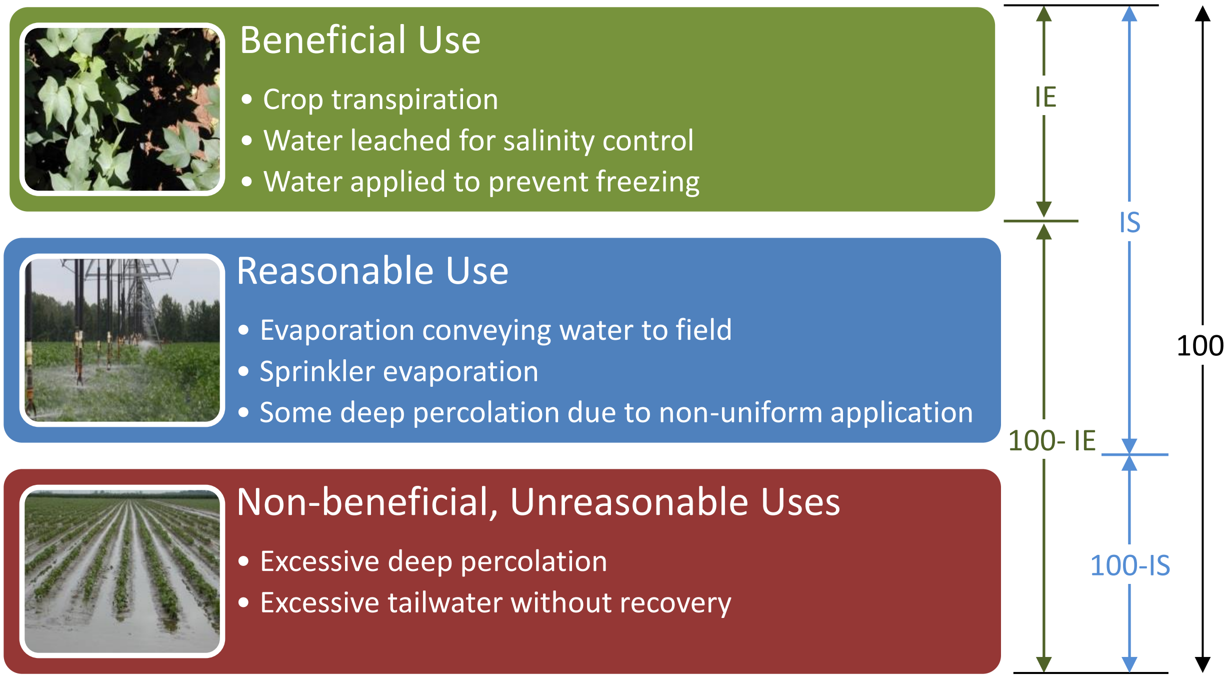

Figure 1. Comparison between irrigation efficiency (IE) and irrigation sagacity (IS). (Adapted from Solomon and Burt, 1999).

Another key concept in evaluation agricultural water use is the mass of economically valuable material produced per volume of water used. Historically this was often referred to as "Water Use Efficiency" (WUE), but as with irrigation efficiency, the quantification of WUE requires a definition of scale. Howell (2001) reviews several forms of WUE definitions, where the numerator is typically economic yield, but how the "water used" is determined varies. Howell (2001) also reports on an irrigation water use efficiency (I_{WUE}):

$$I_{WUE} = \frac{(Irrigated\ Yield) - (Non - Irrigated\ Yield)}{Irrigation\ Applied}$$

More recent literature (e.g., Zwart and Bastiaanssen, 2004) has adopted the term "Crop Water Productivity" (CWP, kg m^{-3}) defined as:

$$CWP = \frac{Marketable\ Crop\ Yield}{Actual\ Seasonal\ Evapotranspiration}$$

These metrics reflect a return-on-investment approach to efficiency. They are useful for comparative assessment of water use at the enterprise level (maximum potential gain by cropping system for available resources), within a region (which production strategies give greatest yields for a cropping system), or across regions for a given production system. These metrics can help identify opportunities for increased efficiency. However, they do not address competing demands associated with scarcity, or impacts associated with runoff or infiltration. The challenge of defining "simple" irrigation performance parameters provides evidence that any effort to quantify water metrics for an agricultural system is not trivial.

General Water Scarcity / Stress Indices

Several approaches to quantifying water scarcity such as the Palmer Drought Index (Palmer, 1965) which addresses short-term climate water limitations and the Falkenmark indicator (Falkenmark, 1989), an index that considers population demands and availability of local water resources in the long term, have been developed over the last five decades. The current trend in quantifying water stress in regions is to move beyond a simple water balance and also consider impacts on water quality and the economic and social capacity of the region to adapt to water shortages (e.g., Ohlsson, 2000). Brown and Matlock (2011) provide a review of many water scarcity indices and, in that review, divide scarcity indices into three categories: 1) indices based on human water requirements; 2) those based on water supply; and 3) indices incorporating environmental water requirements.

With regard to human requirements, Figure 2 illustrates the distribution of basic human water needs from Gleick (1996) as summarized in Brown and Matlock (2011). The total estimate is that at least 50 liters per person per day is needed to meet direct basic human water needs (that is, water delivered directly to a person). In addition to direct water use, a United Nations reports data indicating that 2000 to 4000 liters of water per day are needed to supply a person's food requirements (UN, 2013). The fact that water associated with a person's food requirements is almost 100 times their direct water needs is a clear indication that the biggest societal impact of future water shortages will be related to meeting nutritional requirements.

