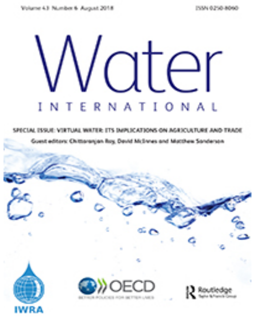

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EDITORS' INTRODUCTION

Virtual water: its implications on agriculture and trade

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Water is the basis of life. And, unlike various forms of energy generation, water cannot simply be created where it is needed. Freshwater is remarkably scarce, comprising just 2.5% of the global water supply. Although this water at an annual level may be judged as sufficient for human use, spatio-temporal variations in the availability of freshwater over the globe is a challenge. Growing populations and rising levels of affluence mean increased competition for water, raising vital questions of equity, access, and social justice at the global scale. Water is thus a lens through which to examine an array of vital issues facing humanity and the planet: human and animal health; food production; environmental management; resource consumption; climate change adaptation and mitigation; economic development, trade and competitiveness; and ethics and consumer trust – to name but a few.

The articles here, arising from a workshop supported by the OECD Co-operative Research Programme: Biological Resources Management for Sustainable Agricultural Systems, on virtual water, agriculture, and trade at the University of Nebraska-Lincoln in September 2016, consider questions of gaps in knowledge, why sustainability matters, and the policy implications of virtual water trade.

What we don't know can hurt us

A pervasive theme throughout the articles herein, and the workshop that initiated them, is the general lack of knowledge of the use of water in producing and consuming food. For instance:

- Consumers are generally unaware, when they purchase imported goods, that they are effectively outsourcing water depletion in the form of crop or food demands in another country or region. This can be described as 'off-shoring environmental burdens' (Hess and Sutcliffe, this issue).
- Agricultural regions suffering from droughts invite public scrutiny about producers' water practices (e.g. irrigation) particularly when consumers in nearby cities are subjected to water advisories or supply cutbacks. More broadly, managing water issues is about maintaining consumer trust among citizens who are often far-removed from the source and use of that water (at the farm/ranch level).

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The opinions expressed and arguments employed in this publication are the sole responsibility of the authors and do not necessarily reflect those of the OECD or of the governments of its Member countries.

- The lack of good data, computing tools, and interpretation techniques (in the context of future climatic scenarios and impact on water supply) is a major issue in terms of how water is managed now and in the future. For example, not all irrigation wells in the High Plains/Ogallala Aquifer (HPOA) are metered to provide data on pumpage. Even when adequate data are available, improved water footprint calculation methods are required to properly understand and manage stressed water resources.
- As water stresses increase, we need better transparency of policies that incentivize or determine water use in agriculture. Water is not generally priced in terms of its cost of depletion. Various subsidies hide the true cost of water which causes market-distorting behaviors with negative environmental effects.
- Also unclear is whether food producers and the food system in general (i.e., processors and retailers) fully understand the long-term implications of unsustainable water use from aquifers. Put another way, market signals may not be incentivizing the right water use practices. That said, food supply chains are becoming far more focused on sustainable sourcing, and demonstrating that to consumers. This shift could be a game-changer to make current practices to be more sustainable.

Understanding virtual water and the water footprint

Virtual water is the amount of water 'embedded' in a product (Allan, 2011). As agricultural products are sold and traded, the water that is used to produce them (natural rainfall or irrigation) is also essentially traded. Identifying the amount of virtual water embedded in a product has implications for water management, practice, and policy. For instance, with irrigation, many arid regions around the world are major producers of our food and feed, and an important source of agricultural exports. Yet, increasing climate stress and competition for scarce water in these regions raise significant questions for stakeholders in an integrated, globalizing food system: Where should food be produced? How best to use limited water resources? What information should be available to consumers to assist them in making more informed decisions?

