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Water consumption by livestock: how to calculate and optimize its use. Focus on Brazil

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ABSTRACT

Water scarcity is a risk for the planet, and agriculture's contribution to water resource depletion is significant. It is thus important to implement methods to assess water use, especially by livestock. One method is the "water footprint", based on calculations of blue water (from rivers and groundwater, consumed by and for livestock and to irrigate their feed crops), green water (evapotranspiration of crops fed to livestock), and gray water (a virtual amount needed to dilute water pollution). Separately, these 3 types of water are useful for managing water resources, but summing them may lead to misinterpretations; in addition, the sum is not related to water scarcity. Another method, life cycle assessment, generally considers only blue water but also includes off-site activities needed to produce inputs for animal production. A water stress index, a function of local water-depletion risk, is used to weigh water use to predict contribution of animal production on water scarcity. Regardless of the method, wide differences in water use exist depending upon country and type of livestock system. Attention is drawn to water resources and use in Brazil because of the importance of animal production there. Brazil has high regional heterogeneity in water resources, and water footprints can suggest ways to improve water use. Extensive recommendations are provided for reducing blue, green, and gray water use in livestock systems. Special focus is placed on ways to decrease crop irrigation. It is concluded that livestock water use needs to be analyzed in greater detail to improve water management, but that it should be done in a multicriteria approach, considering other environmental impacts at the same time.

Key words: Brazil, life cycle assessment, livestock systems, water footprint, water scarcity, water use

INTRODUCTION

Water scarcity results when cumulative human impacts decrease water supply or quality to the point that water demand of humans and the environment cannot be satisfied (UN-Water, 2007). Water scarcity is generally related to harsh climatic conditions, but is sometimes increased by low economic development that limits exploitation of groundwater resources or optimal management of available water. It is expected that global warming will change rainfall patterns and accelerate the water cycle due to increased evapotranspiration (IPCC, 2007). Rainfall will probably increase at high latitudes and in equatorial zones and decrease most in subtropical areas. In addition, annual rainfall patterns will

probably change, with more summer droughts. As a consequence, the number of countries affected by water scarcity is expected to increase (Figure 1).

Agriculture represents 70% of global water withdrawals, mainly for irrigation (WWAP, 2009), being highest in areas of limited water resources. Water consumption will likely increase in countries with rapid development, due to demographic growth and changes in food habits, which shift food consumption towards more animal products. This increase will probably concern countries suffering from water scarcity. It is thus necessary to assess the contribution of their production to water scarcity. At the same time, water use can be viewed as more than water scarcity alone, and tools are being developed to manage water resources better.

This paper reviews the main methods used for analyzing water use, with their advantages and limitations, and outlines the main factors controlling water use in livestock farming. Special attention is paid to water use by livestock in Brazil, as an example for analyzing water-related issues and water management. Indeed, Brazil is a major livestock producer, with large interregional differences in water supply and use.

SIGNIFICANCE OF THE WATER CYCLE AND BLUE, GREEN AND GRAY WATER TO ANIMAL PRODUCTION

The global air-soil-plant water cycle is complex (e.g., WWAP, 2009). Rainfall that reaches the soil is either taken up by plants, recharges groundwater by percolation, or runs off towards surface water, lakes or rivers, the latter which lead to oceans. At the same time, water is taken up for human activities from rivers, lakes or groundwater. Some of this water returns to the atmosphere through evapotranspiration (i.e., evaporation by soil plus transpiration by plants via their stomas), while the rest returns to surface waters or groundwater. For land areas, rainfall exceeds evapotranspiration by ca. 70%, whereas for oceans evaporation exceeds rainfall. Despite this apparently closed cycle involving land masses, oceans and atmosphere, depletion of freshwater resources is frequent. This is due to the slow recharge rate of deep groundwater, on the scale of hundreds of years, and to changes in rainfall patterns. Spatially, global climate change results in more rainfall in northern and polar areas but less in some subtropical areas and temperate climates, and seasonally, more rainfall in winter but less in summer (IPCC, 2007). These changes in spatio-temporal water patterns lead to an increasing shortage of freshwater (Figure 1). In the same terrestrial region, water is transferred from one watershed (i.e., a region drained by a given river basin) to another, so that water balance (i.e., the difference between entering and leaving the watershed) may be positive or negative depending upon the location. A large river's watershed is often a too large a hydrological unit in which to analyze water use; thus, it is often divided into sub-watersheds when assessing water resources.

