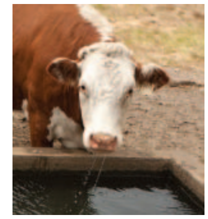
The hidden water resource use behind meat and dairy



Arjen Y. Hoekstra

Twente Water Centre, University of Twente, PO Box 217, 7522AE Enschede, the Netherlands

Implications

- The consumption of animal products contributes to more than one-quarter of the water footprint of humanity. The water needed to produce feed is the major factor behind the water footprint of animal products. Reviewing feed composition and the origin of feed ingredients is essential to find ways to reduce the water footprint of meat and dairy.
- The water footprint of any animal product is larger than the water footprint of a wisely chosen crop product with equivalent nutritional value.
- In industrialized countries, moving toward a vegetarian diet can reduce the food-related water footprint of people by 36%.
- Reducing the water footprint of meat and dairy requires an international approach and product transparency along the full supply chain of animal products.

Key words: consumption, globalization, livestock, sustainability, water footprint

Introduction

The desirability of reducing our carbon footprint is generally recognized, but the related and equally urgent need to reduce our water footprint is often overlooked. Recent research has shown that about 27% of the water footprint of humanity is related to the production of animal products (Mekonnen and Hoekstra, 2011). Only 4% of the water footprint of humanity relates to water use at home. This means that if people consider reducing their water footprint, they should look critically at their diet rather than at their water use in the kitchen, bathroom, and garden. Wasting water never makes sense, so saving water at home when possible is certainly advisable, but if we limit our actions to water reductions at home, many of the most severe water problems in the world would hardly be lessened. The water in the Murray-Darling basin in Australia is so scarce mostly because of water use in irrigated agriculture (Pittock and Connell, 2010). The Ogallala Aquifer in the American Midwest is gradually being depleted because of water abstractions for the irrigation of crops such as corn and wheat (McGuire, 2007). Much of the grain cultivated in the world is not for human consumption but for animal consumption. In the period from 2001 to 2007, on average 37% of the cereals produced in the world were used for animal feed [Food and Agriculture Organization of the United Nations (**FAO**), 2011]. However, surprisingly little attention among scientists or policy makers is given to the relationship between meat and dairy consumption and water use. It is becoming increasingly relevant to study the implications of farm animals on water resource use, not only because global meat production almost doubled in the period from 1980 to 2004 (FAO, 2005), but also because meat production is projected to double in the period from 2000 to 2050 (Steinfeld et al., 2006).

This paper reviews recent research carried out regarding the hidden water resource use behind meat and dairy production. First, the water footprint concept is introduced, an indicator increasingly used worldwide to assess the water resource implications of consumption and trade. Second, results from recent research are summarized, indicating that for assessing the water footprint of meat and dairy, it is most relevant to carefully consider both the feed conversion efficiency when raising animals and the feed composition. Third, the water footprint of animal products is compared with the water footprint of crops. Next, the water footprint of a meat-based diet is compared with the water footprint of a vegetarian diet. It is then shown that understanding the relationship between food consumption and the use of freshwater resources is no longer just a local issue. Water has become a global resource, whereby, because of international trade, food consumption in one place often affects the water demand in another place. Finally, an argument is made for product transparency in the food sector, which would allow us to better link individual food products to associated water impacts, which in turn could drive efforts to reduce those impacts.

The Water Footprint Concept

The water footprint concept is an indicator of water use in relation to consumer goods (Hoekstra et al., 2011). The concept is an analog to the ecological and carbon footprints, but indicates water use instead of land or fossil energy use. The water footprint of a product is the volume of freshwater used to produce the product, measured over the various steps of the production chain (Figure 1). Water use is measured in terms of water volumes consumed (evaporated) or polluted. The water footprint is a geographically explicit indicator that shows not only volumes of water use and pollution, but also the locations. A water footprint generally breaks down into 3 components: the blue, green, and gray water footprint. The blue water footprint is the volume of freshwater that is evaporated from the global blue water resources (surface and groundwater). The green water footprint is the volume of water evaporated from the global green water resources (rainwater stored in the soil). The gray water footprint is the volume of polluted water, which is quantified as the volume of water required to dilute pollutants to such an extent that the quality of the ambient water remains above agreed water quality standards (Hoekstra and Chapagain, 2008). To ensure that scientifically robust methods are applied

http://dx.doi.org/10.2527/af.2012-0038

Figure 1. Water footprint: water use to produce goods for human consumption (source: © 2008 iStockphoto.com/sandsun).

and that a fair comparison can be made between different water footprint studies, the Water Footprint Network and its partners have developed the Global Water Footprint Standard, which was launched in February 2011 (Hoekstra et al., 2011). The water footprint figures presented in this paper are based on this standard.