The 'water footprint' (Hoekstra & Chapagain, 2008; Hoekstra & Mekonnen, 2012) has been developed as a tool, especially by the Water Footprint Network, to measure virtual water use over the entire supply chain from production to delivery to the consumer, and including pollution produced in the process. It refers to the amount of fresh water it takes to produce a product (whether a food or material good), to bring it to the consumer, and in dealing with the pollution created by the product over the supply chain. Vanham's article here describes two methodologies to conduct water footprint assessments – one developed within the Integrated Water Resources Management (IWRM) framework, and one associated with work in the Life Cycle Analysis framework. The author shows that there are non-trivial differences between the methodologies, but also complementarities.

The water footprint is typically divided into three sub-categories: blue, green, and grey (see Figure 1). Blue water refers to the consumption of surface and ground waters (by irrigation) along the supply chain of a product or from growing a crop to bringing it

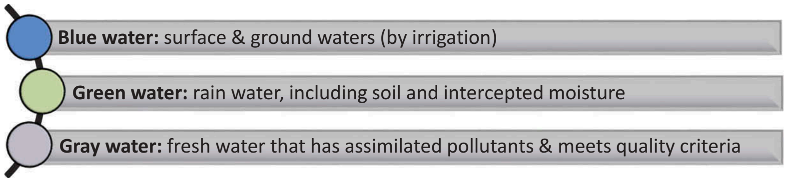

Figure 1. Water footprint categories based on consumption.

to market. Green water relates to the consumption of rainwater (before it becomes runoff). This includes the moisture available to plants from soil and intercepted moisture in the plant canopy or on soil surfaces. The term 'consumption' used in blue and green waters refers to incorporation into the product, evaporation from soil or transpiration from plants, deep percolation to ground water, or movement of surface water from one catchment to another. Grey water is the amount of fresh water that will be required to assimilate the pollutant loads to meet water quality criteria as set by local regulations (i.e., dilution requirements for pollution).

There is often disagreement over the procedures adopted for water footprint calculations. For example, the water footprint of a kilogram of wheat or kilogram of beef often represents an average when expressed as a global number. Averages can conceal important qualitative differences among areas of production, and these figures can often vary from place to place. When it comes to distinguishing blue water (often the more costly component) from green water, discrepancies in methods can be important. For example, the water footprint of a kilogram of beef can have different blue or green water footprints if the cattle are raised in a ranch versus in a confined animal feeding operation (CAFO). The animal feed for the CAFO cattle may be produced using blue water or green water, or some combination. For cattle raised on rangelands or ranches, a major part of the animal's diet comes from natural grass, which is dependent on green water. In the mid-western USA beef cattle production system in the rangelands, some grain is used to fatten the animal before selling into the market, but this method of cattle production would have a lower blue water footprint compared to fully grain-fed beef in these areas. In many parts of the world, the beef cattle raised in the range land or ranches are sold directly in the market rather than fattening them in CAFOs. In such cases, the total water footprint may be high due to low feed to product conversion ratio (i.e., more grass is needed for the same mass of beef than corn or other feed). When considering meat from swine or chicken, most feeding and raising of these animals occurs in CAFOs. Producing animal protein has a definable water footprint at a given location and the blue and green water component will vary. In short, making clear comparisons and understanding the trade-offs of water use is not always clear, can make public dialogues confusing and contentious, and can provide variabilities in understanding environmental impacts. Thus, while it can be useful for decision-making, using the water footprint is not without difficulties. For instance, Wichelns (this issue) argues that water footprint ratios have limitation because they do not consider the conditions in which crops are grown. Going forward, it will be important to clearly understand the advantages and the limitations of water footprint, and virtual water measures, especially if they are used to inform policy and practice.