The concepts of blue, green and gray water appeared a few decades ago to describe all water flows occurring in the global water cycle and to combine water availability and quality in a single figure. Blue water is that in liquid form taken from surface waters (rivers, lakes) or ground water and used for human activities. Green water is that in vapor form that leaves soil and plants by evapotranspiration. Gray water represents an amount of water necessary to add to polluted water to reach quality standards of non-polluted water.

As a liquid, blue water is the only one that can be measured with accuracy. For global livestock-farming activities, water is consumed not only on-farm, mainly for drinking water, servicing and irrigation, but also off-farm, either for upstream processes such as production of inputs or downstream processes such as animal-product processing and handling. Table 1 summarizes the main sources of blue water consumption and specifies whether they result in water transfer between watersheds. When downscaling to the animal level to better understand physiological requirements and water-use efficiency strategies, water intake in any form (e.g., drinking water, water contained in feeds and metabolic water, which results from nutrient catabolism by animals) equals eventual water output, with possible transfers between the farm watershed and other watersheds (Table 2).

Green water is defined as the amount of rainfall that does not run off or recharge groundwater and that is used for evapotranspiration during crop production (Hoekstra et al., 2009). As a consequence, for a given area, green water is roughly proportional to rainfall and crop yield. Green water can be estimated by equations (e.g., Penman-Monteith) that include factors controlling evapotranspiration. The first step is to calculate potential evapotranspiration of soil and plants in a given area, which depends mainly on climatic and crop characteristics. With this, one can estimate crop water requirements per ha, which, when multiplied by crop yield per ha, results in the virtual water content per kg crop.

Gray water is often easy to calculate for a factory, because it is possible to quantify with accuracy flows and pollutant concentrations in water leaving the factory and in water bodies receiving the factory's water. For agriculture, the calculation is much more difficult because water outputs are diffuse and pollutant concentrations are difficult to determine. Hoekstra et al. (2009) calculate gray water by dividing pollutant load, expressed as mass per unit time, by the difference between maximum and natural pollutant concentrations. Pollutant load can be estimated as the fraction of applied chemicals and pesticides that reaches the ground. In addition, the choice of pollutant is a major issue. For example, in the European Union, 33 water pollutants are regulated by environmental standards. One could attempt to use the most dangerous pollutant for the environment (from among fertilizers, pesticides and pharmaceuticals) for a given watershed, but the choice is subjective and does not allow comparisons between watersheds. Mekonnen and Hoekstra (2012) usually calculate gray water from pollution by N fertilizers, which is the easiest to determine.

ASSESSMENT OF WATER CONSUMPTION FOR PRODUCING ANIMAL PRODUCTS AND WATER SCARCITY

Chapagain and Hoekstra (2003) proposed the “water footprint” concept as the sum of blue, green and gray water, defined as a virtual water flow. The initial aim was to describe international trade of water through import and export of foods as a tool for managing water use by countries. The water footprint helps to understand three dimensions of water sources in an animal-production system: use of rainfall for feed production, water withdrawal from available resources and water pollution. It is used as a tool to promote water security, so that animal production can use water while maintaining environmental, economic and social benefits to the individual and society. The theoretical background and practical applications of the water footprint have been assessed by Hoekstra et al. (2009). Deutsch et al. (2010) validated this method but proposed adjusting green water by subtracting evapotranspiration of grazed, but not mown, areas because of the environmental services provided by grazing.