The Relevance of Feed Conversion Efficiency and Feed Composition

The supply chain of an animal product starts with feed crop cultivation and ends with the consumer (Figure 2). In each step of the chain, there is a direct water footprint, which refers to the water consumption in that step, but also an indirect water footprint, which refers to the water consumption in the previous steps. By far, the largest contribution to the total water footprint of all final animal products comes from the first step: growing the feed (Figure 3). This step is the most far removed from the consumer, which explains why consumers generally have little notion about the fact that animal products require a lot of land and water (Naylor et al., 2005). Furthermore, the feed will often be grown in areas completely different from where the consumption of the final product takes place.

To better understand the water footprint of an animal product, we need to start with the water footprint of feed crops. The combined green and blue water footprint of a crop (in m^3/ton) when harvested from the field is equal to the total evapotranspiration from the crop field during the growing period (m^3/ha) divided by the crop yield (tons/ha). The crop water use depends on the crop water requirement on the one hand and the actual soil water available on the other hand. Soil water is replenished either naturally through rainwater or artificially through irrigation water. The crop water requirement is the total water needed for evapotranspiration under ideal growth conditions, measured from planting to harvest. It obviously depends on the type of crop and climate. Actual water use by the crop is equal to the crop water requirement if rainwater is sufficient or if shortages are supplemented through irrigation. In the case of rainwater deficiency and the absence of irrigation, actual crop water use is equal to effective rainfall. The green water footprint refers to the part of the crop water requirement met through rainfall, whereas the blue water footprint is the part of the crop water requirement met through irrigation. The gray water footprint of a crop is calculated as the load of pollutants (fertilizers, pesticides) that are leached from the field to the groundwater (kg/ha) divided by the ambient water quality for the chemical considered (g/L) and the crop yield (ton/ha).

The water footprint of an animal at the end of its lifetime can be calculated based on the water footprint of all feed consumed during its lifetime and the volumes of water consumed for drinking and, for example,

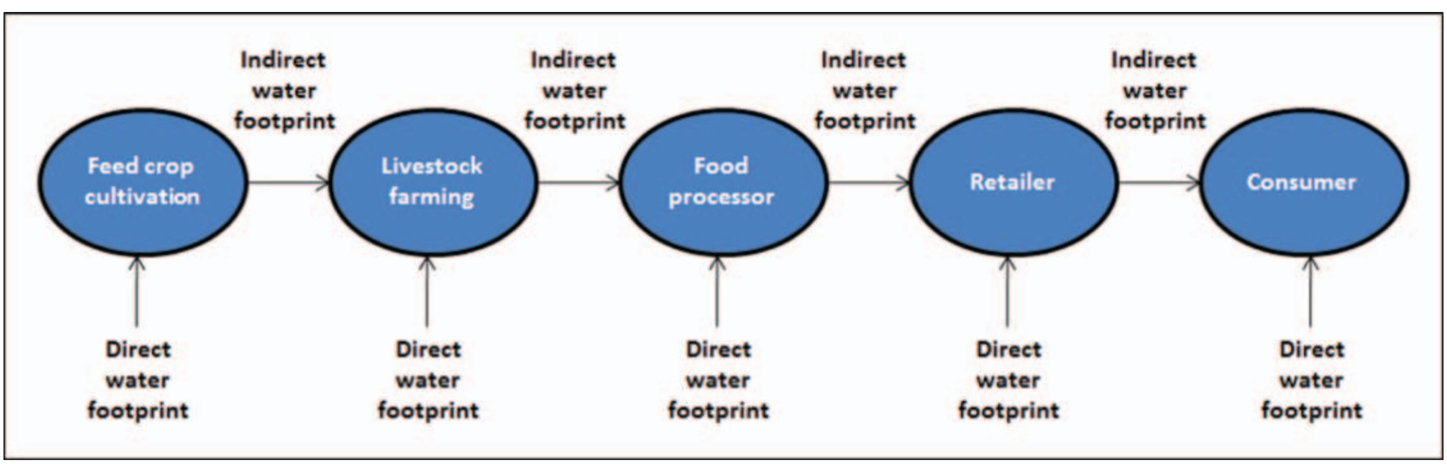


Figure 2. The direct and indirect water footprints in each stage of the supply chain of an animal product (source: Hoekstra, 2010; copyright © 2010 Earthscan; used with permission).