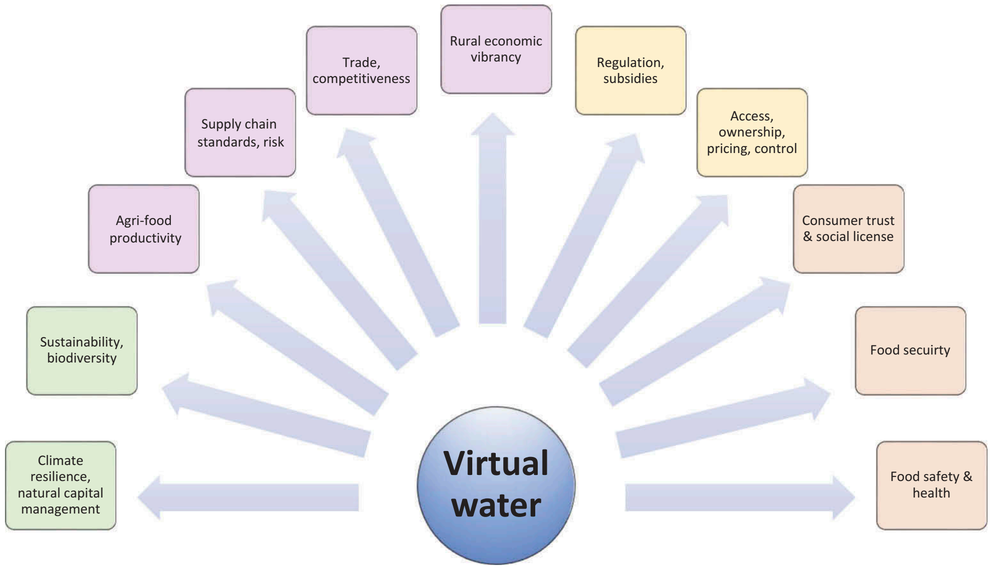

Figure 2. Water is a lens to examine key issues facing agriculture, people, and the planet.

How we grow, process, trade and consume our food is intimately linked to how we use and manage water. Below, we elaborate on insights emerging from the articles in this issue.

Perspectives on blue water

Many of the contributions here focus on one of the most productive growing regions on Earth, the American Great Plains, but we have included a number of insightful international cases. Combined, this offered a lens (see Figure 2) to explore a variety of major issues about water used in modern agriculture and the global food system – a number of which are elaborated upon below.

Food production and food security

In the HPOA region of the American Midwest, large-scale production of corn, soybean, wheat, cotton, and sorghum rely heavily on locally available groundwater (Martson, Konar, Cai, & Troy, 2015). However, in many parts of the region, irrigation pumping exceeds the recharge rates (Scanlon et al., 2012), resulting in groundwater depletion. In southern part of the HPOA (particularly in Texas, Oklahoma, and western Kansas), groundwater depletion has been so severe that existing irrigation systems are unable to fully irrigate fields. As Konar et al. show, other large aquifers such as the Central Valley and the Mississippi Embayment are also experiencing significant overdraft and long-term sustainability concerns. Their paper raises vital questions about temporal and spatial trade-offs. Clearly, consumption and production today comes at the expense of future use. This is apparent for the HPOA, which is essentially nonrenewable in its southern and central regions owing to minimal recharge and high evaporation rates. Tracing virtual water through trade flows can reveal where – or who – is consuming the water embedded in the agricultural products. These analyses are raising important, and difficult, questions for policy in an increasingly inter-connected global food system.

One key issue is about global accountability. While considerable attention is devoted to the smooth functioning of global supply chains, which results in a relatively reliable and safe food supply for consumers, less consideration appears to be given to deciding what institutions and capacity are needed to properly manage, or govern, water consumption at requisite scales. Improving transparency of water allocation and management practices may help address this challenge.

Future food security is also made more challenging because depletion is accompanied by competition for, and increased scrutiny of, the water resource (World Water Assessment Programme [WWAP], 2012). Agriculture competes for water with other economic interests. Oil exploration and processing rely on ground water from the HPOA in Southwest Kansas, West Texas, New Mexico and Oklahoma. Competition for water creates a contentious debate over who should have access to it. The situation also puts a greater spotlight on big users of water, including farming practices. For instance, in the Great Plains of the US, many farmers have been producing consecutive corn crops over the last decade or so, a more intensively irrigated and fertilized commodity than other common crops produced in the region. Producers respond to customer demand signals for their crops and to government signals (subsidies). The push to increase yields is prompting more interest in sustainability practices, such as how nitrogen fertilizer is used and managed (which can affect water quality) and in prompting watershed-wide analyses of irrigation practices.

