

<https://doi.org/10.5942/jawwa.2017.109.0100>

Value Propositions of the Water Footprint Concept for Sustainable Water Utilities

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The water footprint concept has been used by agricultural, commercial, and industrial water users to measure and report their water consumption, assess the magnitude of potential environmental impacts arising from this consumption, and identify opportunities for risk mitigation strategies that promote sustainable water use. However, water and wastewater utilities have not studied and documented the application of this concept in the same manner that other industries have. This article summarizes the growing body of information on the water footprint concept and the opportunities for integrating the concept into water utility planning efforts as a broader means of achieving and maintaining sustainable communities. The application of the water footprint concept for capital improvement planning, water resources decision-making, operational benchmarking, and stakeholder communications is discussed, as is how the methodology, developed by the International Organization for Standardization, can be used for a water utility.

KEYWORDS: environmental impact, ISO14046, life cycle assessment, water consumption

A “footprint” is an indicator, or a profile of indicators, that reflects the impact of human activities on an aspect of the environment and can be used as a means of illustrating the potential environmental impact of the operations of a water utility. For instance, the carbon footprints of water utilities—a measure of the global warming potential of greenhouse gases emitted by water utilities (e.g., through the abstraction, transportation, and treatment of water and wastewater) and a proxy of their energy consumption—have been explored in some detail (Griffiths-Sattenspiel & Wilson 2009, Strutt et al. 2008).

The “water footprint,” introduced by Hoekstra and Hung (2002), is analogous to the concept of the “ecological footprint” developed by Wackernagel and Rees (1996) and is an estimate of the human appropriation of water. The concept is closely linked to that of virtual water in that it accounts for the appropriation of natural capital in terms of the water volumes required to support human consumption of goods and services (Galli et al. 2012).

More recently, the water footprint has been used as an indicator of the potential effects of an activity on water (ISO 2014). This is closely related to the life cycle assessment (LCA) approach because it aims to measure the environmental impacts of products and services through all stages of their life cycle to improve processes, support policy, and provide a sound basis for informed decisions. The goals of water footprint studies vary among sectors, as summarized in Table 1.

Although the water footprint concept has been seen in the academic literature for more than a decade, it was not until 2007 that the idea entered the worlds of business, government, and civil society (Hoekstra et al. 2011). The majority of water footprint studies to date have been for agricultural products and commodities (Hess et al. 2015, Gerbens-Leenes et al. 2013, Mekonnen & Hoekstra 2010), but also for various beverages, including tea, coffee (Chapagain & Hoekstra 2007), and wine (Batista de Pina et al. 2011). Fewer studies have calculated the water footprint of industrial products, mainly because of the complex production chains of industrial products and their variability across nations and companies. Some corporate applications of the water footprint approach for industrial products include Austria-based Borealis' assessment of the polyolefin's value chain (Katsoufis 2009) and Finnish forest industry company UPM Kymmene's assessed paper products and water consumption and the resulting effects of automobile manufacturing (Berger et al. 2012). Several studies on energy and transport, including for electricity generation (Wilson et al. 2012), hydropower (Herath et al. 2011, Mekonnen & Hoekstra 2011), and biofuel-based transport (Gerbens-Leenes et al. 2013, van Lienden et al. 2010) have also been reported. Volumetric water footprints have been expressed per person (e.g., Mekonnen & Hoekstra 2011) or according to unit mass (cubic meter/kilogram), value (cubic meter/\$US), food value (cubic meter/kilocalorie; e.g., Hess et al. 2016), or energy (cubic meter/millijoule; e.g., Wilson et al. 2012).

As an indicator of the impact of water use, the volumetric water footprint differs from the classical measure of water withdrawal in two ways. First, it is not restricted to direct water use. Instead, the volumetric water footprint also includes water used in the supply chain of a product (e.g., water used in production of infrastructure, chemicals used in water treatment as well as water lost through leakage). This is relevant because the actual volume of freshwater a utility draws from the environment is likely to be somewhat higher than its direct water use. The water footprint can, therefore, be used to build a truer picture of the water dependence of a utility. Second, the volumetric water footprint accounts for consumptive water use only; that is, water that is removed from, but not returned to, the same drainage basin.

One of the key criticisms of the volumetric water footprint approach has been the lack of relationship between a volumetric water footprint and its associated environmental and/or social impact (Ridoutt & Poulton 2009). The water consumed over the life cycle of a product or operation comes from different sources (e.g., rivers, groundwater), comes from different locations around the world, and is used at different times. A volumetric water footprint would not distinguish between the potential impact/damage associated with these different sources. For example, 100 m³ of water taken from a water-stressed catchment is likely to have a significantly higher effect on other water users than an equivalent volume taken from a catchment where water is abundant. In this respect, the impact of water resource consumption on society and the environment is unlike the impact of greenhouse gas emissions.

As a result, the life cycle impact assessment approach has been used to define a water footprint based on the overall impact of water use, rather than just volumes of water consumed (Berger & Finkbeiner 2012, Jeswani & Azapagic 2011, Pfister & Hellweg 2011). The aim of life cycle impact assessment is to generate an aggregated index that reflects the environmental impacts of water use, accounting for location and timing as well as the type of water used (e.g., groundwater, river water). These approaches have been formalized in ISO (2014).

The application of the water footprint concept has relevance for water utility operations. The direct impact occurs in two main ways: (1) the withdrawal and consumption of water from

freshwater resources results in a depletion of the resource for other users and (2) the return of effluent water into freshwater resources limits the suitability of that water for other uses (including habitat uses). In both cases, the use of water affects other domestic, industrial, or environmental water users. There are also indirect water effects associated with the manufacture and supply of goods and services that support the operations of a water utility (e.g., electricity provision, supply of chemicals and other materials used in treatment, supply of other products such as laboratory equipment or paper used for billing).

Water utilities have not yet embraced the water footprint concept as part of their water supply management, conservation plan, or in their dialog with customers, partners, and regulators. The applicability of the water footprint concept as a planning tool within the water sector has yet to be systematically explored and articulated. However, the Global Water Research Coalition (GWRC) investigated the applicability of the water footprint concept and tools to the urban water sector (GWRC 2011) by providing a comprehensive overview of the urban water sector, its roles, and its responsibilities, and by identifying a range of possible effects of their activities on the environment. The same study presented a conceptual framework for the application of the water footprint to the water sector, which drew heavily on the approach proposed by the Water Footprint Network (Hoekstra et al. 2011) and Veolia's Water Impact Index (WII) (Veolia 2011) for a water sector. However, the GWRC report provided limited guidance on applying the water footprinting concept within the boundary of a water utility. Therefore, this article aims to fill the knowledge gaps by critically expanding the understanding of the water footprint concept and its applicability to water utilities. The specific objectives of this article are to

- identify opportunities for integrating the water footprint concept into water utility planning efforts as a broader means of achieving and maintaining sustainable communities, and
- propose guidance for implementing this concept within water utility organizations.