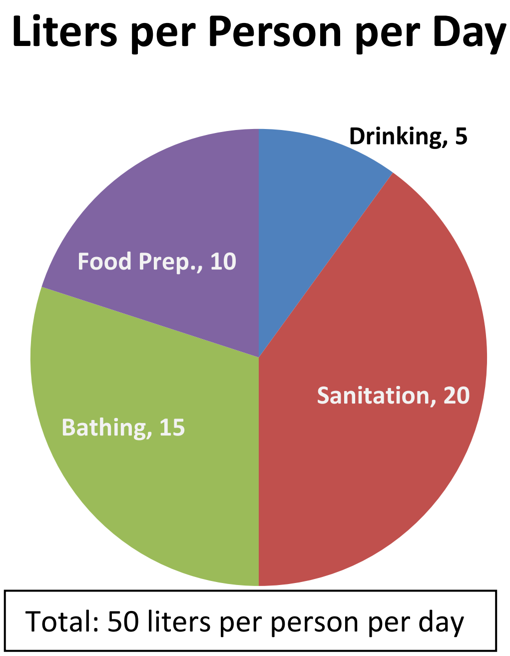

Figure 2. Basic human direct water needs.

One current tool used to estimate water risk is provided by the World Resource Institute's Aqueduct (http://aqueduct.wri.org/). The tool provides a number of metrics, including the "baseline water stress" (BWS) shown in Figure 3. It is defined as the total water withdrawn as a percent of total annual flow (Gassert et al., 2013). The BWS is one of twelve water indicators computed on a global basis and available from the Aqueduct web site. The concept is that companies can use these indicators to identify areas in the business supply chain with high water risk and provide guidance to investors on their water readiness plans (Reig et al., 2013). Reig et al. (2013) divide water risk into three categories: 1) Physical Quantity (lack of water); 2) Physical Quality (impacts on water quality); and 3) Reputational (if a company's product is deemed to negatively impact water resources, the brand is threatened).

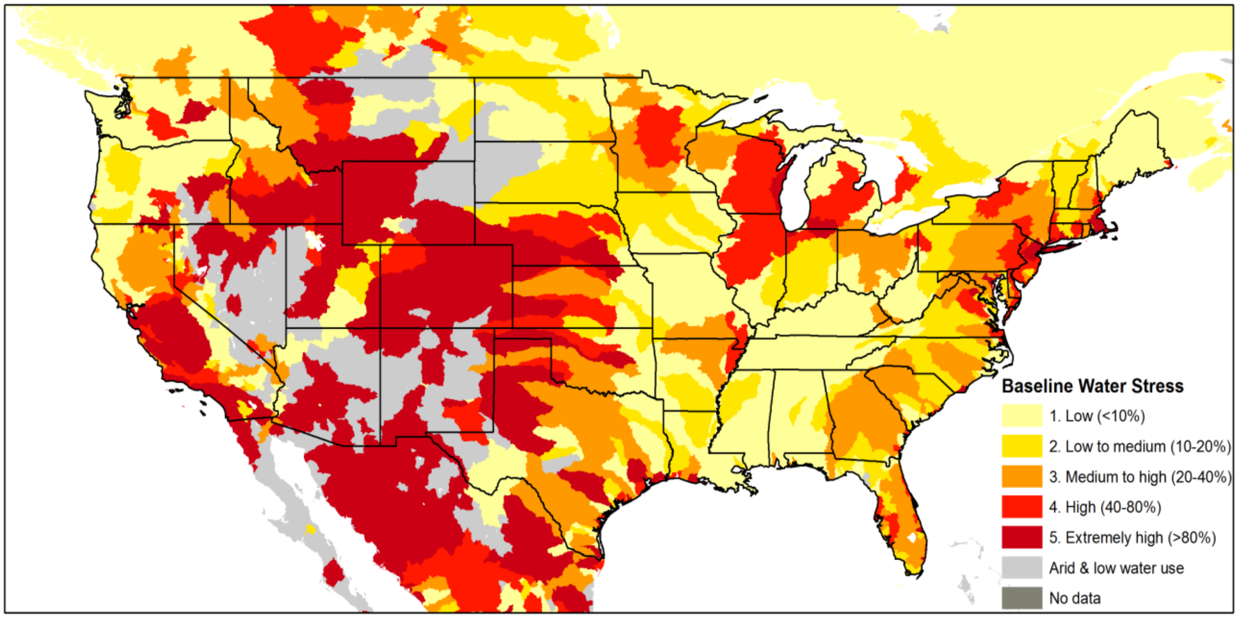

Figure 3. Baseline water stress from WRI's Aqueduct (Gassert et al., 2013).

Another term used in water resources discussion is "water security." The United Nations currently defines water security: *"as the capacity of a population to safeguard sustainable access to adequate quantities of acceptable quality water for sustaining livelihoods, human well-being, and socio-economic development, for ensuring protection against water-borne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability."* (UN, 2013). The same UN report acknowledges the tight linkage between water, energy and food.

Water Footprints

The concept of a water footprint is similar to (and essentially derived from) an ecological footprint; and one of the first uses was introduced in the discussions of virtual water by Hoekstra and Hung (2002). For the purpose of this paper, the water footprint definition will be based largely on the definitions provided by the Water Footprint Network (www.waterfootprint.org). A recent review of the evolution of the water footprint is provided by Chapagain and Tickner (2012).