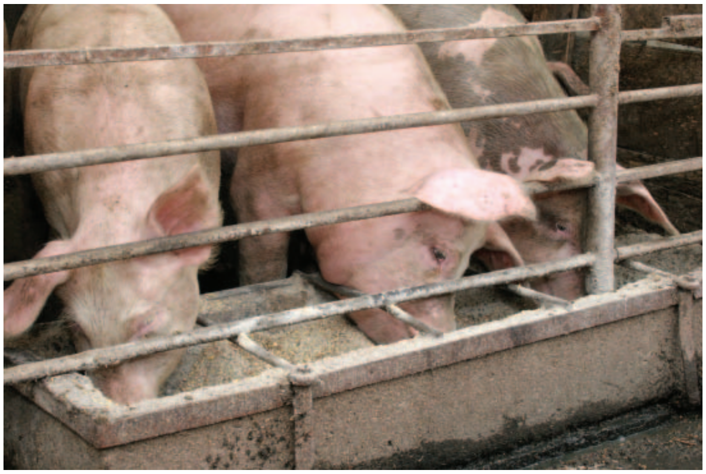


Figure 3. Water to grow feed crops contributes about 98% to the total water footprint of animal products (source: © 2006 iStockphoto.com/Vladimir Mucibabic).

cleaning the stables. One will have to know the age of the animal when slaughtered and the diet of the animal during its various stages of life. The water footprint of the animal as a whole is allocated to the different products that are derived from the animal. This allocation is done on the basis of the relative values of the various animal products, as can be calculated from the market prices of the different products. The allocation is done such that there is no double counting and that the largest shares of the total water input are assigned to the high-value products and smaller shares to the low-value products.

About 98% of the water footprint of animal products relates to water use for feed (Mekonnen and Hoekstra, 2010). A recent study by Gerbens-Leenes et al. (2011) showed that there are 2 major determining factors in the water footprint of animal products. The first factor is the feed conversion efficiency, which measures the amount of feed to produce a given amount of meat, eggs, or milk. Because animals are generally able to move more and take longer to reach slaughter weight in grazing systems, they consume a greater proportion of feed to convert to meat. Because of this, the feed conversion efficiency improves from grazing systems through mixed systems to industrial systems and leads to a smaller water footprint in industrial systems. The second factor works precisely in the other direction, that is, in favor of grazing systems. This second factor is the composition of the feed eaten by the animals in each system. When the amount of feed concentrates increases, the water footprint will increase as well because feed concentrates have a relatively large water footprint, whereas roughages (grass, crop residues, and fodder crops) have a relatively small water footprint. The increasing fraction of animal feed concentrates and decreasing fraction of roughages from grazing through mixed to industrial systems (Hendy et al., 1995) results in a smaller water footprint in grazing and mixed systems compared with industrial systems. In general, the water footprint of concentrates is 5 times larger than the water footprint of roughages. Although the total mixture of roughages has a water footprint of approximately 200 m^3/tonne (global average), this is about 1,000 m^3/tonne for the package of ingredients contained in the concentrates. Because roughages are mainly rain fed and crops for concentrates are often irrigated and fertilized, the blue and gray water footprints of concentrates are even 43 and 61 times those of roughages, respectively.

If we take beef as an example, it is clear from the above discussion that the water footprint will vary strongly depending on the production region, feed composition, and origin of the feed ingredients. The water footprint of beef from an industrial system may partly refer to irrigation water (blue water) to grow feed in an area remote from where the cow is raised. This can be an area where water is abundantly available, but it may also be an area where water is scarce and where minimum environmental flow requirements are not met because of overdraft. The water footprint of beef from a grazing system will mostly refer to green water used in nearby pastures. If the pastures used are either dry- or wetlands that cannot be used for crop cultivation, the green water flow turned into meat could not have been used to produce food crops instead. If, however, the pastures can be substituted by cropland, the green water allocated to meat production is