These objectives were met by conducting a literature review on the uses and benefits of water footprinting supported by two facilitated workshops conducted with water utility stakeholders. The critical views of the utility managers, water resources planners, and sustainability experts from more than 25 utilities were captured to assess the applicability of the water footprint concept for water utilities and critically evaluate the related metrics and the potential benefits for water utilities.

VALUE PROPOSITIONS OF THE WATER FOOTPRINT CONCEPT

To understand a water utility's or water treatment plant's water footprint, both direct and indirect water consumption should be properly inventoried. A comprehensive water footprint assessment (WFA) of a water or wastewater facility should include the compilation and evaluation of direct and indirect water consumed and disposed of as well as potential environmental impacts related to water consumption and wastewater disposal. A conceptual schematic of both direct and indirect flows in an urban water cycle, including the water and wastewater system, is presented in Figure 1.

In relation to the water footprint concept, a number of potential value propositions were identified. The details of the value propositions are presented here.

To understand a water utility's water consumption. A water footprint inventory is critical to determine the direct and indirect water consumption of a utility and to identify opportunities to minimize them within the water utility's operation. The "direct" water consumption of a water utility represents the total volume of water that has been withdrawn from, but not returned to, the same watershed as a result of evaporation processes (e.g., from reservoirs), integration into solids (e.g., sludge), or discharge to a different watershed or the sea (ISO 2014) while delivering treated water and wastewater. The direct water flows include utility sources, imported and exported waters, water supplied, water consumed, and water lost (e.g., leakage in the distribution system). Previous studies attempted to calculate the direct consumption of a water utility through performing water footprint inventories. Niccolucci et al. (2011) estimated that approximately 3.5 L of water was abstracted to provide consumers in Siena, Italy, with 1.50 L of treated tap water; leakage was the most significant loss in the distribution system. However, leakage may not be considered consumption if the water stays within the watershed. For example, Lerner (1987) found that, in Lima, Peru, leakage from the public water supply provided 30% of the groundwater recharge that in turn supplied 40% of the city's water.

Indirect water consumption embraces the embodied water associated with operations, including energy and consumables, and embodied water associated with the water utility infrastructure. The water used for producing electricity that sustains water utility operations may contribute significantly to the indirect water consumption. Two studies (Stillwell et al. 2011, Stokes & Horvath 2011) estimated the amount of energy required to deliver water to customers by combining energy consumption for raw water supply, treatment, and distribution. Stillwell et al. (2011) found that the state of Texas used an estimated 2.1–2.7 TW/h of electricity each year to supply 5.6 ML of municipal water and 1.8–2.0 TW/h for wastewater systems. The equivalent life cycle energy consumption is 0.8 MW•h/ML of water supplied, lower than the 1.5 MW•h/ML estimated by Stokes and Horvath (2011) for a California utility.

In addition, there are large differences in water consumption among different sources of power generation, with hydropower estimated to be the largest water consumer of all the sources studied (largely from evaporation losses from reservoirs) (Wilson et al. 2012). The average water consumption of US electricity generation from all sources was estimated at approximately 4 m³ per MW•h produced (Wilson et al. 2012). Using the embodied water of energy production (4,000 L/MW•h) as suggested by Wilson et al. (2012), and the energy consumption estimation of Stillwell et al. (2011) for Texas (0.8 MW•h/ML) and Stokes and Horvath (2011) for California (1.5 MW•h/ML), it is possible to calculate that, for every liter of municipal water produced, approximately 0.003–0.006 L of water is consumed in the generation of energy needed to treat and transport both the drinking water and the resulting wastewater.

As with other consumer products, a certain amount of water is embodied within the "hard assets" of the water utility, such as the pipes, buildings, and treatment works. This consists of water consumed in the production of the materials and reflects the degree of appropriation of water resources associated with infrastructure. For example, the Concrete Pipeline Systems Association (2011) compared the embodied water of wastewater pipelines made from different materials and estimated that the cradle-to-gate water use (not consumption) of precast concrete pipe (78–1,000 L/m for 0.3–1.2 m diameters) was between 2.6 and 6.7 times lower than an equivalent size plastic pipe. In addition, it was estimated that the majority of the water consumption of plastic

pipes used in the United Kingdom was associated with the production of polypropylene and high-density polyethylene resins in other parts of the world.

To address various aspects of their water footprint, water utilities might work with their energy, chemical, or other supply chain providers to reduce the effect of this indirect water use. The assessment of embedded water of infrastructure, for example, could be used for many purposes, such as to develop a water footprint of an asset (e.g., a pipeline) or a construction activity, to use the water footprint as one of the criterion for infrastructure selection (e.g., concrete versus plastic pipe), to benchmark water consumption of a construction activity, and to develop objectives and strategies to support the organization's sustainability goals (e.g., minimize indirect water consumption).

To understand effects on water quality. Water utilities can affect the quality of local water bodies through discharges of treated wastewater and residuals from treatment processes. The concept of the water footprint could be used by a water utility to estimate the effect of their wastewater discharges on water availability. Morera et al. (2016) assessed the appropriation of water resources in wastewater treatment plants (WWTPs) by considering both the volume of water consumed and the water required to dilute discharges to acceptable standards. In that article, the usefulness of the proposed methodology in assessing the environmental impact and benefits of the discharge from a WWTP were illustrated using three scenarios: no treatment, secondary treatment, and phosphorus removal. A reduction of the water appropriation by 51.5 and 72.4% was achieved using secondary treatment and chemical phosphorus removal, respectively, to fulfill the legal limits. These results indicate that when treating wastewater, there is a large decrease in the water required to dilute pollutants compared with the no-treatment scenario.

Although a water utility could quantify the total volume of polluted water discharged, it might be considerably more difficult to gather the information necessary to calculate the volume of water required to dilute pollutants. A water utility would not only need to know the concentration of pollutants in both the discharge and receiving waters at the time and point of discharge, but also the exact volumes required to achieve a set of discharge concentrations. The quality standard of the utility's discharge (as set by the discharge permit) should be the target, rather than the quality standard for the catchment as a whole to account for the cumulative effects of pollution caused by other water users in a catchment. It is worth debating, however, whether a utility that is meeting legal discharge standards would be creating a significant effect, because these factors are already measured in establishing discharge limits.