A goal of the water footprint concept is to raise awareness and to quantify all of the water *consumed* in the production of a product, or in some cases water consumed by groups or nations. Because the focus of the water footprint concept is on consumption, with the exception of a rough estimate of the impact of water pollution associated with a product, issues arise when comparing products such as apparel that are derived from both agricultural and synthetic raw materials. For example, by definition, water consumed is water that has been taken from one watershed yet returned to another. The water applied to crops through irrigation is considered water consumed since the water may no longer be available within that watershed. However, no consideration is given to the fact that the water that might return as rainfall to the same watershed. In contrast, the vast amount of water associated with power generation is largely ignored since most of the water used for power generation is returned to the same watershed, albeit of a different quality. Kenny et al. (2009) reported that water for thermoelectric power generation was 51% of all water withdrawn in the United States in 2005, followed by irrigation at 31%. With a focus solely on water consumption, the water footprint of an agricultural product will always be greater than that of a product derived from a synthetic raw material even though vast amounts of energy are required for the production of the synthetic product. Hence, a methodology based solely on water consumption will not capture all of the water resource needs of a product, especially those dependent on energy intensive processes.

The water footprint is broken down into three major components:

1. **Green** water consumption – water that originates directly from soil moisture derived from rainfall.
2. **Blue** water consumption – water that is diverted from rivers, lakes, and groundwater. Note that recycled water (e.g., use of effluent for irrigation) still counts as blue water use in a water footprint.
3. **Grey** water – volume of water in the creation of a product that would be needed to dilute any pollution to an established concentration accounting for the background concentration at the point of emission.

The water footprint assigns equal weight to green and blue water even though they are tracked separately. The water footprint of a product is often report as a total of the three categories, so the portion of water in an agricultural commodity from rainfall is not always apparent. For crops, the mass produced per evapotranspiration over the time span of production (a single growing season in the case of crops, or years of growth in the case of forestry products) is used to define total water use. While a direct measure of crop water use efficiency is ideal, such data is not always available on a site-specific basis and the CROPWAT program (FAO, 2010) is recommended by the Water Footprint Network for calculating water use at regional levels.

Ridoutt and Pfister (2012) have proposed a different methodology to allow water pollution to be included in a single score measure of water use by adapting life cycle assessment methodologies, as opposed to the Water Footprint Network approach. The resulting water footprint is referred to as “H_2Oe”, i.e., water equivalents in the same manner used for reporting greenhouse gas emissions in terms of carbon dioxide equivalents.

In addition to work by the Water Footprint Network, the International Organization for Standardization (ISO) is drafting Standard 14046 – “Principles and Guidelines for Water Footprinting” (ISO, 2013). The Draft International Standard follows closely the same requirements set forth in the standards for life cycle assessment. Water footprint may be integrated with LCA or may be a standalone assessment. The requirements include defining the goal and scope, developing a water footprint inventory analysis and conducting an impact assessment with subsequent interpretation of the assessment. There is geographic and temporal specificity, and all environmentally-related aspects of environment, human health and resources are considered, although economic or social impacts are not considered. The pressure on water availability and the impacts related to water degradation are assessed. If only one impact is studied then the term water footprint should be qualified, e.g., water acidification footprint or water scarcity footprint. A water footprint profile is compiled from all of the indicators chosen in the goal and scope. This profile can be aggregated into a single score, but the single score cannot be used for comparative public assertions.

Life Cycle Assessment Water Metrics

Life cycle assessment (LCA) attempts to track multiple environmental impacts of a product from its production, including raw materials, through consumer use to disposal. The ISO 14040 series of standards for Life Cycle Assessment define the processes needed to conduct an LCA for a specific product (ISO, 2006a and 2006b). Historically, LCA methodologies were more focused on water quality impacts. Many life cycle inventories included total water withdrawn but did not distinguish between consumptive versus total use. More recently, life cycle inventory (LCI) software began to include water consumption, for example, in GaBi with the release of version 5 (GaBi, 2011). In contrast to water footprints, most LCA methodologies do not include rainfall (green water) in either water consumption or water use. Most of the popular inventory databases are inconsistent in the type of water that is tracked. For example, Kounina et al. (2013) note that of the most common LCA databases only one considers evaporation from reservoirs. This is, however, being addressed in the water footprint ISO standard.

The difference in water consumption versus total withdrawn from an LCA perspective is illustrated in Figure 4 for a knit shirt using data from Cotton Incorporated (2012). In that study, the shirt's life cycle was divided into three major phases: 1) agricultural (agricultural production to ginning); 2) textile production (fiber to fabric); and 3) use (cut and sew plus consumer use including washing and drying). From Figure 4 it is clear that the agricultural phase dominates the amount of water consumed, but the textile production and consumer use phases are larger when considering total water withdrawn ("withdrawn" in is sometimes referred to as "water used" in LCA reports). The major reason for the difference is that water withdrawn includes water for power generation, and these two phases had much greater energy use than the agricultural phase.

Another point illustrated by Figure 4 is the concept of "direct" and "indirect" water use. For example, water diverted to a textile mill for fabric dyeing is direct water use while the water supplying the power plant that provides electricity to the mill (assuming it is off-site) is indirect. Both consumptive and water withdrawn can be categorized into direct and indirect uses. Therefore, a product that is derived from an energy intensive process may have a high level of water withdrawal from an LCA perspective although there may be very little actual water use at the manufacturing facility.

