Review of water assessment methodologies and application to Australian agriculture

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ABSTRACT

Water use is perhaps the primary resource allocation issue facing Australia. With the proliferation of approaches to estimating 'water use' for agricultural products and confusion over the meaning of these data, Australian agricultural industries have sought a robust, sound method that can be used to develop meaningful results at the product level. Life cycle assessment (LCA) is an ideal tool for achieving this, though clear methods for assessment are still under development. In particular, LCA can draw from traditional water engineering and water footprinting (WF) approaches, while developing methods and impact assessment categories to contribute to a better understanding of water management. Considering these frameworks are more widely accepted than LCA, results need to be understandable in this context. This paper investigates several methods for collecting water inventory data in the Australian context.

Keywords: Water, Water footprint, Agriculture.

1. Introduction

Water scarcity is an issue of growing concern worldwide, with an estimated 1.1 billion people suffering from inadequate access to improved water supply sources (WHO, 2009). With a growing human population, it follows that stress on water reserves will increase dramatically in the next 30-40 years (Rockström *et al.*, 2007). Scarcity of fresh water reserves is a question of both water quality and quantity. This paper is focussed on the quantity of water available for competitive uses, these being agriculture (and between competitive agricultural industries), the environment, industrial and domestic users. As in other parts of the world, the vast majority of water resources in Australia are used for agriculture (for 65-70% of water use nation-wide, ABS (2006)). While Australia does have adequate water resources nation-wide, these resources are not easily accessible to areas of high demand, and competition for water resources is perhaps the most severe resource allocation issue facing the country.

This paper reviews several inventory methods for assessing water use outside the field of life cycle assessment (LCA), together with recent developments by LCA researchers. The focus is on definitions of water use and the quantification of water use rather than impact assessment.The methods were reviewed in the context of Australian agriculture and relate to the current 'state-of-the-science' for water management. The need for improved methods have been prompted by the wide range of data available in the published and popular media spheres regarding 'water use' for various food products. Table 1 shows water use data for beef production as an example.

Table 1: Literature estimates of 'water use' required to produce one kilogram of beef

Water Required (L/kg beef)	Methodology	Functional Unit and System Boundary	Country	Reference
105,400	Not defined by author	Unclear – Pasture / grain fed cattle.	USA	Pimentel *et al.* (1997)
15,000 – 70,000	Not defined by author	1 kilogram of meat, Boundaries are unclear	not known	Gleick, in Gleick *et al.*(2009)
43,000	Not defined by author	Unclear – Grain fed cattle.	USA	Pimentel *et al.* (2004)
17,112	Virtual water / water footprint	Boneless beef [1]	Australian average	Hoekstra & Chapagain (2007)
15,497	Virtual water / water footprint	Boneless beef [1]	World average	Hoekstra & Chapagain (2007)
27 – 540	LCA – water use defined as extracted water [2]	Carcass weight	Australian southern beef production	Peters *et al.* (2010)

[1] Water use is over the slaughter animal's lifetime only and does not include upstream impacts
[2] Methodology defined by Australia's data accounting agency, the Australian Bureau of Statistics (ABS).

Within LCA water can be described using the standard classification for abiotic resources, based on the regeneration potential. The three main types of freshwater resources thus classified include deposits, funds and flows (Koehler, 2008). Owens (2002) further defined water in terms of in-stream uses (i.e. hydroelectric generation) and off-stream withdrawal, and suggests classifying water by source from surface water or groundwater. Owens (2002) presents five water use and water depletion indicators, of which the most relevant to Australian agriculture are: 1. in-stream water consumption indicator (i.e. evaporative losses from storages and canals in excess of unrestricted river losses); 2. off-stream water consumption indicator (evaporative losses and other conveyance losses, and transfers to another river basin); 3. off-stream water depletion indicator (withdrawals from overdrawn, un-replenished groundwater sources.

We suggest that two additional sources need to be considered, both of which relate to water derived directly from rainfall.

1. Water sourced from rainfall may be captured prior to entering a stream (i.e. capture of runoff) and stored for use on farm.
2. Rainfall that is stored in soil for use by plants. This is an important water source for agriculture both in Australia and worldwide where substantial improvements may be made to efficiency of use.

These water sources have important attributes that need to be handled carefully within LCA. Outside the field of LCA, water use methods may be classified into two broad fields, those based on; i) virtual water (including water footprinting) frameworks, and ii) water engineering frameworks. A series of inventory methods were assessed under each of these fields. The usefulness of terms and methods from these fields as a means of estimating water use for LCA is discussed.

2. Virtual Water and Water Footprinting

The virtual water (VW) concept was first proposed by Allan (1998) to describe the water required to produce tradable commodities (particularly food) in water stressed economies. The VW method makes a useful contribution to the global understanding of water transferability by showing that irrigation water in one region can be saved by importing food, thereby reducing water stress. Moreover, stress on irrigation water because of agriculture can be alleviated by growing products in regions where water requirements can be met by soil stored moisture.

To further improve the understanding of virtual water, Falkenmark (2003) describes water in terms of ‘blue’ water (which represents our general understanding of liquid water that may be sourced from surface or groundwater supplies) and ‘green’ water, which may be classed as evapotranspiration water (i.e. Falkenmark, 2003, Falkenmark &Rockstrom, 2006) or ‘soil stored moisture from rainfall’. These terms have now been adopted (along with the term ‘grey water’ to identify waste water) by the latest contributions from the field of water footprinting (Hoekstra *et al.*, 2009). Water footprint research is based on retrospective analyses of crop evapotranspiration requirements (using CROPWAT (FAO, 1998)). For livestock products, pasture water use requirements are derived from required livestock dry matter intake. Livestock drinking water and other minor uses such as cleaning and processing water are also estimated retrospectively.