Table 1. The global-average water footprint of crop and animal products[1]

	Water footprint per unit of weight, L/kg				Nutritional content			Water footprint per unit of nutritional value		
Food item	Green	Blue	Gray	Total	Calories, kcal/kg	Protein, g/kg	Fat, g/kg	Calories, L/kcal	Protein, L/g of protein	Fat, L/g of fat
Sugar crops	130	52	15	197	285	0.0	0.0	0.69	0.0	0.0
Vegetables	194	43	85	322	240	12	2.1	1.34	26	154
Starchy roots	327	16	43	387	827	13	1.7	0.47	31	226
Fruits	726	147	89	962	460	5.3	2.8	2.09	180	348
Cereals	1,232	228	184	1,644	3,208	80	15	0.51	21	112
Oil crops	2,023	220	121	2,364	2,908	146	209	0.81	16	11
Pulses	3,180	141	734	4,055	3,412	215	23	1.19	19	180
Nuts	7,016	1,367	680	9,063	2,500	65	193	3.63	139	47
Milk	863	86	72	1,020	560	33	31	1.82	31	33
Eggs	2,592	244	429	3,265	1,425	111	100	2.29	29	33
Chicken meat	3,545	313	467	4,325	1,440	127	100	3.00	34	43
Butter	4,695	465	393	5,553	7,692	0.0	872	0.72	0.0	6.4
Pig meat	4,907	459	622	5,988	2,786	105	259	2.15	57	23
Sheep or goat meat	8,253	457	53	8,763	2,059	139	163	4.25	63	54
Bovine meat	14,414	550	451	15,415	1,513	138	101	10.19	112	153

[1]Source: Mekonnen and Hoekstra (2010). Reprinted with permission of the authors.

no longer available for food-crop production. This explains why the water footprint is to be seen as a multidimensional indicator. Not only should one look at the total water footprint as a volumetric value, but one should also consider the green, blue, and gray components separately and look at where each of the water footprint components is located. The social and ecological impacts of water use at a certain location depend on the scarcity and alternative uses of water at that location.

The Water Footprint of Animal Products Versus Crop Products

In a recent study, Mekonnen and Hoekstra (2010) showed that the water footprint of any animal product is larger than the water footprint of a wisely chosen crop product with equivalent nutritional value. Ercin et al. (2011) illustrated this by comparing the water footprint of 2 soybean products with 2 equivalent animal products. They calculated that 1 L of soy milk produced in Belgium had a water footprint of approximately 300 L, whereas the water footprint of 1 L of milk from cows was more than 3 times larger. The water footprint of a 150-g soy burger produced in the Netherlands appears to be about 160 L, whereas the water footprint of an average 150-g beef burger is nearly 15 times larger. Table 1 shows the global-average water footprint of a number of crop and animal products. The numbers show that the average water footprint per calorie for beef is 20 times larger than that for cereals and starchy roots. The water footprint per gram of protein for milk, eggs, and chicken meat is about 1.5 times larger than that for pulses. For beef, the water footprint per gram of protein is 6 times larger than that for pulses. Butter has a relatively small water footprint per gram of fat, even less than for oilseed crops, but all other animal products have larger water footprints per gram of fat when compared with oilseed crops.

The global water footprint of animal production amounts to 2,422 billion m^3/year (87% green, 6% blue, 7% gray). One-third of this total is related to beef cattle, and another 19% is related to dairy cattle (Mekonnen and Hoekstra, 2010). The largest fraction (98%) of the water footprint of animal products refers to the water footprint of the feed for the animals. Drinking water for the animals, service water, and feed mixing water account for 1.1, 0.8, and 0.03%, respectively (Figure 4).

The Water Footprint of a Meat Versus a Vegetarian Diet

Dietary habits greatly influence the overall water footprint of people. In industrialized countries, the average calorie consumption is about 3,400 kcal/day (FAO, 2011); roughly 30% of that comes from animal products. When we assume that the average daily portion of animal products is a reasonable mix of beef, pork, poultry, fish, eggs, and dairy products, we can estimate that 1 kcal of animal product requires roughly 2.5 L of water on average. Products of vegetable origin, on the other hand, require roughly 0.5 L of water/kcal, this time assuming a reasonable mix of cereals, pulses, roots, fruits, and vegetables. Under these circumstances, producing the food for 1 d costs 3,600 L of water (Table 2). For the vegetarian diet, we assume that a smaller fraction is of animal origin (not zero, because of dairy products still being consumed) but keep all other factors equal. This reduces the food-related water footprint to 2,300 L/day, which means a reduction of 36%. Keeping in mind that for the meat eater, we took the average diet of a whole population and that meat consumption varies within a population, larger water savings can be achieved by individuals that eat more meat than the average person.