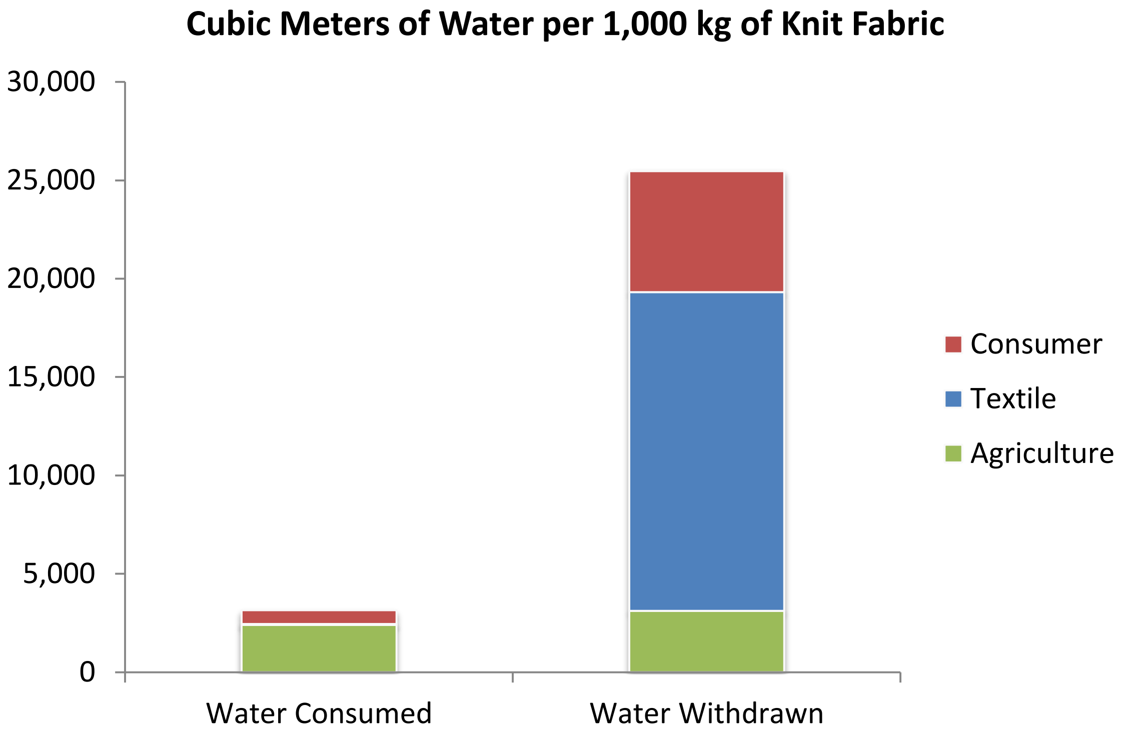

Figure 4. Comparison of water consumed and water withdrawn based on the LCA of a knit shirt from Cotton Incorporated (2012).

The distinction between LCA water-consumption and water-withdrawn metrics illustrate an important point in assessing the water risk in a product's supply chain. If only consumption is considered, products based on synthetic inputs may falsely appear to have low water risk. For example, if a synthetic product relies on energy intensive manufacturing processes, and the water that is supplying the power plants that are providing that energy becomes limited, there is a risk to the supply chain due to disruptions in water supplies (Webber, 2012).

There are now efforts in the LCA community to go beyond accounting for the volume of water consumed or withdrawn by also considering the impacts of water availability in the region where it is used. For example, Pfister et al. (2009) estimates the impact of freshwater consumption on human health by predicting malnutrition caused by reduced food availability due to the diversion of water away from agriculture. They also have two additional impact indicators: ecosystem health impacts are estimated by assuming a loss of biodiversity as water becomes scarce in the region; and a resource depletion indicator, a calculation based on the energy it would take to replace the blue water consumed by the desalination of seawater.

Boulay et al. (2011) also have proposed a methodology for LCAs that predicts the impact of changes in water availability on human health at a regional level. It has been used to create a water stress index that is integrated as part of a new LCIA methodology referred to as "IMPACT World+" (see http://www.impactworldplus.org/en/index.php). The Boulay approach defines different water uses (e.g., domestic, agriculture, power) and 17 water categories that are related to the source of water (surface, ground, rain) and the quality of that water. The impact on different users in the region is determined by their upstream or downstream relationship to the water withdrawal and impacts take into account an area's economic status (assumes low income areas will experience the impact of water deficits, while high income areas can compensate for water loss). The method also calculates a human health impact related to malnutrition due to decreased agricultural productivity from lack of water. The method assumes water scarcity occurs mostly due to water consumed although there is some accounting the loss of functionality of degraded water returned to the system for specific user categories.

The models of both Pfister et al. (2009) and Boulay et al. (2011) utilize data from the Water Global Assessment Prognosis 2 model (WaterGAP 2, Alcamo et al., 2010). The WaterGAP 2 model attempts to estimate water availability within a river basin and also models the water use from all sectors (industrial, municipal, agricultural) in the basin. For domestic water use, "domestic structural water intensity" (m^3 per person) is defined as a function of the gross domestic product (GDP) of a region assuming water use increases with GDP. Industrial water intensity is also related to GDP and is assigned units of m^3 per MWh. The method also includes the ability to make adjustments for technology changes that will improve water use efficiency. Agricultural water use is focused on water drawn for irrigation which is considered to be consumed (evaporated). The irrigation model is based on Doll and Siebert (2002) and assumes crop water needs will be met; it does not account for situations where deficit irrigation may occur due to limited water resources. The net irrigation is computed as the difference between crop demand estimated from a crop coefficient approach, and precipitation. The water supply is based on a global hydrology model that conducts a daily water balance on a regional basis.

An example of the water stress classification from the WaterGAP 2 model for the continental United States is presented in Figure 5. In general, the areas listed as having some level of stress correspond to areas of lower annual rainfall with the exception of the state of Florida and the mountains of California (see Figure 6).