In addition to the water quality impacts of discharges, these impacts in the supply chain (e.g., associated with infrastructure and operations) should also be considered. In the same way that power generation contributes to water consumption, it also contributes to the degradation of water quality. Wilson et al. (2012) estimated that, in 2009, the water required to dilute pollutants of US electricity generation was more than 150 m³/MW•h and was 37 times the consumption of water.

To understand impacts on water. Veolia (2011) proposed approaches to impact-based analysis based on the WII, which explicitly aimed to provide a combined assessment of water quality and

quantity impacts, rather than volumes alone. The WII incorporates a water stress index—an indication of whether water is being abstracted from water-rich or water-stressed sources—and a quality index, described as the difference between the quality of the water (abstracted or discharged) and the quality standards associated with the given water body. The City of Milwaukee was used as a case study within an assessment and planning framework that sought ways to minimize the city’s overall WII (Veolia 2011).

According to the results presented in Table 2, most of the WII in a drinking water operation is from raw water abstraction, whereas the majority of WII in wastewater operation is from the discharge of treated water. The negative value of the WII in the wastewater operation resulted from the assumption that the treated wastewater was discharged into the same watershed and helped minimize the total operation’s water consumption. Such an analysis assisted the City of Milwaukee (Wis.) in understanding the combined water quantity and quality effects of its operation. Although holistic approaches, such as the WII, are needed, some limitations of the WII have been pointed out: for instance, Berger and Finkbeiner (2012) point out that an assessment of impact from water quality degradation requires specification and careful consideration of impact pathways (from the source of the contaminant to the recipient of its effects), which are not specified in Veolia’s approach.

More complete evaluations of the environmental impacts of water supply and wastewater treatment have used LCA approaches. Vince et al. (2008) developed an LCA tool that could systematically evaluate different scenarios for potable water production. The model they used considered a range of effects on the environment and human health, but the authors acknowledged that the model could not adequately deal with water quality impacts resulting from pollutant emissions (e.g., ecotoxicity) because the nature of such impacts are dependent on the condition of local ecosystems. Similarly, Muñoz et al. (2010) used LCA to compare the overall impacts of large-scale water supply plans in Spain and excluded evaluations of ecotoxicity impacts. This study included an assessment of impacts on freshwater ecosystems resulting from abstraction, which is not yet considered standardized for LCA methodologies. Pasqualino et al. (2010) used LCA to assess the environmental profile of a Spanish WWTP and to compare four alternative final destinations for wastewater. The study showed that tertiary treatment slightly increased the environmental impact of the treatment plant, but the resulting reclaimed water could be reused for nonpotable uses and become beneficial in water-stressed areas.

To understand the relationship between carbon footprint and water footprint. There are complex interrelationships between water use and energy use, often referred to as the water–energy nexus. Water utilities use large amounts of energy to abstract, treat, and transport water and wastewater, with significant carbon footprints (Griffiths-Sattenspiel & Wilson 2009, Strutt et al. 2008). This energy use contributes substantially to the overall environmental impact of the water sector. Water footprint and carbon footprint information may assist water utilities in determining the impact of their energy mix on the environment. Such analysis is critical to understanding the link between the operations of electric and water utilities and promoting strategic integrated planning between the two sectors.

A few studies have attempted to combine water footprint analysis with energy-related impacts. A comparison of the carbon footprint and embodied water consumption of plastic and concrete

pipes was published by the Concrete Pipeline Systems Association (2011) that indicated that concrete pipes have a lower carbon footprint and a lower embodied water footprint compared with plastic pipes. Thus, knowledge on the embodied carbon footprint and water footprint may assist water utilities in making critical decisions about infrastructure material selection.

In another study, the ecological footprint assessment of Sydney Water Corporation (Lenzen et al. 2003) combined energy use with water use measures. Although this study omitted important measures, such as downstream water quality effects, it showed that the most significant contribution to Sydney Water Corporation's ecological footprint was from its electricity consumption, not its water abstraction. Furthermore, after water was delivered, customers used more energy for heating, cooling, and general purposes.

The simultaneous analysis of water footprint and carbon footprint may become increasingly important for water utilities, particularly when considering future development options. Some options may become more favorable if they reduce both water and energy footprints; techniques for energy recovery from wastewater treatment may offer some examples of such options and have become a considerable focus of research interest in recent years (Stillwell et al. 2010). However, for some energy-intensive development options (e.g., desalination), it is likely that utilities will need to carefully evaluate the tradeoffs between reducing water footprints and reducing energy needs.

To achieve sustainable water supply planning. Water footprint analysis can be an important strategic planning tool in developing and implementing a sustainable water supply portfolio. The water footprint concept may be used to achieve several water supply planning objectives: water use benchmarking, water conservation or water reuse promotion, water resources planning integration, and economic productivity assessment. The water footprinting concept may also influence the water supply planning process by assisting water utilities in developing strategies that provide better water demand management in short- and long-term environmental impact assessment at local, regional, or national levels, or in watershed management and protection.

To date, there has been no published literature showing the application of the water footprinting concept in water supply planning through pilot studies. However, several research studies have demonstrated its application in high-level allocation decisions, the implementation of targeted efficiency measures, an understanding of the complex tension between environmental water needs and dependency on irrigated agriculture, or spatial redistribution of water-intensive crops.

Zhao et al. (2010, 2009) have attempted to calculate regional (e.g., river basin) or national water footprints. Such studies often illustrate different levels of water use by sector, which can help with high-level allocation decisions and in developing targeted water efficiency measures. Additionally, water footprint analyses around the Guadiana river basin (Aldaya & Llamas 2009) and the Doñana region (Aldaya et al. 2010) in Spain specifically sought to incorporate both hydrologic and economic analyses and to illustrate environmental water requirements. The goal of these analyses was to develop a framework to help deal with the complex tensions between environmental water needs and the dependency on irrigated agriculture. The analyses provided a basis for recommending the purchase of water rights from farmers growing low-value, water-intensive crops. Similarly, Montesinos et al. (2011) used a virtual water balance approach to argue for the spatial redistribution of certain water-intensive crops, particularly olives, within the Guadalquivir river basin (Spain).

Water footprinting has also been used in the Breede Catchment (South Africa) to support national policy objectives for the water sector by comparing the direct farm job and gross income impacts of water consumption between subcatchments and between crops (Pegasys 2010). As with the Spanish examples, this analysis highlights how certain irrigated crops might be economically inefficient uses of water.