For the past several years, life cycle assessment (LCA) principles have been applied to water consumption for the production of animal products. Theoretically, all production steps are included, from the beginning of the production process (extraction of raw materials for inputs) to animal-product production, including all water use by factories that produce inputs (e.g., fertilizers, seeds, pesticides, concentrated feed), transport up to and including the farm (“cradle to farm-gate LCA”) and, in certain cases, consumption by consumers and waste recycling (“cradle to grave LCA”) (Guinée et al., 2002). System boundaries are generally large. For example, boundaries for beef systems often include the cow-calf and fattening phases. Studies are performed at the level of animal production chains rather than at the farm level; LCA is thus more comprehensive than the water footprint. Many variants of LCA of water consumption have been proposed (see review by Kounina et al., 2013). All such LCAs include water for drinking, servicing, on-farm irrigation and off-farm irrigation for purchased feeds. With the exception of Zonderland-Thomassen and Ledgard (2012), who calculated a water footprint including blue, green and gray water, and, LCAs have been limited to blue water. Most LCA methodologies consider that green water use is accounted by the land occupation impact, because it is an intrinsic property of land. Ridoutt et al. (2012) added the water that evaporates from holding ponds used to provide water to animals. However, De Boer et al. (2013) included a difference in green water due to land-use change, since some soybean production in South America is associated with deforestation of primary forest, whose evapotranspiration differs from that of crops and forages. Effects of other changes in land use (e.g. between crops, forages, and natural grasslands and shrublands) on green water are usually not included in LCAs because evapotranspiration on agricultural land often differs little from that on land with natural vegetation. In agricultural LCAs, resource use and potential impacts are often allocated among co-products of systems, if applicable. For example, since dairy systems provide both milk and meat, the latter being

produced from culled cows, fattened dairy bulls and heifers not used for herd renewal, their impact on water use can be shared between both products. Zonderland-Thomassen and Ledgard (2012) used economic allocation between milk and meat, while De Boer et al. (2013) used no allocation, attributing all impacts to milk.

The methods described above are life cycle inventories, which simply sum the water consumed to produce animal products. A more complete LCA approach consists of estimating potential impacts of water consumption, as is done for other impacts, such as climate change, eutrophication and acidification. Pfister et al. (2009) developed the concept of the water stress index, which describes the risk of water scarcity in a given watershed, based on the ratio of water withdrawal to available freshwater resources. Water quality impacts in LCA are generally assessed through eutrophication, aggregating nitrate and phosphate pollution, and aquatic ecotoxicity, aggregating pollution by organic compounds and heavy metals. For this reason, gray water is seldom calculated in LCA.

The use of LCA for estimating impacts on water resources is more recent than the use of the water footprint. The total water footprint (adding blue, green, and gray water together) is often considered as the reference value to use to compare the impact of food production on water resources. However blue, green and gray water have completely different natures, and the water footprint estimates only total water use, not its impact on available water resources and thus the risk of water scarcity. The preponderance of green water in the total water footprint (> 90% for plant and animal products, Mekonnen and Hoekstra, 2012) hides the risk of water depletion shown by blue water and of water pollution shown by gray water. Green water accounts for water output from plants but not for their major water input (i.e. rainfall) and thus is not adjusted according to local water balances. Average water footprint values of 15,000 L per kg beef and 3,000 L per kg milk are often cited for standard systems with high productivity in developed countries. Pimentel and Pimentel (2003) calculated 200,000 L of water footprint per kg beef for cattle grazing extensive pastures. This calculation results in a high water footprint for low-productivity breeds managed extensively on rangelands or mountain areas, even when rainfall is sufficient. For example, a typical beef production system in the humid tropics of West Africa (800-1000 mm annual rainfall) produces animals slaughtered at 320 kg at 42 months of age, with a stocking rate of 0.4 animal per ha. Including the cow-calf stage, the water footprint of beef from this system exceeds one million L water per kg beef, despite there being no impact on water scarcity and green water use being equivalent for natural plant cover in the absence of domestic animals. If each kg of beef had a water footprint of 15,000 L, annual world beef production (80 million t), would use 1,200 billion m³ water, i.e. a quarter of world available freshwater reserves, which are estimated as less than 5,000 billion m³ (WWAP, 2009). Thus, the three components of water footprint taken separately are a valuable tool for water management, and weighted LCA provides the most accurate approach for estimating impacts of water use on freshwater depletion.