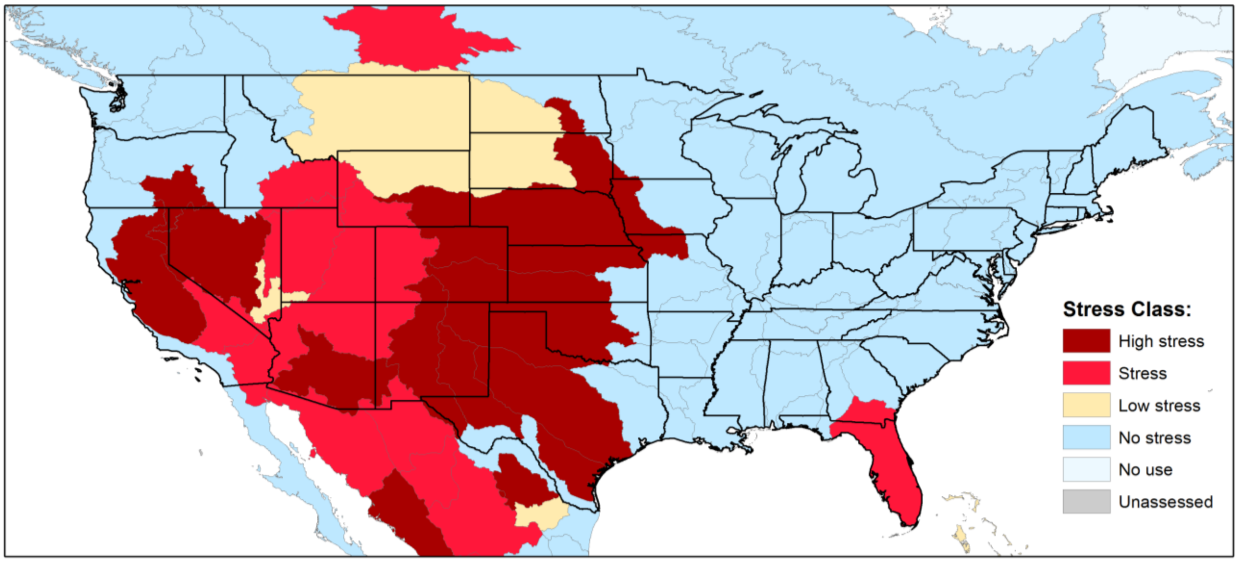

Figure 5. Degree of water stress by freshwater eco-region – derived from data of Alcamo et al. (2010) as prepared by the Nature Conservancy and accessed through ArcMap 10.1 (ESRI, 2012).

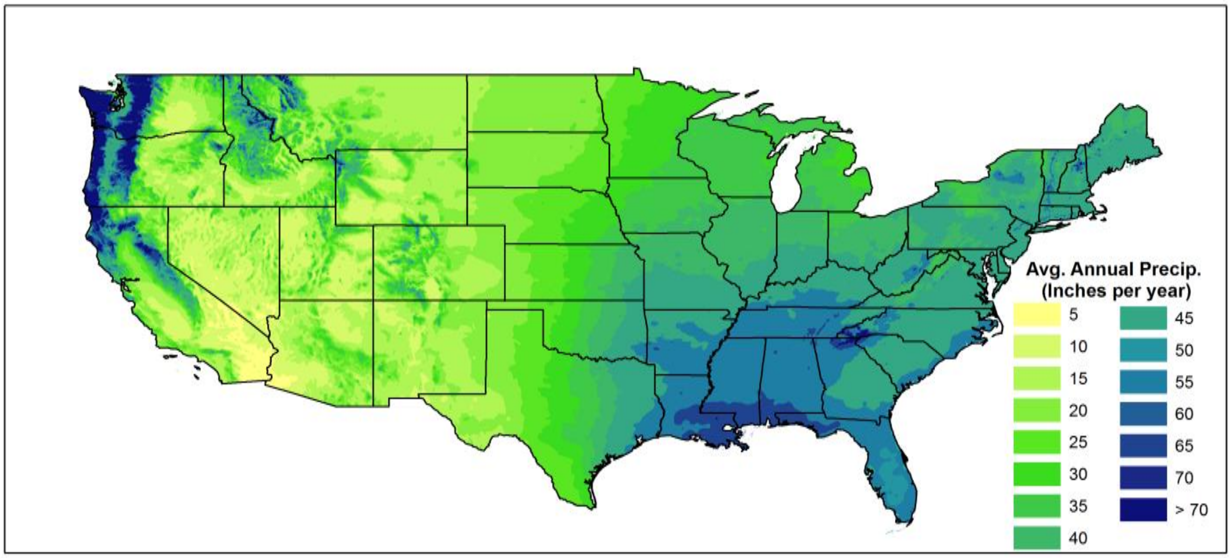

Figure 6. Average annual rainfall from 1961 to 1990. Derived from data provided by the USDA-NRCS National Cartography and Geospatial Center.

There is now an effort among those in the life cycle assessment community to build consensus on what characterization methods should be used for LCA through an international group referred to as WULCA (http://www.wulca-waterlca.org/). The group is part of the United Nations Environment Programme (UNEP) and Society of Environmental Toxicology and Chemistry (SETAC) Life Cycle Initiative. As part of that effort, Kounina et al. (2013) published a review of current LCA approaches and attempted to define the attributes a system should have in order to address the impact of fresh water use in LCA. They concluded there is a need to track water based on its origin (surface, ground or precipitation stored as soil moisture) and that assessments need to be done at a regional level due to the geographic variability in water scarcity.

Because water scarcity and end-point impacts such as those on human health are built into LCA metrics, the complexity of the models and their associated uncertainty is increased. As seen in the previously described examples, the attempt to quantify the complexities of water availability at small regions on a global basis requires many assumptions and estimates. And many of these estimates are not only related to hydrologic parameters, but also to socioeconomic information.