Some of the different styles of water footprint analysis mentioned earlier (e.g., the “urban water footprint”) (Jenerette et al. 2006, Jenerette & Larsen 2006) and the “water supply footprint” (Stoeglehner et al. 2011) can also be used to support strategic-level planning for urban development. In particular, the water supply footprint analysis, which was applied in Australia, was used to demonstrate how rainwater and stormwater harvesting, and wastewater recycling as supplemental supply sources, could be used to meet a substantial portion of residential water demand, thus easing pressure on local ground and surface water sources.

To enhance communication among stakeholders. Regardless of the approach used, water footprints are all (to varying degrees) simplifications of highly complex scenarios and intuitively illustrate the burden placed on water resources. As a result, they are becoming powerful tools for communication and awareness-raising around the need to reduce the overall impact of human activities and illustrate general patterns of water use (Hoekstra et al. 2011). For instance, the environmental group WWF now uses a water footprint approach as a solid platform for research, education, and campaigning. In a similar vein, a water utility could potentially use a water footprint as a tool for improving communication with its own customers or other water users, or for benchmarking and reporting on its own performance.

The need for managing water demand is becoming increasingly important, particularly for promoting water conservation measures among customers (e.g., metering, price increases) (Sharp 2006). Water footprint approaches could be used as an important means to instill a culture of water efficiency, based on the understanding that water use has immediate or long-term, localized, and far-reaching consequences.

Each water utility faces its own unique challenges to convey the value of water to its customers. The value of water often differs from its marginal cost (expense of producing and delivering a unit of water) and its price (the rate charged to a customer for the unit of water delivered), and this is not always properly understood by the general public. The value of water also depends on several other factors, such as how the water is used, its quality, the time and location at which it is available, and its relative scarcity. Often, the value of water is difficult to determine and communicate because a number of factors, beyond the cost and price of water, need to be considered. Therefore, awareness and education of the public toward principles of water value and water efficiency are of great importance for sustainable management of water use; however, it is important to coordinate this with communication plans already in place on the value of water.

The costs of some elements (economic and environmental externalities, societal objectives, and intrinsic values) are difficult to assess, which creates a challenge in determining the full value of water and its impact in society. However, water utilities and major water using industries can use the water footprint concept to raise awareness about the nonmarket value of water usage among decision makers, stakeholders, and consumers, and thereby encourage sustainable consumption of water.

Water footprints could also be used by utilities to raise awareness among domestic consumers of wasteful behaviors in their homes by including water footprint-related information on water bills to show domestic customers the impact of leaving taps running, using old washing machines, or even throwing away waste food. In the United Kingdom, some water companies offer water efficiency advisory services for business users to reduce their overall water footprint. Water footprint analyses could be used as a tool to leverage downstream users to a more efficient use of water within their operations. In addition, footprinting could be used by a utility to highlight the water-related financial risks to which their investors are exposed (e.g., for highlighting the potential for lost revenues) if access to water resources becomes constrained.

Certification and labeling systems aim to provide assurance that specified production methods or product characteristics have been met, and there are several product labeling systems globally that attempt to convey information regarding a product's water efficiency. For example, the Smart Approved WaterMark in Australia (SWM 2012), the WaterSense Label in the United States (USEPA 2012), and the Waterwise Recommended Checkmark in the United Kingdom (Waterwise 2012) are indicators of the water-saving potential of bathroom and kitchen appliances and outdoor water-using products. Such labeling systems can encourage water utility customers to reduce their water demand and, by implication, their impact on the water environment. Thus, water footprint labeling could provide a means of communicating to customers the water-related impacts of their purchasing and consumption habits in a manner analogous to carbon footprint labeling.

To improve environmental performance reporting. The water footprinting concept could also be used for reporting of water utilities' environmental performance. The Global Reporting Initiative has published a suite of sustainability reporting guidelines that provide guidance to corporations on reporting numerous aspects of their environmental performance, including total water withdrawal by source, water sources significantly affected by withdrawal, and the amount of water recycled (GRI 2011). Morikawa et al. (2007) assessed how these reporting protocols were being used across a range of sectors and found wide variation in how water-related indicators were measured, defined, and reported. They also found that in the utilities sector (which encompassed the water sector), there was no assessment or reporting of water measures for supply chains (i.e., indicators of embodied water). If used coherently, a water footprint framework might therefore add depth and consistency to environmental performance reporting within the water sector.

Water footprint analyses can also be used to highlight other features of water sector performance, such as economic aspects. For instance, Zhang et al. (2008) calculated the "water footprint intensity" (cost per unit of water) for a region in China and argued that long-term changes in the metric (i.e., decreasing cost over time) demonstrated efficiency improvements in water utilities. These kinds of efficiency analyses might also be used to compare utilities with one another or with multiple facilities owned or operated by a single entity.

Detailed water footprint accounts could also be used to benchmark different industrial processes (e.g., within a water utility customer's operations) and products, ensuring that water consumption is accounted for over the full life cycle. As an example, consider one appliance manufacturer might produce A-rated washing machines while another produces D-rated washing machines.

The manufacturer producing A-rated washing machines might use more water in its operations, but over the lifetime of the product, significant amounts of water might be saved.

To develop community sustainability. A potential application of the water footprint concept is to identify a portfolio that may lower the effects of a utility's own operations on the environment. However, to ensure that the community is sustainable, it is also important to recognize that water is a regional resource and that existing water resources are stressed in many places, competition for new water sources is growing, multiuse of water is growing, and quality of new water sources is of concern. Although water utilities should ensure during their water supply planning (water supply portfolio selection) that their water footprint is sustainable, it is also important that they share the responsibility with other industries (commercial, industrial, agricultural) for managing sustainable allocation of water resources within their community. An example of distribution of water use among sectors in the United States in 2005 presented in Table 3 suggests that most of the water withdrawal in the United States is due to power generation and irrigation (Kenny et al. 2005).

Irrigation practices and crop types have also changed with time, technology, and the economy. According to the US Geological Survey, in some areas, increased costs and reduced water availability have led to the use of more efficient irrigation practices and reduced related water use (Kenny et al. 2005). In other areas, both water use and irrigated areas have increased because of water availability, demand for certain crops, and the desire to improve crop yield by using irrigation to supplement rainfall. The water footprint concept may provide a better communication tool for effective dialog with agricultural water users on water use in the local context.

Climatic fluctuations have a prominent effect on water withdrawals, particularly those for irrigation, thermoelectric power generation, and public supply. For example, in 2012, many regions in the United States experienced drought conditions through the late winter and spring months that lasted into the summer. Periodic droughts have drawn attention to the limits of local and regional water supplies. In addition, changes in global climate with rising temperatures could cause irrigation requirements for crops and landscaping to increase along with in-stream flow requirements.