WATER USE BY LIVESTOCK SYSTEMS: EVIDENCE OF LARGE DIFFERENCES

Due to the wide variety in methodologies, large differences in water use estimates exist, for example for milk production (Table 3). Besides differences between water footprints and LCA estimates and differences in methodology within LCA, huge differences for blue water are observed, likely due to irrigation water. In addition to regional differences, there are differences in calculation, since irrigation water can be either measured or estimated from climatic data as the freshwater necessary to achieve crop production, once evapotranspiration has been estimated. Application of the water stress index to estimate water depletion moderately (30% lower) or greatly decreases (up to 99% lower) raw water use, depending on water scarcity in the region studied. Ridoutt et al. (2012) obtained the same result for Australian beef, finding that weighted water use was higher than raw water use when the local stress index was higher than the average Australian water stress index.

Mekonnen and Hoekstra (2012) compared water footprints of animal products from seven countries and found large differences. For beef, milk, pork, chicken meat and eggs, blue water use varied from 178-722, 33-145, 268-1226, 30-873, and 27-635 L per kg product, respectively. Except for pork, the lowest water use was found for Brazil and the highest water use for China or India, with the other four countries (Australia, USA, Russia, Netherlands) in between. Differences in blue water are likely linked to irrigation and the proportion of intensive systems in each country. Differences in gray water follow a similar pattern. Moreover, when a livestock system is considered as a whole, the higher its productivity (e.g. milk yield, carcass weight or eggs per animal), the lower its water use per kg product. In addition to between-country differences, large differences from one year to another due to weather have been observed (e.g., Peters et al. (2010)). Climate influences water use not only where animals are produced but also where their purchased feeds are produced.

Farming systems have a major effect on water use. Mekonnen and Hoekstra (2012) defined three types of animal-production systems, grazing, mixed and industrial, but whose main characteristics within countries are unknown. Differences between grazing, mixed and industrial systems varied: blue water use for beef was 150, 187 and 147 L/kg in Brazil and 0, 533 and 1471 L/kg in India, respectively. More detailed comparisons of systems (e.g., Zonderland-Thomassen and Ledgard (2012) for milk and Ridoutt et al. (2012) for beef) show the influence of the amount of irrigated crops or forages, the proportion of supplementary feed purchased, the water content of forages and evaporation from watering ponds.

BRAZIL, WATER SOURCES AND LIVESTOCK

Brazilian meat production (beef, pork and poultry) is predicted to increase to 10.9 million metric tons by 2021, an increase of 43% compared to 2011 production (MAPA, 2012). Brazil already ranks among the leading global producers and exporters of beef, poultry and pork and is increasing production of milk, eggs, and fish. Studies from the FAO, OECD and World Bank predict that Brazil will become the largest producer of animal protein in the world within ten years. These institutions have identified a global “Livestock Revolution”, in which animal production is migrating from developed to emerging and developing countries. One major reason for this migration is the greater availability of natural resources; other reasons include a strong increase in domestic consumption (e.g., China) and lower production costs for international companies.

In discussions of the competitiveness of Brazilian animal production in international forums, water sources appear as a major competitive advantage. Latin America is rich in natural resources, especially in freshwater (WWAP, 2009), and preserving their quantity and quality is strategic for maintaining competitiveness and sustainable production of animal protein.

Water is a key factor for animal production and competitiveness between countries and regions; intensification is commonly performed to increase supplies of animal protein; increased productivity and efficiency in using inputs and natural resources will increase production. Historically, Brazilian animal production has not managed water use because it is believed that the country is rich in water. Brazil does have abundant fresh water, but much of it is in the north (Amazon River basin); therefore, conflicts over water use occur in regions of high population density and industrialization, where water demand exceeds supply.