Sustainability Efforts and Water Metrics

There are a significant number of global efforts aimed towards quantifying or certifying the "sustainability" of a product or supply chain. Some are based on prescribed practices while others are focused on the development of ways to measure sustainability. This section reviews some of the initiatives that include agricultural products and that use water as one of the measures of sustainability. Note that many of the organizations using water metrics have key members whose decisions could have a major impact on agricultural supply chains.

CEO Water Mandate

The CEO Water Mandate was started in 2007 by the United Nations Secretary-General to help companies develop and disclose sustainable water practices and policies (http://ceowatermandate.org/). Companies that commit to the mandate agree to conduct a water use assessment, set targets for water conservation, invest in water conserving technologies, and consider water sustainability in their business decisions. The organization suggests several potential tools a company can use for self-assessment, including water footprints and LCA. They also recommend other tools such as The World Business Council for Sustainable Development's (WBCSD) Global Water Tool (GWT, http://www.wbcsd.org/work-program/sector-projects/water/global-water-tool.aspx) that focuses on assessing water scarcity risk on a site-by-site basis. The tool uses an Excel spreadsheet to collect data on water use for each site in a supply chain and shows the water metrics associated with those sites. It also allows the sites to be shown on a map, and the map is coded based on different water metrics such as availability and stress. The GWT is integrated with the "Local Water Tool" (LWT) developed by Global Environmental Management Initiative (GEMI). Data from the GWT can be loaded into the LWT for more location-specific risk, impacts and management of water use and discharge.

Sustainable Apparel Coalition

The Sustainable Apparel Coalition (SAC, http://www.apparelcoalition.org/) "is an industry-wide group of over 100 leading apparel and footwear brands, retailers, suppliers, nonprofits, and NGOs working to reduce the environmental and social impacts of apparel and footwear products around the world." Members include Nike, Adidas, Puma, Gap, REI, Coca-Cola, Hanesbrands, Levi's, JCPenney, Target and Walmart. A significant outcome of the SAC's efforts is the Higg Index which is a still-evolving Excel-based tool designed to enable the apparel industry to evaluate the sustainability of their supplier facilities, products, and specific brands. Currently, the indicator questions within the Higg Index are qualitative measures of company actions in various areas of the supply chain. Water use and water quality are addressed in the facility module by asking whether the facility measures water use and whether goals are set or plans exist for water reduction. Similar questions are asked about wastewater discharge, treatment, and reduction. In the brand and product modules, questions are focused on encouraging brands to better understand the water requirements of their supplier's manufacturing equipment and processes, chemical use during manufacturing, the environmental profile of raw materials and the design of products that require less water or less polluting chemistry during manufacturing. The questions are assigned points and are designed within a framework in which more responsible choices result in higher scores.

Future versions of the index may be based on more quantitative, LCA-type measurements. Another significant effort by the SAC has been the development of guidelines for apparel ecolabels. The guidelines, called Product Category Rules (PCR's), is a like a recipe for creating an Environmental Product Declaration's (EPD), which is essentially an ecolabel. EPD's and ecolabels are common in Europe and are currently voluntary but will become mandatory in the coming years. The water-related impacts currently required by the SAC's PCR for apparel products are water depletion and eutrophication. This could change in future versions of the PCR or for specific product categories if the ISO standard 14046 is adopted or if other LCIA methods for measuring water become accepted.

The Sustainability Consortium

The Sustainability Consortium (TSC) is another industry organization that is taking a metrics-based approach towards driving sustainable practices (http://www.sustainabilityconsortium.org/). The scope of TSC includes a broad range of product categories that include food, beverages and agriculture; textile and clothing; electronics; toys; health and beauty products; and paper, pulp, and forestry. The range of categories results in a diverse membership including brands and retailers such as Best Buy, Dell, Disney, Proctor and Gamble, Walmart, Tyson, Smuckers, and McDonalds, as well as agribusiness and chemical companies such as Syngenta, Bayer CropScience, BASF, DOW and Monsanto. A number of NGO's such as World Wildlife Fund (WWF), Environmental Defense Fund (EDF), The Nature Conservancy (TNC) and the Natural Resources Defense Council (NRDC) are also represented. The Food, Beverage and Agriculture (FBA) sector is the largest sector in TSC with 26 current product categories. Recently, TSC has compiled several products into one category, e.g., milk, cheese, butter, and yogurt under Dairy and beef and pork into Livestock. Cotton holds a spot in both the FBA and Clothing, Footwear and Textiles (CFT) sectors. Figure 7 is a representation of the current categories listed under FBA.

Figure 7. TSC Food, Beverage and Agriculture categories as of August 2013 (from: http://www.sustainabilityconsortium.org/product-categories/).

The TSC's primary product has been the development of a Sustainability Metric and Reporting System, or SMRS, a process designed to provide retail buyers with a mechanism in which to compare and choose suppliers based on environmental and social performance. The SMRS is comprised of "knowledge products", documents containing product- or commodity-specific information derived from literature and research reports. With member input, environmental and social hotspots and improvement opportunities are identified and Key Performance Indicators (KPI's) are eventually developed. The KPI's are sets of questions that retail buyers can use to start a sustainability discussion with a supplier, or a retailer may also opt to use the KPI's as a supplier scorecard. Like SAC, the KPI's are designed to be a tiered point system in which the more environmentally- and socially-responsible suppliers are rewarded with higher points. In the textile sector, water is a hotspot on the farm, in manufacturing, and in consumer use, so several or more KPIs have been drafted to address each of these areas of the supply chain and to determine a supplier's progress on reducing water use and improving water quality. (The textile sector is a recent addition for TSC, so the number of KPIs has not been finalized.) In the FBA sector, several KPI's relate to on-farm water use. Irrigation is designated as a hotspot for all food, beverage and commodity products although the response options are designed to capture irrigation optimization strategies that a grower might implement. Water scarcity and sourcing questions related to water scarce regions are listed as separate KPI's. To encourage change throughout the supply chain, apparel suppliers to Walmart, for instance, are expected to either know, or be involved in an initiative that does know, about the percentage of cotton farmers who track on-farm irrigation water use, for example. TSC recognizes that a typical apparel manufacturer does not have this information but is asking the question to encourage dialog between the manufacturer and the farmer. Likewise, a KPI about water scarcity expects the supplier to know whether and what percent of their raw material is sourced from a water scarce region. A list of tools for measuring water use is provided in the additional guidance that accompanies the KPI's. A challenge that both the SAC and TSC face is whether these systems will actually drive enough change to have impact at the natural resource level.