These issues will likely become even more important in the context of a changing climate. The article by Lu et al., for example, finds that in Nebraska, irrigated crops are less sensitive to changing climate than dryland crops, but irrigated crops have lower water productivity. Among their findings, they suggest that expanding irrigated winter wheat acreages could maintain high yields while conserving more water. Similarly, the article by West and Baxter reports that the legume lucerne (alfalfa, *Medicago sativa*) could be introduced to lower the water footprint of the stocker phase of beef production in the U.S. High Plains. Informed choices about crop mixes and rotations are crucial for improving the sustainability of agri-food systems in changing climates.

The case has also been made for expanding irrigation investment in certain regions. As Xie et al. argue in this volume, irrigation may help address Sub-Saharan Africa's food security and nutrition situation and reduce food import dependency. Small-scale irrigation could substantially benefit the production of vegetables and groundnuts. Such activity has a multiplier effect, such as on providing employment and trade opportunities. However, the UN Sustainable Development Goals (SDGs) offer guidance here. Finding the optimum pathway to eliminate hunger and malnutrition (Goal 2) must include ensuring sustainable water withdrawals (Goal 6) and pursuing sustainable use of natural resources that takes into account the situation in developing countries (Goal 12).

Environmental sustainability

The environmental sustainability of water used in agriculture is complex. Understanding impacts on primary aquifers is paramount. As sources of irrigation water, aquifers can become stressed when human demand (pumpage) outstrips natural recharge rates and captures water that would otherwise feed surface flows (Bredehoeft, 2002; Gleeson, Wada, Bierkens, & van Beek, 2012). Few argue that aquifers can be practically restored to the original (pre-pumping) state unless agriculture is completely or significantly curtailed – the politics of which are not feasible. In such situations, the focus shifts to how to do 'no more harm.' This largely reflects the situation in HPOA today, although the magnitude of the problem varies across the region (i.e., north to south). For example, the southern region of the HPOA (western Kansas, and the panhandle regions of Oklahoma and Texas) has seen significant declines in water levels compared to the pre-development era (Haacker, Kendall, & Hyndman, 2016). Some areas have seen water levels lowered more than 150 feet (45 metres) and other areas are no longer irrigable (McGuire, 2014). At this rate of consumption, and with current cropping systems in place, even more of the southern and central parts of the HPOA are expected to face questions about the longevity of the aquifer for irrigated crop production.

It is apparent that good data are required so that modeling and analytics can help us respond to the challenges of water trade. As Butler et al.'s paper shows, water use and water level data can be used to increase the effectiveness of forecasting models. Kansas data, in this sense, are rare in the detail they provide analysts, but when such data are available, the insights are exceedingly useful for understanding that policies needed to extend the useful life of the resource. Butler et al. find that 'practically feasible pumping reductions' of 10–20% would have large impacts on rates of water decline, and that slightly larger reductions (20–30%) could even lead to near-stable water levels. Yet, there remains much room for improvement in the area of water data collection and availability. For example, while flow meters are required in western Kansas, many irrigation wells in the HPOA are not yet metered to provide data on pumping, which is a more direct and reliable measurement of the volume of groundwater extracted. The absence of complete data on water consumption is a clear challenge for scientists' capacity to model and assess impacts. In the context of future climate change scenarios, an increase in the temperature in the summer growing season is likely to enhance evapotranspiration, which will increase the demand for irrigation. Changing climates and the persistence of droughts (such as the 2012 drought in the Great Plains region) puts increasing pressure on the aquifer. While the U.S. Geological Survey has also had a monitoring program for HPOA water levels since the mid-1980s, the need for good data and better water footprint calculation methods becomes more important as this resource becomes more stressed.