From the values above, it is obvious that consumers can reduce their water footprint by reducing their volume of meat consumption. Alternatively (or in addition), however, consumers can reduce their water footprint by being more selective in the choice of which piece of meat they pick. Chickens are less water intensive than cows, and beef from one production system cannot be compared, in terms of associated water impacts, with beef from another production system.

The Local and Global Dimensions of Water Governance

Problems of water scarcity and pollution always become manifest locally and during specific parts of the year. However, research on the relationships between consumption, trade, and water resource use during

Figure 4. Drinking water contributes only 1% to the total water footprint of beef (source: © 2011 iStockphoto.com/Skyhobo).

Table 2. The water footprint of 2 different diets in industrialized countries

Item	Meat diet			Vegetarian diet		
	kcal/day[1]	L/kcal[2]	L/day	kcal/day[3]	L/kcal[2]	L/day
Animal origin	950	2.5	2,375	300	2.5	750
Vegetable origin	2,450	0.5	1,225	3,100	0.5	1,550
Total	3,400		3,600	3,400		2,300

[1]The numbers are taken equal to the actual daily caloric intake of people in the period from 1997 to 1999 (FAO, 2011).
[2]For each food category, a rough estimate has been made by taking the weighted average of the water footprints (L/kg) of the various products in the food category (from Hoekstra and Chapagain, 2008) divided by their respective caloric values (kcal/kg). The estimate for food of vegetable origin coincides with the estimate made by Falkenmark and Rockström (2004); for food of animal origin, Falkenmark and Rockström (2004) use a greater value of 4 L/kcal.
[3]This example assumes that the vegetarian diet still contains dairy products.

the past decade has made clear that protection of freshwater resources can no longer be regarded as just an issue for individual countries or river basins. Although, in many countries, most of the food still originates from the country itself, substantial volumes of food, feed, and animal products are internationally traded. As a result, all countries import and export water in virtual form, that is, in the form of agricultural commodities (Hoekstra and Chapagain, 2008; Allan, 2011). Total international virtual water flows related to global trade in animal products add up to 272 billion m^3/year, a volume equivalent to about one-half the annual Mississippi runoff (Mekonnen and Hoekstra, 2011).

Not only are livestock and livestock products internationally traded, but also feed crops are traded (Galloway et al., 2007). In trade statistics, however, it is difficult to distinguish between food and feed crops because they are mostly the same crops; only the application is different. Worldwide, trade in crops and crop products results in international virtual water flows that add up to 1,766 billion m^3/year (Mekonnen and Hoekstra, 2011).

Until today, water is still mostly considered a local or regional resource, to be managed preferably at the catchment or river basin level. However, this approach obscures the fact that many water problems are related to remote consumption elsewhere. Water problems are an intrinsic part of the world's economic structure, in which water scarcity is not translated into costs to either producers or consumers; as a result, there are many places where water resources are depleted or polluted, with producers and consumers along the supply chain benefiting at the cost of local communities and ecosystems. It is unlikely that consumption and trade are sustainable if they are accompanied by water depletion or pollution somewhere along the supply chain. Typical products that can often be associated with remote water depletion and pollution are cotton and sugar products. For animal products, it is much more difficult to tell whether they relate to such problems because animals are often fed a variety of feed ingredients and their feed supply chains are difficult to trace. Hence, unless we have milk, cheese, eggs, or meat from an animal that was raised locally and that grazed locally or was otherwise fed with locally grown feedstuffs, it is hard to say something about which claim such a product has put on the world's scarce freshwater resources. The increasing complexity of our food system in general and the animal product system in particular hides the existing links between the food we buy and the resource use and associated impacts that underlie it.

Product Transparency in the Food Sector

To know what we eat, we will need a form of product transparency that is currently completely lacking. It is reasonable that consumers (or consumer organizations on their behalf) have access to information about the history of a product. A relevant question is, "How water intensive is a particular product that is for sale, and to what extent does it relate to water depletion, water pollution, or both?" Establishing a mechanism that ensures such information is available is not an easy task. It requires a form of accounting along production and supply chains that accumulates relevant information all the way to the end point of a chain.