Carbon Disclosure Project – Water Risk

The Carbon Disclosure Project (CDP) water program encourages companies to evaluate and report the water risk across their supply chains (https://www.cdproject.net/water). The goal of the project includes creating better access to corporate water data to allow better decision making, and accelerate the development of standard water metrics. In 2012 more than 50% of the 191 companies responding to their questionnaire indicated negative impacts on their business due to water issues (CDP, 2012). In 2012, companies reported 470 investors supported their information request.

Sustainable Agriculture Initiative (SAI)

SAI is an organization started by Nestlé and Danone to support the development of principles and practices that form the basis for different agricultural production systems (see http://www.saiplatform.org/) on a global basis. The current water focus of that effort is centered on farm level practices (SAI, 2010); however, they are piloting a Water Impact Calculator. The SAI does appear to have an interest in the water footprint approach of Hoekstra and Hung (2002), but also point out some of the shortcomings of the methodology including the lack of rigor in estimating "grey" water for agriculture, and that often water requirements are calculated based on the assumption that all crop water needs are met (SAI, 2009).

The SAI water focus includes both quality and quantity. To address the quality aspect, SAI encourages approaches such as integrated pest management (IPM) and conservation tillage. For some of the performance indicators they do recommend the use of distribution uniformity (after of lowest quarter divided by average of all catch cans); and metering water delivery systems.

Field to Market (FTM)

Field to Market (www.FieldToMarket.org) is an alliance, across the agricultural supply chain, of organizations who have adopted an outcome-based approach to evaluate progress towards sustainability. A large part of the effort is to use publicly available national data to track several environmental indicators for major crops over time. Water-related measures include an estimate of soil erosion from RUSLE2 and a water quality index (WQI) developed by the USDA, NRCS. The FTM report includes trends in total water used for irrigation, and the primary metric is an estimate of the amount of yield increase attributed to the use of irrigation per unit of irrigation applied, very similar to Irrigation Water Use Efficiency metric previous noted from Howell (2001).

Challenges to Interpreting Water Metrics for Policy and Product Decisions

While considerable effort has been devoted to defining water metrics and a number of organizations are attempting to use these metrics as part of their sourcing decisions, there is a real possibility that the complexities of agricultural systems could to lead poor decision-making. For example, McGuire (2011) documents the decline of the Ogallala Aquifer in the central United States over the last 50 years. It is clear that sections of the Ogallala, particularly in western Kansas and the Texas Panhandle, do not receive significant recharge and will eventually be depleted. The water metrics and certification systems that consider regional water stress will score all crops and manufacturing processes in this region poorly. However, crops like cotton and sorghum are already predominately grown without irrigation. Thus, when the aquifer is depleted, these crops may well present the only sources of income for farmers in the region. It seems illogical and punitive, then, to score these crops poorly based solely on a regional water stress metric.

Another challenge is the definition of “consumption” as water leaving a watershed and the classification of irrigation water as being water consumed. Lo and Famiglietti (2013) have demonstrated that the increased evapotranspiration due to irrigation in California’s Central Valley increases precipitation over the Colorado River Basin, corresponding to an approximately 30% increase in the stream flow of the Colorado River. So, while it is true that a portion of irrigation water evaporates, not all of that evaporated water meets the technical definition of “consumption” since part of that water falls back as rainfall into the hydrologic basin of origin.

Another issue in many of these metrics is the uncertainty surrounding the estimate is either not reported or is extremely high. For agriculturally based products, a more robust approach may be to use a reported value of the crops’ crop water productivity (CWP) to estimate the water used in its creation. For example, Zwart and Bastiaanssen (2004) conducted a global literature review of the CWP for several crops, including cotton. In the data reported for seed cotton (fiber + seed), the CWP was reported with a mean of 0.65 kg m^{-3} with a standard deviation of 0.23 kg m^{-3} and coefficient of variation (CV) of 35%. The mean value is equivalent to 1.53 m^3 of water per kg of seed cotton. This is in contrast to Chapagain et al. (2006) who compute a global average water foot print of 3.6 m^3 per kg of seed cotton (essentially split between green and blue water), twice that of Zwart and Bastiaanssen (2004). While no statistic on the variance in their data is directly report, the tabular data suggest the standard deviation for values reported by country is on the order of 2.1 m^3 kg^{-1}, resulting in a CV of 58%. Chapagain et al. (2006) also report an allocation method to assign water to the fiber and seed; however, even after that allocation method, there estimate of the fiber water footprint is still twice that reported by Zwart and Bastiaanseen (2004). More work is needed to determine what method will best minimize the uncertainty in crop water use / footprint estimates. Without quantitative uncertainty water footprint data are simple anecdotes, and useless for informing better decision making with regards to water use allocation and conservation.