The water footprint concept provides a common parameter that could be used to initiate water management discussions among water users on a local, regional, or national level so that the sustainability of a community can be maintained. Water utilities may be able to use the water footprinting concept to communicate their water resource management approach and thereby determine the right balance for use of water in a local context. For instance, the water footprint concept might be useful in making effective decisions related to conserving water resources for drought seasons and establish a basis for determining management strategies for balancing different water resources in an area (lakes, rivers, boreholes) for drinking water, recreation, energy production, and agricultural uses.

WATER FOOTPRINT APPLICATION GUIDANCE

ISO 14046, *Environmental Management – Water Footprint – Principles, Requirements and Guidelines* (ISO 2014), is considered the primary reference for any LCA-based WFA. A WFA

should include a water footprint inventory (WFI) assessment that involves compilation and quantification of the water consumption within the system boundaries (i.e., criteria specifying the unit processes under consideration). A WFA should also include a compilation of impact category indicator results addressing the potential impacts (e.g., water stress, water quality) related to the water environment. The results obtained from such an assessment define a water footprint profile (WFP). Although the WFI refers to water consumption, the WFP relates to different impacts (e.g., water scarcity footprint, eutrophication footprint) that are not weighted or normalized.

The WFA can be conducted at different scales: for an entire organization, at a treatment plant, or at the infrastructure level. The scope and definition of the boundaries and the reporting units should be properly identified. A WFA is an iterative process and the results of one phase or unit may affect the results of other phases or units. To ensure comprehensiveness and consistency of the assessment, the iterative approach within and between the phases needs to be maintained. Typically, a WFA should start with the smaller units and gradually be expanded to larger operational units such as the entire water utility as conceptualized in Figure 2. Community-owned utilities may wish to add another higher level of use above the organization's water footprint to consider how water is being exploited in the local context. Although this bottom-up approach is necessary for assessing water consumption within a water utility's operation, the time and resources required for such an assessment can be substantial. Therefore, the objectives and boundary conditions should be carefully defined during the planning stage and a multidisciplinary team including sustainability, operations, and procurement employees needs to be formed for water footprinting activities.

To meet any of the objectives listed here, water utilities need to go through a WFI or WFP assessment for one or more infrastructures. The assessment can be performed on existing infrastructure or on new infrastructure that will be built in the near future. Each infrastructure or treatment plant project deals with a wide variety of construction materials, construction activities, and commissioning steps. The first step of a WFA for an infrastructure project is to identify the four major elements: (1) water consumption of all construction materials, (2) water consumption of construction and commissioning activities, (3) water consumption of asset management, and (4) water consumption for decommissioning activities. A conceptual schematic of the major elements is presented in Figure 3.

The water footprint of construction materials may vary significantly depending on the types of materials used. Similarly water consumption of the construction activities may vary widely. Some of the common construction activities in a water utility include excavation and onsite disposal, sheet pile driving, concrete placing, installation of mechanical and electrical plants, and filling and compaction. Therefore, different water and wastewater infrastructure may have different impacts on the water environment. The infrastructure can be compared based on the WFA of each of the four major categories or all four elements combined. The application of the WFI for developing a water footprint profile or for comparing two alternatives is presented in Figures 4 and 5.

The WFI assessment of a water utility may include different activities such as abstraction, raw water transmission, water treatment, water distribution, chemicals addition, discharge of treated water, disposal of sludge, wastewater collection, sludge treatment, sludge to land, sludge liquor, groundwater recharge, and evaporation. Each of these activities involves both direct and indirect consumption of water. Typically, the direct water consumption data are readily available from

the water auditing and data collection process conducted by the water utility; however, a more deliberate initiative is required to estimate the WFI of infrastructure and construction activities. Figure 4 describes a conceptual framework to calculate the WFI of infrastructure, construction activities, and consumables (e.g., energy, chemicals). The framework is applicable at various levels from individual components to water treatment plants to infrastructure systems, catchment operations, and ultimately to an entire organization. This process involves a systematic review of water consumption from initial construction through operation to end of life. The direct water consumption components are combined with the indirect components in an overall WFI. Water consumed through activities such as process losses, leakage, flushing, and cleaning can be significant and need to be taken into account.

Figure 5 presents a framework that might be used to calculate the water footprint profile. When a WFA is conducted for multiple impact categories (e.g., water scarcity, water eutrophication), the results should be normalized relative to reference information (e.g., global water scarcity). This normalization may be helpful in checking for inconsistencies and providing and communicating information on the relative significance of the indicator results. A complete WFA requires an impact assessment of all activities on the environment and includes a compilation of impact category indicator results addressing all the potential impacts related to water. The indicator results of different impact categories can be weighted by numerical factors based on value choices (ISO 2006) and summed to produce an overall water footprint (ISO 2014).

The water footprint values might be used in conjunction with other parameters (e.g., carbon footprint, life cycle costs) for optioneering purposes. The frameworks presented in Figures 4 and 5 are conceptual and should be validated, modified, or customized for the needs of each utility for assessing the value propositions identified in this article.

IMPLICATIONS

Water footprinting is still at its early stage of implementation in the industry. Over time, the science has developed and evolved; as a result, there are many inconsistencies among the research to date. It is clear that, although there is general agreement regarding what the water footprint should represent (i.e., it should be an indicator of the potential impacts of human activities on the water environment) and that it has been used for a wide range of applications, there are certain levels of challenges associated with all applications. The limitations on the applicability of the water footprinting concept at water utilities for different application categories are presented in Table 4.

A particular issue for water utilities relates to the definition of water consumption in a spatial context. The volume of water consumed is relevant to a water utility because it is a measure of the amount of freshwater no longer available for other purposes as a result of delivering freshwater services (GWRC 2011). The majority of the water withdrawn from a water resource for public water supply is returned through the wastewater system or transmission losses (leakage); however, this water is not returned at the same point or time as the withdrawal. On a watershed and annual scale, only wastewater discharged to estuaries or the sea would be considered consumptive use; the rest is available for use within the basin. However, withdrawal may occur from a surface water body or aquifer unit that is overexploited within a basin not otherwise water-stressed. Equally, the wastewater returns may help sustain flows in otherwise stressed parts of the basin and leakage from the public water supply system may contribute to

local recharge. The choice of the appropriate scale at which to define “consumption” is, therefore, critical.

Many types of water use vary over time. For example, during a hot year, water utilities may need to abstract more water as their customers use more water for their gardens. Alternatively, a water utility might have invested in a significant amount of new infrastructure in one year, but would be using the infrastructure for several decades (a reservoir, for example). Hence, the higher water footprint estimated during the same year does not necessarily indicate that the water is being used less wisely by the utility. Hoekstra et al. (2011) note that water footprint data will often show a more meaningful picture if taken as an average over a period of years rather than over a shorter time frame.