In 2010, 51% of water withdrawals in Brazil were for consumptive purposes, of which 72% went to irrigation, 11% to animal watering, 9% to urban supply, 7% to industrial supply, and 1% to rural supply (ANA, 2012). It is noteworthy that in some river basins (RB), the percentage of water used for livestock is relatively high: 41% in Paraguay RB, 32% in Amazon RB, 18% in North West RB, and 16% in Tocantins-Araguaia RB.

The potential impacts of animal production on surface and ground water quality and quantity have aroused the concern of society. Regions such as southwestern Rio Grande do Sul, western Santa Catarina and Parana, western Sao Paulo, northern Mato Grosso, southern Goiás and Mato Grosso do Sul, the coastal region of the Northeast, and, more recently, the region encompassed by Amazon Biome, have faced conflicts over water use by animal production. These conflicts are based on trade-offs between economic and social benefits and the maintenance of environmental quality and water resources.

Estimates of how much water is consumed by a livestock herd or to produce one kg of meat or milk in Brazil remain scarce. Such information needs to be given to society and water resource managers. In this way, animal production chains can become less confrontational and demonstrate that, despite being water intensive, they have practices and programs for increasing water efficiency.

Recently, studies have begun to perform such estimates using a variety of methods, such as the water footprint approach. Knowing the water requirements of animal production can help strengthen water management according to the Brazilian Water Act, which decrees that water resources must be collectively managed in a decentralized manner by the government, users, and communities to allow multiple uses. Another fundamental rule of the Brazilian Water Act related to animal production is that in situations of water scarcity, water needs of humans and animal production have priority over other needs, such as those for irrigation, industry, navigation, and hydropower. Global trends in animal production, its concentration in Brazil and negative impacts it can have on resource and environmental preservation, of which water availability and quality is a major issue, result in the urgent need to meet environmental standards so that animal production has to continue to be synonymous with social and economic values.

WATER FOOTPRINT AND BRAZILIAN ANIMAL PRODUCTION

Information in the media about water footprints of animal products began to be released in Brazil in 2009, raising questions by the animal-production sector and society about the relation between water and animal production. Consequently, the Brazilian livestock sector strongly resists the term “water footprint” and any discussion about calculating it. Society and the animal-production sector did not know about the methodology and its premises, how to interpret the results, or how to use them in decision making; so, conflicts were intense. This highlighted that, regardless of the method used to calculate water use and its assumptions, a strategy should exist for reporting results and describing production systems of reference and their geographic areas and period over which they were analyzed. Only in this way would the results have potential to be used in decision-making, and the value of the water footprint could be internalized by actors and used to improve the water efficiency of animal production.

One should calculate the water footprint of production systems prevailing in Brazil, considering the existing production and environmental contexts. Only then can the footprint be used as an indicator to help manage water resources and improve water efficiency. Based on this understanding, Brazilian researchers have begun to study water footprints considering the production contexts of the country. The first studies were performed for pigs and poultry production.

Palhares (2011) calculated the water footprint of pigs slaughtered in 2008 in the central and southern states of Brazil (Table 4). The study estimated green water consumed for grain production (maize and soybean, which are produced without irrigation) and blue water consumed for drinking and servicing. Most water in the footprints was green, demonstrating the importance of improving the water-use efficiency of crops used in pig diets, especially of maize and soybean. This does not prohibit, however, initiatives, programs and policies from reducing consumption of drinking and servicing water on farms. Pig production is highly concentrated in southern Brazil; so, consumption for drinking and servicing will always influence water security there. The fact that most water consumption to produce pigs occurs for crop production rather than drinking and servicing induces a change in perspective: water management for pig production should occur not only inside the pig farm but throughout the production chain.