Water pricing

Pricing water is directly relevant to the economics of sustainability. It is controversial. Politicians, citizens and the agri-food sector need to confront trade-offs associated with the reliance on government subsidies to produce feed, food, fiber and fuel from agricultural crops. Subsidies may be well-intentioned but they can hide the true cost of water and encourage unsustainable agricultural practices. In Nebraska, for example, price supports and subsidies for corn have changed crop rotations as producers seek consecutive high yields. What seemed at one time like an endless bounty of groundwater, combined with relatively inexpensive energy to pump it, has created significant momentum to continuously grow the crops that show the greatest short-term profit. In the U.S., federal government subsidies, including the corn ethanol subsidy, support this practice.

While farmers are generally motivated for cost reasons to reduce nitrogen fertilization use and to maintain healthy soils, consecutive cropping of corn over the past decades in this region has led to significant input of nitrogen fertilizers (Exner, Hirsh, & Spalding, 2014; Juntakut, Snow, Haacker, & Ray, submitted). This has led to high nitrate levels in groundwater which has impacted many communities, challenging them in providing water that meets health standards for human consumption. Fertilizer impacts also vary with soil type. In the Midwestern corn belt, sandy soils tend to facilitate groundwater contamination. There are also other complications with high nitrates in groundwater. Green and Anapalli provide distributions of water percolation and nitrate leaching based on irrigation variability and projected climate change. Groundwater nitrate contamination can also increase the risk of further contamination from naturally-occurring toxins. Denitrification can enhance the mobilization of uranium naturally present in the subsurface (Nolan & Weber, 2015). Notwithstanding the fact that agriculture is not the only source of water contamination, local communities are still left with the task of ensuring drinking water quality and adequacy for its citizens. Grand Island and McCook are among the Nebraska communities that have installed treatment plants for uranium.

In essence, citizens pay for water three times. As Vanham describes, taxpayers pay for the farm subsidy that encourages corn production; consumers pay a hidden price when purchasing food (as water has some cost of food production or processing as an input cost); and residents pay for any municipal/regional cleanup or rehabilitation cost of the groundwater from production practices. While there is widespread pressure by cities to require the farmers or farmers associations to pay for cost of treating water contaminated with nitrate or pesticides, there is no precedence in the United States to pay for this cost. In a recent court case in Iowa, the City of Des Moines filed a lawsuit against counties upstream from its storage reservoir that provides water to its residents. The claim in the lawsuit was to recover cost of treatment; however, this lawsuit was thrown out by the Iowa Supreme Court, which ruled that it was a legislative matter, not a judicial matter.[1] There are many small towns in Nebraska, Iowa, Illinois and other Midwestern states where the farmers indirectly pay for cost of treatment because they live in those towns, and the town increases the cost of supplied water and raises property taxes to pay for shortfalls in state and federal funding of treatment plants.

Water pricing can be used to manage water as a scarce resource and achieve improved productivity. Engaging producers on the economics of water is a matter of self-interest and societal benefit – and should be seen as such. Water productivity is a measure of the amount of water used per unit of agricultural product: the higher the water use relative to yield, the lower the efficiency. However, a crop simulation model has shown that farmers tend to apply more irrigation water than what is needed (Carr, Yang, & Ray, 2016). Use of variable rate irrigation to reduce overwatering in different soil types, and installation of variable drive pumps to reduce energy demand (generated from electricity, diesel or natural gas), are a few of the features available to reduce overwatering. The ultimate objective – which is in the best interests of farmers and society – is more sustainable water use: less blue water used per unit of production. Widely adopting this key measure of efficiency appears to be an essential farm management and sustainability tool. However, additional economic analysis is warranted, including how to promote its widespread adoption.