The calculation of any water footprint should be specified in river basins and water bodies (groundwater bodies and aquifers in the case of groundwater). It is, however, recognized that difficulty might arise in obtaining data in terms of hydrological boundaries (as data sets are generally compiled for administrative regions rather than for river basins, catchments, or water bodies), which in turn may require the redefinition of spatial boundaries. Annual averages or totals of water related information are generally considered to be of limited value when monitoring or assessing water resources. In order to take into account the effects of seasonality, data aggregation at least at a monthly resolution is recommended, although this may need to be refined depending on availability of data and resources to undertake the assessment (GWRC 2011).

Despite the challenges, the value of conducting a WFA is increasingly being recognized. To increase widespread application of the water footprint concept, the following research on the accounting methods and applications is warranted in the future:

- Further development of the water footprint concept and accounting methods that are specific to water utilities is needed to better understand the benefits and challenges of its application.
- Pilot studies should be conducted to demonstrate the applicability of existing frameworks for water utilities and to demonstrate how the water footprint concept can be implemented by a water utility.
- Stakeholder involvement should be ensured in future research efforts so that their feedback can be included in identifying the most valuable application propositions and in developing a WFA framework specific to water utilities.

ACKNOWLEDGMENT

The authors gratefully acknowledge the Water Research Foundation’s financial, technical, and administrative assistance in funding and managing the project. The authors thank the Foundation Project Officer, Maureen Hodgins, all participating project stakeholders, Joan Oppenheimer, and the project advisory committee of the Water Research Foundation. The following individuals attended the workshops and provided valuable input to the findings of the study: Adrian Johnson, MWH, United Kingdom; Aracely Jaramillo, Los Angeles County, Calif., USA; Angela Wallis, England and Wales Environment Agency, United Kingdom; Bill Swanson, MWH; Bo N. Jacobsen, European Environment Protection, Denmark; Brad Ridoutt, Commonwealth Scientific

and Industrial Research Association, Australia; Celeste Cantu, Santa Ana Watershed, Calif., USA; David Torres, El Paso Water District, Texas, USA; David Riley, Anglian Water, United Kingdom; Ed Pinero, Veolia, USA; Frans Schulting, Global Water Research Coalition, the Netherlands; Fraser Schilling, University of California, Davis, Calif., USA; Gavin Helen, Atkins, United Kingdom; Hal Schmidt, MWH; Iain Millar, Tata Steel, United Kingdom; Jenny Banks, Yorkshire Water, United Kingdom; John Swift, SCA Packaging, UK; Joe Smith, Austin Water, Texas, USA; John Peichel, GE, USA; Jean-Christophe Blingy, Danone, France; Karen Sans, Milwaukee Metropolitan Sewer District, Wis., USA; Neal Shinkre, St. John County, Fla., USA; Omar Moghaddam, Los Angeles Bureau of Sanitation District, Calif., USA; Patti Reyes, Coachella Valley Water District, Calif., USA; Steve Whipp, Water Innovation Consultant, United Kingdom; and Vance Fong, US Environmental Protection Agency, Calif., USA. The comments and conclusions detailed in this article do not reflect the views of the Water Research Foundation, its officers, affiliates, or agents.

REFERENCES

- Aldaya, M.M. & Hoekstra, A.Y., 2010. The Water Needed for Italians to Eat Pasta and Pizza. *Agricultural Systems*, 103:6:351. <https://doi.org/10.1016/j.agsy.2010.03.004>.
- Aldaya, M.M. & Llamas, M.R., 2009. *Water Footprint Analysis for the Guadiana River Basin*. Value of Water Research Report Series, No.35, UNESCO-IHE, Delft, the Netherlands.
- Aldaya, M.M.; García-Novo, F.; & Llamas, M.R., 2010. *Incorporating the Water Footprint and Environmental Water Requirements Into Policy: Reflections From the Doñana Region (Spain)*. Papeles de Agua Virtual, No. 5. Observatorio del Agua. Impreso en REALIFRAF, Madrid, Spain.
- Auguste, L., 2010. *The Blue Footprint in Milwaukee, First-Ever Water Impact Index and Carbon-Water-Economic Analysis*. A presentation by Veolia Water Americas. www.metroplanning.org/uploads/cms/documents/benichou_water_impact_index_aug_3_2010.pdf (accessed June 21, 2017).
- Batista de Pina, L.A.; Dias, A.C.; Neto, B.; Arroja, L.; & Quinteiro, P., 2011. The Water Footprint of Wine Production in Portugal. A Case-Study on “Vinho Verde.” hdl.handle.net/10216/55964 (accessed June 21, 2017).
- Berger, M. & Finkbeiner, M., 2012. Methodological Challenges in Volumetric and Impact-Oriented Water Footprints. *Journal of Industrial Ecology*, 16:3:79. <https://doi.org/10.1111/j.1530-9290.2012.00495.x>.
- Berger, M.; Warsen, J.; Krinke, S.; Bach, V.; & Finkbeiner, M., 2012. Water Footprint of European Cars: Potential Impacts of Water Consumption Along Automobile Life Cycles. *Environmental Science and Technology*, 46:4091. <https://doi.org/10.1021/es2040043>.
- Chapagain, A.K. & Hoekstra, A.Y., 2007. The Water Footprint of Coffee and Tea Consumption in the Netherlands. *Ecological Economics*, 64:1:109. <https://doi.org/10.1016/j.ecolecon.2007.02.022>.
- Concrete Pipeline Systems Association, 2011. *Water Footprinting of Wastewater Pipelines*. Leicestershire, UK.
- Galli, A.; Wiedmann, T.; Ercin, E.; Knoblauch, D.; Ewing, B.; & Giljum, S., 2012. Integrating Ecological, Carbon and Water Footprint Into a “Footprint Family” of Indicators. Definition and Role in Tracking Human Pressure on the Planet. *Ecological Indicators*, 16:100. <https://doi.org/10.1016/j.ecolind.2011.06.017>.