Palhares (2012) calculated the water footprint (green and blue water) of broiler chickens slaughtered from 2000-2010 in central and southern states of Brazil. The calculation included indirect water, consumed in grain production (maize and soybean), and direct water (for drinking and servicing). Years with lower water footprints were those in which green water consumption was lower due higher yields of maize and soybean. Water consumption for cooling facilities was included only for the central states Mato Grosso, Mato Grosso do Sul, and Goias due to their climate. These states also had low water footprints, similar to those in which cooling was not considered, indicating that water consumption for cooling is not significant when green water is considered. Southern states had the highest footprints and the largest number of chickens slaughtered during the period. The average footprint was 4,334 m³ (99.7% green and 0.3% blue) for Parana and 4,216 m³ (99.8% green and 0.2% blue) for Rio Grande do Sul. Although the mean difference in water footprint among years was 0.027% (due to maize and soybean yields), that for the number slaughtered was 7.1%. The largest and smallest footprints occurred in 2005 and 2001, respectively. The number slaughtered increased or remained constant in all states.

Currently, the challenges to calculating the water footprint for Brazilian animal production are the following:

- lack of concern about water use and water management in farms and production chains
- lack of data, which increases assumptions, uncertainties, and conflicts
- the need to measure both point-source and diffuse pollution from animal production to improve calculations
- absence of systemic vision in supply-chain actors and decision makers
- aversion of some actors to the water footprint methodology and thus little cooperation
- little understanding of the methodology by actors and society
- sensationalism of water footprint values by the media

Knowledge of water consumption by animal production systems is an opportunity for the following:

- provide water-use data for Brazilian production systems
- ensure availability of water quantity and quality
- internalize the concept of water use in animal production as natural resource, input, and in feed
- estimate the water consumption of green, blue and gray water by animal-production systems in different regions and conditions to facilitate water management, promote water-use efficiency, and establish best water practices
- reduce conflicts between production chains and society
- identify vulnerable areas
- formulate policies and set goals for reducing water demand
- assist in formulating zoning and water management programs

OPTIMIZING WATER USE

Society has new demands for the production of animal foods, including environmental quality and natural-resource-use efficiency. For animal production to meet this societal need, actors should widen their understanding of production systems to a holistic vision. Since water is an essential resource for the production of animal protein, its quantity and quality should be monitored continuously.

Best management practices for water use must be proposed, evaluated, and established in animal-production chains. These practices will generate additional information and indicators to explain the relation between water use and animal production, enabling planning, management, evaluation, and adjustment. Figure 2 presents a proposal for best management practices and their environmental, social and economic impacts for short and medium terms. The use of these practices will result in the internalization of water management, reducing the cost of water and conflicts between animal production and society and increasing water security.

Irrigation pressure on water resources, defined as the ratio between water withdrawal for irrigation and available water resources, is 58% in the Near East / North Africa but less than 5% in Europe, North America, Latin America and sub-Saharan Africa, the latter practicing rainfed agriculture (FAO, 2011). Reducing irrigation is a concrete example of optimizing water use that may noticeably decrease freshwater consumption. One efficient technique may be to decrease irrigation where rainfall is too low to avoid water shortages, at least during some periods of the year. Irrigation increases food security for humans by maximizing food and feed production but decreases groundwater reserves and, in extreme cases, decreases the level of inland seas and increases their salinity (e.g., the Aral Sea, following massive irrigation of cotton crops). Irrigation efficiency may increase in several ways. The first is to optimize timing and amount of irrigation, and water amount to be delivered and thus implement technological solutions (FAO, 2003, Steinfeld et al., 2006).

Another possibility is to reduce water use by crops. Maize, widely fed to animals and whose yield depends greatly on water supply, requires irrigation in many countries to achieve its potential yield when rainfall is insufficient. Early varieties can be sown so that the period of maximum plant growth corresponds to water availability. The utility of such varieties during periods of water stress has been shown in France (Epignat-Le Signor et al., 2001), and similar studies have been carried out in tropical areas. However, their yields are lower than those of traditional varieties, which may limit their practical use. Seed companies and research institutes have been working for several years to develop varieties resistant to drought via traditional selection in arid countries, marker-assisted selection and transgenesis. Traditional selection for yield simultaneously provides varieties with higher yields under hydric stress, and drought-resistant varieties are sold in tropical areas (Bruce et al., 2002; Campos et al., 2004). Drought-resistant transgenic varieties are not expected in the short-term, however, despite frequent announcements. Farmers also could buy non-irrigated maize, but it is necessary to check that doing so does not increase land-use change or its environmental impacts or greatly increase transport distances to farms. Finally, maize could be replaced by other cereals, although some nutritional characteristics, such as amino-acid composition, may change. Replacement by sorghum is often suggested because it grows in the same areas as maize and in countries such as France, produces more biomass in the absence of irrigation than maize does (Lemaire et al., 1996).