Ownership

Water ownership is central to addressing sustainability. In Chile, for example, Alvarez describes how water law fails to promote sustainable water use by allocating water rights according to basin water supply rather than crop irrigation demand. Alvarez's research is a reminder that how we manage water is, essentially, a governance issue. In the U.S. context, water rights and ownership vary significantly among the states. This invites different sustainability options, including the role government can play depending on state or individual rights of water. For example, Peck (2007) states that Nebraska uses a hybrid approach to managing the ground water rights, which includes the 'Reasonable Use Doctrine' and the 'Correlative Rights Doctrine.' The right to use comes from the ownership of land overlying the water. If the site is within a groundwater management area, a permit is needed. All well owners are required to register their wells. Statutes also regulate the location of wells with respect to rivers/streams or other wells and the reasonable use clause is employed where the owner cannot use more than a reasonable quantity and it must be shared among others. On the other hand, Texas employs the 'Rule of Capture,' which allows landowners to extract all the water beneath the land and do whatever they want with it. As the landowner is not liable to the neighbor, this has spurred severe aquifer drawdown. However, local regulations are slowly becoming more stringent across the Central and Southern HPOA. In the case of Texas, there are eleven ground water conservation districts (GCDs) in the HPOA region of Texas and each still recognizes landowners as groundwater owners. However, GCDs are required to work with the Texas Water Development Board to enumerate 'desired future conditions,' and to submit a water plan to meet those conditions. These water plans are evaluated using a groundwater model (Deeds & Jigmond, 2015). While restrictions primarily affect cities and their ability to use state funding for new water supply infrastructure, agricultural management is increasingly involved in conservation measures. In 2015, the High Plains Underground Water Conservation District No. 1 implemented metering requirements for irrigation wells, and set a maximum irrigation limit of 18 inches (450 mm) per year for double cropping.

Policy implications

While the workshop was not intended to catalogue every issue relating to water, the dialogue uncovered several pertinent policy issues.

Global trade and agricultural subsidies

Some 70% of the world's fresh water from rivers, lakes, and aquifers (blue water) is used to produce the food for humanity. A great deal of this water is exported in the form of virtual water (Hoekstra & Mekonnen, 2012). Of critical importance is the extent to which this volume of trade has disproportionate negative impacts on the world's water resources. Hess and Sutcliffe's article raises this issue in the context of the United Kingdom's reliance on other countries, such as Spain, to supply many of its fruits and vegetables (a matter that could equally apply to many other countries). As a semi-arid country, Spain is facing severe water stress so its food exports are, effectively, allowing Britain and other nations to 'off-shore' their environmental burdens.

This situation is sustained in part because of the existence of government subsidies. To discuss trade and ecosystem impacts, one must consider the role that agricultural subsidies play in encouraging global agricultural production and groundwater depletion, water quality deterioration and biodiversity impacts. However, subsidies have not drawn a great deal of attention or concern for their impact on the environment; there has not been a World Trade Organization challenge yet against a country based on how it subsidizes water for on-farm use (see Garrido, 2017).

Subsidies exist in many forms. Across the OECD, subsidies (total producer support) have been calculated to be nearly US$240 billion (2014 data) (Canadian Agri-Food Policy Institute [CAPI], 2017). Not all subsidies are necessarily bad; it is the unintended consequences and degree of this impact that is the issue. For instance, while subsidized pricing for fertilizer in India has helped poor farmers in that country, highly subsidized and basically free power use to pump water has not helped the agricultural sector of India. Over-pumping has caused severe groundwater depletion in many areas, particularly the state of Punjab. In 2002, agricultural pumping accounted for more than 31% of total power use in India (Centre for Monitoring Indian Economy [CMIE], 2002).

The issue is difficult to comprehend given that reporting on subsidies has been changing. The 2014 US Farm Bill abolished direct payment based on land ownership, and instead farmers can get subsidies for insurance and for other needs (Polzkill et al., 2017). However, the impact of subsidy practices still masks understanding environmental impacts. The World Trade Organization reporting system, for instance, tends to under-report certain practices that encourage unsustainable practices, including excessive drawdown of aquifers worldwide (Canadian Agri-Food Policy Institute [CAPI], 2017). As demand for food rises and pressure to use water increases, the lack of transparency of these forms of subsidy will only challenge policy-makers further about clearly understanding the causes and effects of their decisions. Meanwhile, the depletion of natural capital will largely continue.