In particular, governments that place emphasis on "sustainable consumption" may translate this interest into their trade policy. The UK government, for example, given the fact that about 75% of the total water footprint of the UK citizens lies outside its own territory (Mekonnen and Hoekstra, 2011), may strive toward more transparency about the water impacts of imported products. Achieving such a goal will obviously be much easier if there is international cooperation in this field. In cases in which industrialized countries import feed from developing countries, the former can support the latter within the context of development cooperation policy in reducing the impacts on local water systems by helping set up better systems of water governance.

Businesses can have a key role as well, particularly the large food processors and retailers. Because they form an intermediary between farmers and consumers, they are the ones that have to pass on key information about the products they are trading. As big customers, they can also put pressure on and support farmers to actually reduce their water footprint and require them to provide proper environmental accounts. When it comes to water accounting, several parallel processes are currently going on in the business world. First, there is an increasing interest in the water use in supply chains, on top of the traditional interest in their own operational water use. Second, several companies, including, for instance, Unilever and Nestlé, have started to explore how water footprint accounting can be practically implemented. Some businesses are thinking about extending their annual environmental report with a paragraph on the water footprint of the business. Others are speaking about water labeling of products (either on the product itself or through information available online), and still others are exploring the idea of water certification for companies. The interest in water footprint accounting comes from various business sectors, ranging from the food and beverage industry to the apparel and paper industry, but within the food industry, there is still little interest when it comes to the most water-intensive form of food: animal products.

Conclusion

The interest in the water footprint in the food sector is growing rapidly, but most interest thus far has come from the beverage sector (Sarni, 2011). In addition, most companies still restrict their interest in water to their own operational water footprint, leaving the supply-chain water footprint out of scope. Little interest in water has been shown in the meat and dairy sectors, which is surprising given the fact that the meat and dairy sectors contribute more than one-quarter to the global water footprint of humanity. In addition, from the governmental side, hardly any attention is given to the relationship between animal products and water resources. Nowhere in the world does a national water plan exist that addresses the issue that meat and dairy are among the most water-intensive consumer products, let alone that national water policies somehow involve consumers or the meat and dairy industry in this respect. Water policies are often focused on sustainable production, but they seldom address sustainable consumption. They address the issue of water-use efficiency within agriculture (more crop per drop), but hardly ever the issue of water-use efficiency in the food system as a whole (more kilocalories per drop). The advantage of involving the whole supply chain is that enormous leverage can be created to establish change.

The issue of wise water governance is a shared responsibility of consumers, governments, businesses, and investors. Each of those players has a different role. Consumers (or consumer and environmental organizations) may demand of businesses and governments more product transparency of animal products so that one is better informed about associated water resources use and impacts. Consumers can choose to consume fewer animal products or can choose, whenever proper information allows, the meat, eggs, and dairy products that have a relatively low water footprint or for which this water footprint has no negative environmental impacts. National governments can, preferably in the context of an international agreement, put in place regulations that urge businesses along the supply chain of animal products to cooperate in creating product transparency. Governments can also tune their trade and development cooperation policies toward their wish to promote consumption of and trade in sustainable products. Companies, particularly big food processors and retailers, can use their power in the supply chain to effectuate product transparency of animal products. They can also cooperate in water labeling, certification, and benchmarking schemes and can produce annual water accounts that include a report of the supply-chain water footprints and associated impacts of their products. Finally, investors can be an important driving force to encourage companies to put water risk and good water stewardship higher on their corporate agendas. Some steps have been made in creating product transparency in the meat and dairy industry to address concerns of product quality and public health. It is likely that in the future, there will be increasing interest in transparency regarding environmental issues such as water resource use as well.

Literature Cited

Allan, T. 2011. Virtual Water: Tackling the Threat to Our Planet's Most Precious Resource. I. B. Taurus, London, UK.

Ercin, A. E., M. M. Aldaya, and A. Y. Hoekstra. 2011. The water footprint of soy milk and soy burger and equivalent animal products. Value of Water Res. Rep. Ser. No. 49. UNESCO-IHE, Delft, the Netherlands.

Falkenmark, M., and J. Rockström. 2004. Balancing Water for Humans and Nature: The New Approach in Ecohydrology. Earthscan, London, UK.