- Gerbens-Leenes, P.W.; Mekonnen, M.M.; & Hoekstra, A.Y., 2013. The Water Footprint of Poultry, Pork and Beef: A Comparative Study in Different Countries and Production Systems. *Water Resources and Industry*, 1:25. <https://doi.org/10.1016/j.wri.2013.03.001>.
- GRI (Global Reporting Initiative), 2011. *Indicator Protocols Set - Environment* (v 3.1). Amsterdam, the Netherlands.
- Griffiths-Sattenspiel, B. & Wilson, W., 2009. *The Carbon Footprint of Water*. River Network, Portland. www.csu.edu/cerc/researchreports/documents/CarbonFootprintofWater-RiverNetwork-2009.pdf (accessed June 21, 2017).
- GWRC (Global Water Research Coalition), 2011. *Water Footprinting in the Urban Water Sector*. Global Water Research Coalition, London.
- Herath, I.; Deurer, M.; Horne, D.; Singh, R.; & Clothier, B., 2011. The Water Footprint of Hydroelectricity. A Methodological Comparison From a Case Study in New Zealand. *Journal of Cleaner Production*, 19:14:1582. <https://doi.org/10.1016/j.jclepro.2011.05.007>.
- Hess, T.M.; Chatterton, J.; Daccache, A.; & Williams, A., 2016. The Impact of Changing Food Choices on the Blue Water Scarcity Footprint and Greenhouse Gas Emissions of the British Diet: The Example of Potato, Pasta and Rice. *Journal of Cleaner Production*, 112:5:4558. <https://doi.org/10.1016/j.jclepro.2015.08.098>.
- Hess, T.M.; Lennard, A.T.; & Daccache, A., 2015. Comparing Local and Global Water Scarcity Information in Determining the Water Scarcity Footprint of Potato Cultivation in Great Britain. *Journal of Cleaner Production*, 87:666. <https://doi.org/10.1016/j.jclepro.2014.10.075>.
- Hoekstra, A.Y.; Chapagain, A.K.; Aldaya, M.M.; & Mekonnen, M.M., 2011. *The Water Footprint Assessment Manual, Setting the Global Standard*. www.waterfootprint.org/downloads/TheWaterFootprintAssessmentManual_2.pdf (accessed June 21, 2017).
- Hoekstra, A.Y. & Hung, P.Q., 2002. *Virtual Water Trade. A Quantification of Virtual Water Flows Between Nations in Relation to International Crop Trade*. Value of Water Research Report Series, No 11. UNESCO-IHE, Delft, The Netherlands. <http://waterfootprint.org/media/downloads/Report11.pdf> (accessed June 21, 2017).
- ISO (International Organization for Standardization), 2014. *Environmental Management – Water Footprint – Principles, Requirements and Guidelines*. ISO/DIS 14046.
- ISO, 2006. *Environmental Management - Life Cycle Assessment - Requirements and Guidelines*. ISO 14044:2006.
- Jenerette, G.D. & Larsen, L., 2006. A Global Perspective on Changing Sustainable Urban Water Supplies. *Global and Planetary Change*, 50:3–4:202. <https://doi.org/10.1016/j.gloplacha.2006.01.004>.
- Jenerette, G.D.; Wu, W.; Goldsmith, S.; Marussich, W.A.; & Roach, W.J., 2006. Contrasting Water Footprints of Cities in China and the United States. *Ecological Economics*, 57:3:346. <https://doi.org/10.1016/j.ecolecon.2005.04.016>.
- Jeswani, H.K. & Azapagic, A., 2011. Water Footprint. Methodologies and a Case Study for Assessing the Impacts of Water Use. *Journal of Cleaner Production*, 19:12:1288. <https://doi.org/10.1016/j.jclepro.2011.04.003>.
- Katsoufis, S., 2009. Cradle-to-Gate Water Footprint Analysis of Borealis Group Polyolefin Value Chain. Master's thesis, Division of Industrial Industry, KTH Royal Institute of Technology, Stockholm. <http://waterfortheworld.net/fileadmin/w4w/pdf/case->

- studies/WF_Thesis_Final_Report_internal_version.pdf (accessed June 21, 2017).
- Kenny, F.J.; Barber, L.N.; Hutson, S.B.; Linsey, S.K.; Lovelace, K.J.; & Maupin, A.M., 2005. *Estimated Use of Water in the United States in 2005*. US Geological Survey, Reston, Va. <http://pubs.usgs.gov/circ/1344/pdf/c1344.pdf> (accessed June 21, 2017).
- Lenzen, M.; Lundie, S.; Bransgrove, G.; Charet, L.; & Sack, F., 2003. Assessing the Ecological Footprint of a Large Metropolitan Water Supplier. Lessons for Water Management and Planning Towards Sustainability. *Journal of Environmental Planning and Management*, 46:1:113. <https://doi.org/10.1080/713676700>.
- Lerner, D.N., 1987. Leaking Pipes Recharge Ground Water. *Ground Water*, 24:654. <https://doi.org/10.1111/j.1745-6584.1986.tb03714.x>.
- Mekonnen, M.M. & Hoekstra, A.Y., 2011. National Water Footprint Accounts: The Green, Blue and Grey Water Footprint of Production and Consumption. Volume 1: Main Report. Value of Water Research Report Series, No. 50. UNESCO-IHE, Delft, The Netherlands. <http://waterfootprint.org/media/downloads/Report50-NationalWaterFootprints-Vol1.pdf> (accessed June 21, 2017).
- Mekonnen, M.M. & Hoekstra, A.Y., 2010. A Global and High-Resolution Assessment of the Green, Blue and Grey Water Footprint of Wheat. *Hydrology and Earth System Sciences*, 14:7:1259. <https://doi.org/10.5194/hess-14-1259-2010>.
- Montesinos, P.; Camacho, E.; Campos, B.; & Rodríguez-Díaz, J.A., 2011. Analysis of Virtual Irrigation Water. Application to Water Resources Management in a Mediterranean River Basin. *Water Resource Management*, 25:1635. <https://doi.org/10.1007/s11269-010-9765-y>.
- Morera, S.; Corminas, M.; Poch, M.; Aldaya, M.M.; & Comas, J., 2016. Water Footprint Assessment in Wastewater Treatment Plants. *Journal of Cleaner Production*, 112:4741. <https://doi.org/10.1016/j.jclepro.2015.05.102>.
- Morikawa, M.; Morrison, J.; & Gleick, P., 2007. *Corporate Reporting on Water. A Review of Eleven Global Industries*. Pacific Institute, Oakland, Calif. www.pacinst.org/app/uploads/2013/02/corporate_reporting_on_water3.pdf (accessed June 21, 2017).
- Muñoz, I.; Mila-i-Canals, L.; & Fernandez-Alba, A.R., 2010. Life Cycle Assessment of Water Supply Plans in Mediterranean Spain: The Ebro River Transfer Versus the AGUA Programme. *Journal of Industrial Ecology*, 14:6:902. <https://doi.org/10.1111/j.1530-9290.2010.00271.x>.
- Niccolucci, V.; Botto, S.; Rugani, B.; Nicolardi, V.; Bastianoni, S.; & Gaggi, C., 2011. The Real Water Consumption Behind Drinking Water. The Case of Italy, *Journal of Environmental Management*, 92:10:2611. <https://doi.org/10.1016/j.jenvman.2011.05.033>.
- Pasqualino, J.C.; Meneses, M.; & Castells, F., 2010. Life Cycle Assessment of Urban Wastewater Reclamation and Reuse Alternatives. *Journal of Industrial Ecology*, 15:49. <https://doi.org/10.1111/j.1530-9290.2010.00293.x>.
- Pegasys, 2010. *Water Footprint Analysis for the Breede Catchment, South Africa*. Report prepared by Pegasys for the Catchment Management Agency, Breede Overberg, South Africa.
- Pfister, S. & Hellweg, S., 2011. *Presentation and Evaluation of Existing Methods to Characterize Different Water Use Flows in Life Cycle Studies and Operational Indicators for Water Use*. Report prepared within the EC 7th framework project (Prosuite), Department of Science, Technology and Society, Utrecht University, The