Supply chain risk and resilience

Global processors and retailers depend on reliable supply chains to ensure consumers have safe, reliable and quality products from which to choose every day. These companies are monitoring a variety of supply chain risks, including dependable supply of literally thousands of ingredients and products. Climate change and extreme weather challenges global producers and suppliers, including, as noted earlier, the sourcing of fresh produce from arid growing areas that are highly vulnerable to droughts. Increasingly, these large companies expect producers and supply chains to conform to new sustainability protocols. The action is motivated by demonstrating 'corporate social responsibility' and good corporate governance. Security of supply chains and minimizing reputational risk (i.e., the risk of being accused of not sourcing sustainably) are powerful motivators to change unsustainable practices.

Producers, input suppliers, and processors are also creating bottom-up initiatives to improve crop resilience and sustainability, such as sustainable soy. There are a myriad of initiatives, such as McDonald's Restaurants' participation in a global sustainable beef roundtable that also includes ranchers and many others. Often, major environmental groups are part of these efforts, such as the World Wildlife Fund. A new dynamic is occurring that is linking responsible sourcing with environmental, health, ethical and other objectives. A full assessment is required to discern how these initiatives have implications for groundwater depletion, but the point is that many major supply chains are being responsive to environmental risks.

Technology adoption is also vital to respond to the water challenge and improve sustainability. Technology is key to precision agriculture (and 'precision irrigation'), which will help to ensure that plants get the required nutrients and water at the right time and in the right amount. A global effort is underway to improve fertilizer use (known as the 4R program for 'right source, right rate, right time, and right place'), which is helping to achieve this positive outcome. Farmers are generally motivated to improve their practices as they want to ensure yield and quality, such as using soil moisture sensors to irrigate their fields (and to maximize the ratio of transpiration to evaporation), but the technology is yet to be adopted by all farmers.

What is largely missing is full cost-accounting of the environmental footprint of food production, or at least its widespread adoption within traditional supply chains. As the world population is expected to reach 10 billion by 2050, the need for food is expected to double. The way in which the food system accounts for the impact of food production will become increasingly salient. Moreover, a global effort is underway to promote a new approach, such as with the UN's Sustainable Development Goals. One of its 17 major goals speaks to sustainable production and consumption. Other goals include addressing water use, agricultural production and the environment. At the time of the workshop, the SDGs were not given much consideration since this UN initiative had recently come into being (in early 2016). However, going forward, the SDGs are expected to have increasing relevance for consumers, companies, investors, and governments and are worthy to understand for their implications on managing agri-food system sustainability.

Consumers, health and trust

A major issue facing the sector as a whole is maintaining consumer trust. Mistrust of food production can result in calls for government regulation, shift dietary preferences, invite bad publicity and undermine corporate reputations – and with social media, criticism can be devastating. The move to healthy diets is based on the belief that animal agriculture contributes to environmental degradation (Tilman & Clark, 2014). The Meatless Monday campaign (a global advocacy effort) calls for consumers to reduce meat consumption and improve the health of people and the planet. The water footprint of meat production is much higher than the water footprints for vegetable-based meals (Mekonnen & Hoekstra, 2012). This rationale is used by advocates, consumers, and the media to affirm their position in favor of healthier diets, for the planet and for individuals. The underlying issue is that consumer food choices are increasingly based on expectations of what is good for the environment. A water footprint assessment can provide additional insights into the consumptive effects of diets, food loss, and food waste implicated in producing those diets. For example, Mekonnen and Fulton's article shows that shifting to vegan and vegetarian diets would provide larger reductions in the consumptive water footprint than simply shifting to more healthy diets in the U.S. But, lowering rates of food loss and food waste would decrease the consumptive water footprint in the U.S. even more.