CONCLUSIONS

Water is a precious resource, and all sectors of human activity, including agriculture, should contribute to preserve it. Tools such as the water footprint and LCA are available to improve water management, though methodology requires standardization for better use by policy makers. It must be kept in mind, however, that freshwater availability is only one of the major environmental issues and that other impacts such as climate change, via greenhouse-gas emissions and use of non-renewable energy, should be integrated in a global approach. This sort of multicriteria analysis is one advantage of LCA.

South America has abundant water resources and bases much of its economy on agricultural production, leading to intensive water use. This abundance leads people to believe that water will always be available. This, combined with a low educational level of farmers and little knowledge about water management by agricultural stakeholders, leads to inefficient water use. Environmental metrics are needed to understand the relation between animal production and water resources and to improve water-use efficiency. Methods that organize and support water management help reduce water consumption. It is also important to note that one of the biggest challenges in Latin America is cultural. Internalizing water management into daily activities, understanding the three dimensions of water use in animal production, and

knowing about water flows in farms and watersheds are fundamental, and the water footprint approach can help them to do so. This approach could improve communication between stakeholders, reducing potential conflicts, and contribute to the implementation of laws, programs and policies.

This article focused on negative impacts of livestock on water resources, but livestock also have neutral and positive impacts on them. For example, grazing humid areas has less impact on native biodiversity than draining them to convert them to cropland. In arid areas, the use of draft animals for drilling or hydraulic works, water extraction and transportation makes a sedentary life possible for some populations (Blanfort et al., 2011). More than one billion people depend on livestock farming, which plays a major economic and social role in many communities, especially for smallholders in developing countries. Interactions between livestock and water resources must be analyzed to design, implement, and monitor sustainable farming systems.

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Table 1. Blue water uses by livestock farming: nature and transfer between watersheds

Nature of water use	Transfer from/to another watershed
Animal watering	No
Water used on-farm Soil cleaning, milk tank cleaning, etc.	No
Animal spraying in hot climates in intensive systems	No
On-farm feed irrigation	No
Purchased crops irrigation	Goes to farm watershed (most often)
Water required for upstream processes Feed and fertilizer production, transport, raw material extraction, etc.	Goes to farm watershed (most often)
Water required for downstream processes Slaughterhouses, dairy and meat factories, tanneries, etc.	Leaves farm watershed or remains in the same watershed

Table 2. Water balance in animals¹, and water transfer from/to the farm.

Nature of water	To/from farm area
Water input	
Drinking water (including evaporation when water for watering is stored, e.g. in a pond)	Transfer to farm within the same watershed, or no transfer
Water embedded in feed produced on-farm ²	No transfer
Water embedded in purchased feeds ²	Transfer to farm
Water output	
Urine and feces	No transfer (except if manure is spread in other farms)
Products (milk, meat, eggs, leather, etc)	Transfer from farm (except domestic consumption)
Exhaled vapor, sweat	?