A final challenge to characterizing the water impact of agricultural products is the need for timely data. As shown in Figure 8, crop yields in the United States increase at a steady pace, and these yield increases have come without increased water use on a per acre basis for all of the crops shown from 1980 to 2011 with the exception of wheat which had a small (6%) increase (Field to Market, 2012). Much of the yield increase is driven by improved crop varieties from traditional breeding, better crop management, and in the case of corn, cotton, and soybeans, biotechnology. Therefore, any metric used to quantify products derived from agriculture should be updated at five year intervals.

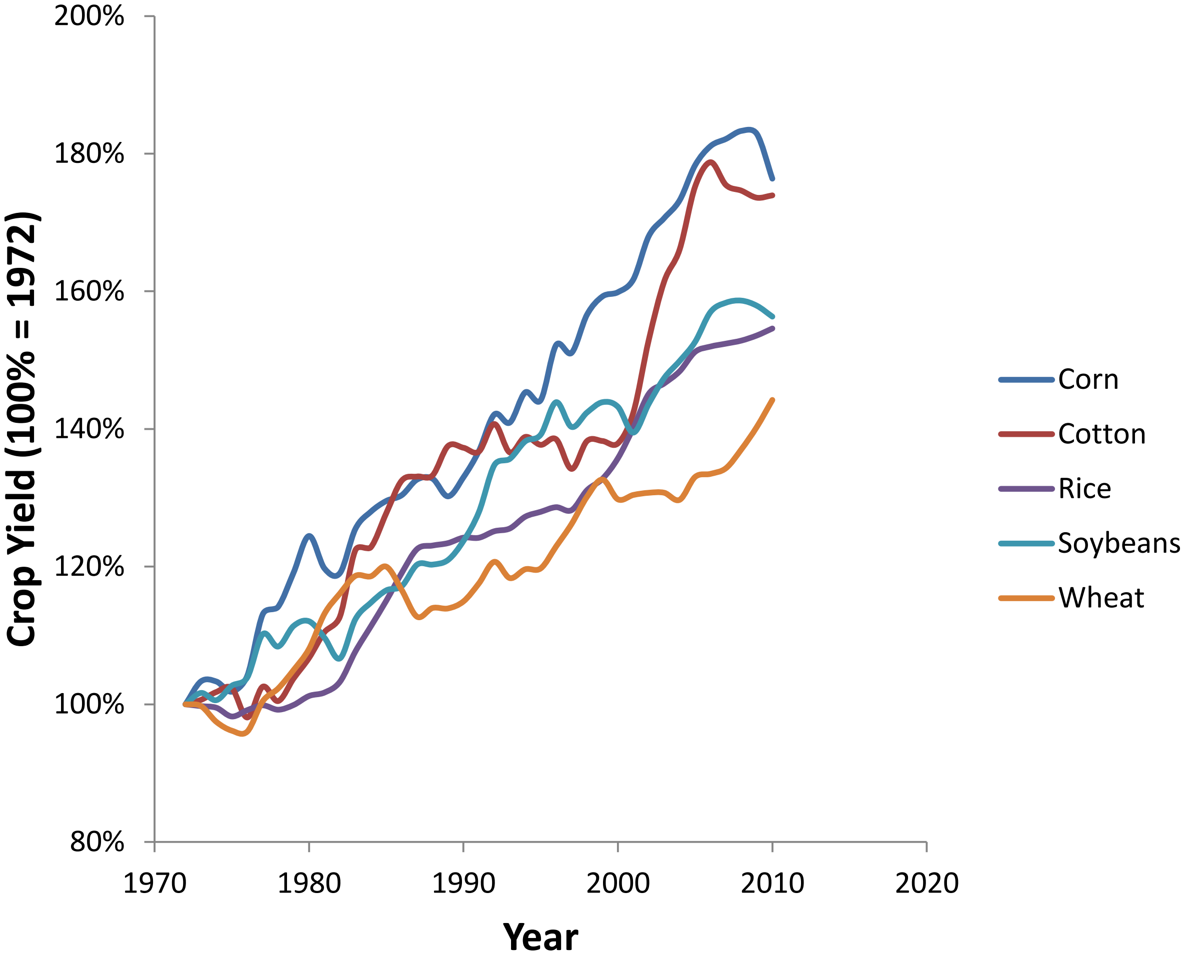

Figure 8. Crop yield trends from 1970 to 2012 using a five year running average with 100% equal to the average yield from 1970 to 1974 (USDA, 2013).

Conclusion

Despite challenges to the numerous methodologies for quantifying global water issues, there is consensus that water resources are inadequate in many areas of the world to meet present human needs, and that water limited areas will increase in the future. And while it will introduce uncertainty into the analysis, these metrics will need to be evaluated at regional scales to appropriately assess water scarcity, while at the same time not over-penalizing products that are derived solely from rainfall in these regions. A second point is that energy and water are tightly linked – while LCA approaches account for energy independently, the need for a dependable water supply for power generation should not be ignored when considering water risk. Finally, the data for products based on agricultural commodities is very time-sensitive and should be updated on a routine basis (5 year intervals suggested).

Understandably, industry sectors and business units need and want to understand and quantify water use throughout their supply chains. Sustainability initiatives offer a pre-competitive collaborative space for businesses to understand the issues and risks that natural resource scarcity could have on supply chain security. Businesses can act collectively to make large-scale changes in practices or business models that will have positive impacts on society, human health, and ecological systems. Likewise, large-scale changes by industry sectors could have the opposite effect if decisions are based on incomplete knowledge of the complexities and technical intricacies behind current models and metrics. This is especially true for decisions about products from agricultural systems which have typically been subject to the application of metrics developed for industrial systems – systems which are inadequate for capturing the complex plant, air, water and soil interactions and processes. There is clear need for irrigation water experts to engage with the various sustainability initiatives to lend their experience in addressing the complexities of agricultural water management.

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