Maintaining rural/agriculture livelihoods is important for all countries. However, most consumers live in urban or peri-urban areas and demands from these populations for sustainable food productions are becoming more pronounced, particularly in wealthier countries. Urban consumers are disconnected from the farm or ranch but still have certain expectations about how their food needs to be produced (e.g., hormone-free, GMO-free, organic, shade-grown, etc.). It is true that such expectations create new marketing opportunities and product innovation opportunities for food suppliers, but there will continue to be a tension in the system to respond to food wants from an increasingly urban consumer population.

The agri-food sector generally responds to these issues with the call for more consumer education. Certainly, better information is needed. However, most consumers will not likely spend much time considering the distinctions between blue and green waters. While most consumers make food choices based on price, taste and quality, consumers are starting to make value decisions based on sustainability, in many cases as a result of advocacy from environmental non-profit groups. This explains why food retailers provide sustainably-sourced seafood and processors certify themselves as protecting ecosystems. Local food is also preferred in part because consumers feel that the carbon footprint is less than food produced from afar, since the energy inputs for transportation are among the most visible and easily grasped components of the food production system.

Understanding sustainability footprints is complex. Lee et al. describe in this volume the usefulness of the water footprint for rice products and the food-energy-water nexus in Korea. But there are trade-offs in the food-energy-water nexus, especially given rapid urbanization, as Taniguchi et al. discuss in the Asia-Pacific region. Another example is to consider the feed needed for beef cattle production in Nebraska. If the feed is sourced from local cooperatives using Nebraska groundwater for corn irrigation, then the water footprint per kilo of beef is expected to be lower compared to the footprint of the feed corn that is transported from Texas, Oklahoma, or southwestern Kansas, where the evapotranspiration demand is high and more water is used to produce similar amount of feed corn. This is a calculation that consumers would obviously want experts to determine. If it is important to consumers, they would just want to trust the verification of any such claims. Often consumers do not trust self-appointed experts because the people with the greatest stake in the water footprint are the 'experts' hired by food companies, and they tend to find a far lower water footprint than independent analyses (Nestle, 2015).

As sustainability issues intensify, the agri-food sector and regulators will need to decide what are the best certification and verification protocols to deploy in order to maintain societal and customer trust. The level and transparency of that bar can only be expected to rise.

Going forward

Irrigation water will continue to be vitally important for agricultural production, the food supply, trade, and for the economic viability of communities. In the case of groundwater resources of the HPOA, can depletion rates continue for shorter term benefits at the expense of long-term sustainability? The answer to agricultural water management problems is made difficult by how we price the extraction of this precious resource, how we incentivize its draw-down and protect it through agricultural practices, and how we price our food and make it visible or not to the final consumer. Surface water diversions often affect resources that cross political boundaries, such as the Republican and Colorado rivers and the Aral Sea in central Asia. The issue has geopolitical and ethical ramifications for the developed and developing world alike. Wealthier economies import many foods from water-stressed regions. In Africa, countries are leasing large tracts of land to produce food on a contract basis for export. Consumers get the benefit of this production, but at the local cost of water depletion, the diminishing resource for current agriculture and the impacts on water quality from excessive or cumulative nutrient-loading or increased salinity of drinking water. This is a legacy we are seeing unfold today and leaving to future generations tomorrow.

The necessary counter-balance could be a combination of technology and transparency of policies and practices, made possible with better data and analytics, plus significant shifts in attitudes. We may be able to better manage aquifers and the food supply chains that depend on them. But this demands an integrated approach for food systems and communities. Documenting the unforeseen consequences of current practices is a vital step to transforming how we produce our food. The global food system is adopting, certifying and branding a host of sustainably-sourced commodities and foods, from sustainable palm oil and soy to reduce the incidence of rainforest deforestation, to sustainable beef and seafood to protect the food supply and the environment. To effect real change, we may have no choice but to put 'sustainably-sourced aquifers' on this list as well.

Disclosure statement

No potential conflict of interest was reported by the authors.

Note

1. https://www.scribd.com/document/342452360/Ruling-on-Summary-Judgment-00795075xB8DF0.

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