¹ Water contained in animals is negligible compared to water flows

² Including metabolic water

Table 3. Water use for milk production, measured by water footprint (WF), life cycle assessment (LCA) or LCA weighted for stress index (LCA-W)

	Method	Type of water	L / kg milk
7 countries ¹	WF	Green	462-1273
		Gray	22-210
		Blue	33-145
Australia ²	LCA	Blue	830
	LCA-W	Blue	108
12 countries ³	WF	Blue + Green	430-2400
USA ⁴	LCA	Blue (crop production only)	152
	LCA-W	Blue (crop production only)	109
New Zealand ⁵	LCA	Green	499-680
		Gray	264-336
		Blue	1-249
	LCA-W	Blue	0.01-7
The Netherlands ⁶	LCA	Blue + correction for land use change	66
	LCA-W	Blue + correction for land use change	33

¹ Mekonnen and Hoekstra, 2012 – between-country ranges are given; ² Ridoutt et al., 2010; ³ Sultana et al., 2011.

⁴ Lessard et al., 2012; ⁵ Zonderland-Thomassen and Ledgard, 2012 – results for 2 regions are given; ⁶ De Boer et al., 2013

Table 4. Contribution of water consumption (%) for maize, soybeans, and drinking and servicing to the water footprint of pigs slaughtered in 2008 in central and southern Brazilian states (from Palhares, 2011).

State	Green Water (%)		Blue water (%)
	Maize	Soybean	Drinking and Servicing
Mato Grosso	65.1	34.7	0.12
Mato Grosso do Sul	52.1	47.8	0.13
Goiás	57.0	42.9	0.14
Distrito Federal	54.4	45.4	0.15
Minas Gerais	60.8	39.0	0.12
Espirito Santo	74.7	25.3	0.08
Rio de Janeiro	75.4	24.5	0.07
Sao Paulo	57.5	42.3	0.12
Parana	52.7	47.2	0.15
Santa Catarina	53.9	46.0	0.12
Rio Grande do Sul	58.3	41.7	0.09

Figure 1. Expected increase in water scarcity in the world.

[source: UNEP/GRID-Arendal Maps and Graphics Library, 2009, design by P. Rekacewicz, http://www.grida.no/graphicslib/detail/freshwater-stress-1995-and-2025_6250].

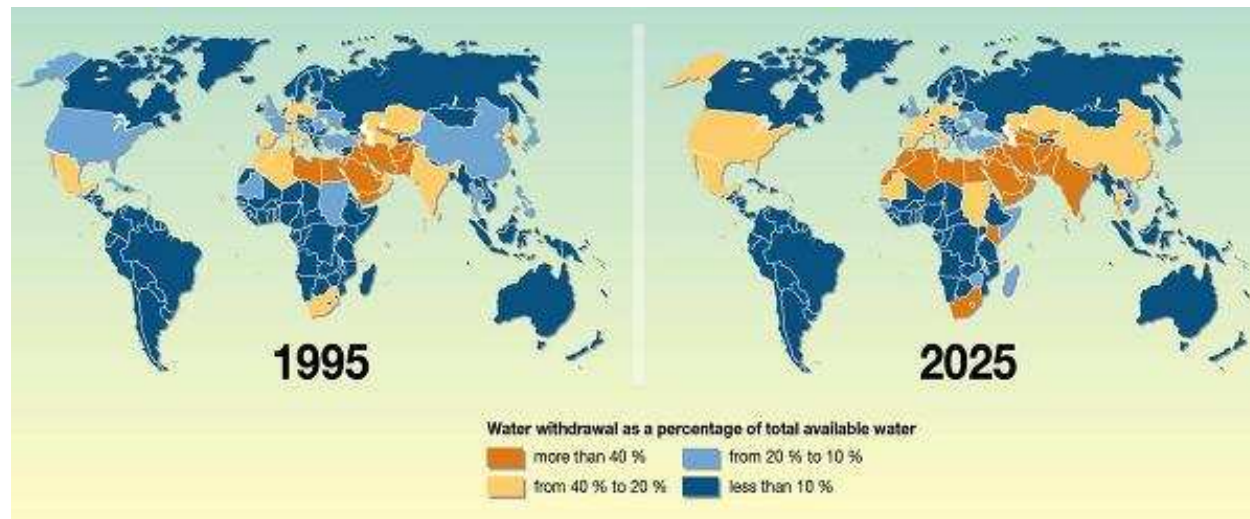


Figure 2. Proposal for improving water management in animal production