- Netherlands.
- Ridoutt, B.G. & Poulton, P., 2009. SAI Platform Australia Water Footprint Pilot Project. Wheat, Barley and Oats Grown in the Australian State of New South Wales, Victoria, Australia. Commonwealth Scientific and Industrial Research Organisation, Canberra, Australia.
- RPA (Risk & Policy Analysts) & Cranfield University, 2011. *Assessment of the Efficiency of the Water Footprinting Approach and of the Agricultural Products and Foodstuff Labeling and Certification Schemes*. Final Report, Part A.
<http://ec.europa.eu/environment/water/quantity/planning.htm> (accessed June 21, 2017).
- Sharp, L., 2006. Water Demand Management in England and Wales. Constructions of the Domestic Water User. *Journal of Environmental Planning and Management*, 49:6:869.
<https://doi.org/10.1080/09640560600946933>.
- Stillwell, A.S.; Hoppock, D.C.; & Webber, M.E., 2010. Energy Recovery From Wastewater Treatment Plants in the United States: A Case Study of the Energy–Water Nexus. *Sustainability*, 2:4:945. <https://doi.org/10.3390/su2040945>.
- Stillwell, A.S.; King, C.W.; Webber, M.E.; Duncan, I.J.; & Hardberger, A., 2011. The Energy–Water Nexus in Texas, Part of a Special Feature on “The Energy–Water Nexus. Managing the Links Between Energy and Water for a Sustainable Future.” *Ecology and Society*, 16:1.
- Stoeglehner, G.; Edwards, P.; Daniels, P.; & Narodoslawsky, M., 2011. The Water Supply Footprint (WSF): A Strategic Planning Tool for Sustainable Regional and Local Water Supplies. *Journal of Cleaner Production*, 19:1677.
<https://doi.org/10.1016/j.jclepro.2011.05.020>.
- Stokes, J. & Horvath, A., 2011. Life-Cycle Assessment of Urban Water Provision: Tool and Case Study in California. *Journal of Infrastructure Systems*, 17:1:15.
[https://doi.org/10.1061/\(ASCE\)IS.1943-555X](https://doi.org/10.1061/(ASCE)IS.1943-555X).
- Strutt, J.; Wilson, S.; Shorney-Darby, H.; Shaw, A.; & Byers, A., 2008. Assessing the Carbon Footprint of Water Production. *Journal AWWA*, 100:6:80.
- SWM (Smart Water Mark), 2012. Smart Approved WaterMark. www.smartwatermark.org (accessed June 21, 2017).
- USEPA (US Environmental Protection Agency), 2012. *The WaterSense Label*. www.epa.gov/watersense/ (accessed June 21, 2017).
- van Lienden, A.R.; Gerbens-Leenes, P.W.; Hoekstra, A.Y.; & van der Meer, T.H., 2010. *Biofuel Scenarios in a Water Perspective: The Global Blue and Green Water Footprint of Road Transport in 2013*. Value of Water Research Report Series, No. 34. UNESCO-IHE Institute for Water Education, Delft, The Netherlands.
<https://doi.org/10.1016/j.gloenvcha.2012.04.001>.
- Veolia, 2011. *The Water Impact Index and the First Carbon-Water Analysis of a Major Metropolitan Water Cycle*. www.2degreesnetwork.com/groups/2degrees-community/resources/water-impact-index-first-carbon-water-analysis-major-metropolitan-water-cycle-veolia/ (accessed June 21, 2017).
- Vince, F.; Aoustin, E.; Bréant, P.; & Marechal, F., 2008. LCA Tool for the Environmental Evaluation of Potable Water Production. *Desalination*, 220:37.
<https://doi.org/10.1016/j.desal.2007.01.021>.
- Wackernagel, M. & Rees, W., 1996. *Our Ecological Footprint. Reducing Human Impact on the Earth*. New Society Publishers, Gabriola Island, B.C., Canada.
- Waterwise 2012. *Waterwise Recommended Checkmark*.

- www.waterwise.org.uk/pages/waterwise-recommended.html (accessed June 21, 2017).
- WBCSD (World Business Council for Sustainable Development), 2010. Water Footprint Workshop for Corporate Pilot Testers, WBCSD Summary Report. <http://temp.waterfootprint.org/downloads/CorporateWaterFootprintWorkshop-Montreux-8March2010.pdf> (accessed June 21, 2017).
- Wilson, W.; Leipzig, T.; & Griffiths-Sattenspiel, B., 2012. *Burning Our Rivers: The Water Footprint of Electricity*. River Network, Portland, Ore.
- Zhang, Y.; Xu, J.; & Lü, G., 2008. Dynamic Analysis of Water Footprint and Resources Utility Efficiency of Xinjiang in Northwest China Arid Areas. *Journal of Desert Research*, 28:4:775.
- Zhao, X.; Chen, B.; & Yang, Z.F., 2009. National Water Footprint in an Input–Output Framework—A Case Study of China 2002. *Ecological Modelling*, 220:2:245. <https://doi.org/10.1016/j.ecolmodel.2008.09.016>.
- Zhao, X.; Yang, H.; Yang, Z.; Chen, B.; & Qin, Y., 2010. Applying the Input-Output Method to Account for Water Footprint and Virtual Water Trade in the Haihe River Basin in China. *Environmental Science and Technology*, 44:23:9150. <https://doi.org/10.1021/es100886r>.



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Value propositions of the water footprint concept for sustainable water utilities

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2017-09-01

American Water Works Association (AWWA)

<http://dx.doi.org/10.5942/jawwa.2017.109.0100>

Badruzzaman M, Hess T, Smith H, et. al., (2017) Value propositions of the water footprint concept for sustainable water utilities. Journal: American Water Works Association, Volume 109, Issue 9, September 2017, pp. E393-E408