Food and Agriculture Organization of the United Nations (FAO). 2005. Livestock policy brief 02. FAO, Rome, Italy.

Food and Agriculture Organization of the United Nations (FAO). 2011. Food balance sheets. FAOSTAT, FAO, Rome, Italy. Accessed Jan. 9, 2012. http://faostat.fao.org.

Galloway, J. N., M. Burke, G. E. Bradford, R. Naylor, W. Falcon, A. K. Chapagain, J. C. Gaskell, E. McCullough, H. A. Mooney, K. L. L. Oleson, H. Steinfeld, T. Wassenaar, and V. Smil. 2007. International trade in meat: The tip of the pork chop. Ambio 36:622–629.

Gerbens-Leenes, P. W., M. M. Mekonnen, and A. Y. Hoekstra. 2011. A comparative study on the water footprint of poultry, pork and beef in different countries and production systems. Value of Water Res. Rep. Ser. No. 55. UNESCO-IHE, Delft, the Netherlands.

Hendy, C. R. C., U. Kleih, R. Crawshaw, and M. Phillips. 1995. Livestock and the environment finding a balance. Interactions between livestock production systems and the environment. Impact domain: Concentrate feed demand. FAO, Rome, Italy. Accessed Jan. 9, 2012. http://www.fao.org/wairdocs/lead/x6123e/x6123e00.htm#Contents.

Hoekstra, A. Y. 2010. The water footprint of animal products. Pages 22–33 in The Meat Crisis: Developing More Sustainable Production and Consumption. J. D'Silva, and J. Webster, ed. Earthscan, London, UK.

Hoekstra, A. Y., and A. K. Chapagain. 2008. Globalization of Water: Sharing the Planet's Freshwater Resources. Blackwell Publishing, Oxford, UK.

Hoekstra, A. Y., A. K. Chapagain, M. M. Aldaya, and M. M. Mekonnen. 2011. The Water Footprint Assessment Manual: Setting the Global Standard. Earthscan, London, UK.

McGuire, V. L. 2007. Water-level changes in the High Plains Aquifer, predevelopment to 2005 and 2003 to 2005. Scientific Investigations Rep. 2006-5324. US Geological Survey, Lincoln, NE.

Mekonnen, M. M., and A. Y. Hoekstra. 2010. The green, blue and grey water footprint of farm animals and animal products. Value of Water Res. Rep. Ser. No. 48. UNESCO-IHE, Delft, the Netherlands.

Mekonnen, M. M., and A. Y. Hoekstra. 2011. National water footprint accounts: The green, blue and grey water footprint of production and consumption. Value of Water Res. Rep. Ser. No. 50. UNESCO-IHE, Delft, the Netherlands.

Naylor, R., H. Steinfeld, W. Falcon, J. Galloway, V. Smil, E. Bradford, J. Alder, and H. Mooney. 2005. Agriculture: Losing the links between livestock and land. Science 310:1621–1622.

Pittock, J., and D. Connell. 2010. Australia demonstrates the planet's future: Water and climate in the Murray-Darling Basin. Int. J. Water Resour. Dev. 26:561–578.

Sarni, W. 2011. Corporate Water Strategies. Earthscan, London, UK.

Steinfeld, H., P. Gerber, T. Wassenaar, V. Castel, M. Rosales, and C. de Haan. 2006. Livestock's long shadow: Environmental issues and options. FAO, Rome, Italy. Accessed Jan. 9, 2012. ftp://ftp.fao.org/docrep/fao/010/a0701e/A0701E.pdf.

About the Author

Arjen Y. Hoekstra is a professor in water management at the University of Twente in the Netherlands and is scientific director of the Water Footprint Network. He specializes in integrated water resources management, river basin management, policy analysis, systems analysis, and the science of sustainable development. He has been participating in and leading a variety of interdisciplinary research projects involving a range of disciplines: earth and environmental sciences, engineering, economics, anthropology, and policy sciences. Hoekstra is creator of the water footprint concept and established the interdisciplinary field of water footprint assessment, a research field addressing the relations among water management, consumption, and trade. He was cofounder of the Water Footprint Network in 2008. His books include *Globalization of Water* (2008) and *The Water Footprint Assessment Manual* (2011).
Correspondence: A.Y.Hoekstra@utwente.nl