2.1. Integrating WF concepts into LCA

Several authors have proposed using a modified WF/LCA approach for estimating water use for agricultural products, including Ridoutt *et al.*(2009a, b*)*, Pfister *et al.* (2009), Milà i Canals *et al.* (2009) and Ridoutt & Pfister (2010). These authors identify the need for more detailed inventory methods (particularly differentiation between blue and green water), and recommend excluding green water from the impact assessment. Ridoutt & Pfister (2010) and Pfister & Hellweg (2009) propose introducing a weighting factor into water footprinting as a means to indicate the environmental impact of water use. This is a useful approach for LCA, though it has not been accepted by leading WF leading researchers (Hoekstra *et al.* 2009b).

Regarding the handling of green water, Ridoutt *et al.* (2009a), Mila i Canals *et al.* (2009) and Ridoutt & Pfister (2010) suggest that green water be handled under the category of land use in LCA. However, Ridoutt *et al.* (2009a) identifies the following limitations to this approach: i) changes in water productivity for rain-fed production systems cannot be identified, and ii) studies are not able to identify systems that maximise the calorific or nutritive value per unit of water consumed. Considering the importance of green water for global food production, we contend that this needs to be reported within LCA as an independent resource. We reason that green water can be stored in soil (over a short period of time) and can be used for a number of alternative crops or livestock production on the same land. In this case, an independent measure of green water efficiency is meaningful. This being said, more research is required to develop suitable impact categories and indicators in conjunction with methodology development for land use.

3. Water Engineering

An alternative water assessment methodology can be drawn from the field of water engineering. Water engineers use a water balance of inputs and outputs in a defined system to identify all flows, from which ‘water use’ is derived. Water balances vary greatly in their degree of complexity and the accuracy of results, and can be complicated by confusion between ‘transfers’, ‘uses’ and ‘losses’. Because water is rarely created or destroyed in the system, most uses and losses are temporary transfers within the broader hydrosphere. However, water balances are useful in their comprehensive coverage of both beneficial uses and losses. Water balances or partial water balances have been created at the local, regional and catchment level in Australia, and data from each of these sources can be useful when creating an inventory of water use for a product.

3.1 Farm Water Balances

Farm scale water balances can provide detailed inventory data for water uses at the farm, and identify both 'beneficial' or 'non-beneficial' uses. For the purposes of LCA, we suggest defining water 'use' as the combination of both these categories. This is an important distinction that may lead to considerably higher water use for some irrigated products, because losses through storage evaporation and seepage are included. In contrast, retrospective water use estimates based on evapotranspiration requirements for plant growth or direct drinking water requirements for livestock will not include these non-beneficial uses.

In addition to creating a more complete inventory, farm level water balancing will inform the impact assessment phase and will also allow practitioners to broadly identify areas for improved efficiency and essential uses. This can easily be reported using the sources and indicators identified by Owens (2002).

3.2 Extracted Water

Water inventory data may be available from farms or from surveys (collected by government collection agencies). These data often represent 'extracted' water use, or water that has been pumped from a bore, creek or storage. Where survey data are used, attention needs to be paid to the definition of the term 'water use' to ensure correct classification. The Australian data collection agency, the Australian Bureau of Statistics (ABS), define water use as *the sum of distributed water use, self-extracted water use and reuse water use.* "Distributed" and "self-extracted" water uses are defined as water supplied from engineered delivery systems. Delivery systems vary greatly in size and degree of infrastructure, incorporating a range of systems, from sub-artesian groundwater extraction to water supply from rivers or state-owned dams.

Water is classified as "distributed" if the water is purchased, or "self-extracted" if not. Depending on the point of extraction, water use may include both beneficial and non-beneficial uses. Water is identified as being drawn from either a surface or groundwater source. This definition is similar to the 'off stream' water indicators proposed by Owens (2002). It can be reasonably assumed for agriculture that all uses are consumptive.

3.2 Application of Farm Scale Water Balances in LCA

Farm scale water balances have been integrated into recent LCAs for Australian pork (Wiedemann *et al.*, 2010) and beef (Peters *et al.*, 2010). Peters *et al.* (2010) defined 'water use' by the ABS (2006) definition as extracted water. Using this approach, the volume of water used for beef production in two supply chains ranged from 27 – 540 L / kg of beef (carcass weight) across two production years. The lower estimate is below the drinking water requirements for beef cattle (which amounts to around 130 L / kg carcass weight) because water sourced from direct rainfall capture in farm dams was omitted from the estimate. If data were taken from national averages of water use in beef production (from the ABS) a similar error would exist. To provide a more comprehensive assessment, water balances for each property were established to define all water flows including rainfall (Peters *et al.*, 2010). For the two systems assessed, >97% of the water used in the grazing beef system was found to be directly derived from rainfall on the property. A major limitation to this approach is the time required to compile the inventory, which generally limits the number of supply chains that can be studied. With a fluctuating resource such as water, results may vary widely from one supply chain to the next, and from one season to the next.

4. Conclusions

Water assessment inventory methodology is a rapidly expanding field, being led by numerous researchers and working groups world-wide. This paper contributes to this discussion using examples from animal agriculture and irrigation in Australia, where water stress and competitive supply are a serious issue for both the government and industry. We suggest that LCA studies adopt two of the water descriptors used for water footprinting (blue and green water). To improve the comprehensiveness of water assessment at the farm level, we suggest using a water balance approach. Within this framework, water can be identified using the indicators provided by Owens (2002) or local indicators based on the ABS classification in Australia. This will enable LCA research to inform supply chain managers of the non-beneficial uses within a supply chain and inform mitigation strategies.

For a country such as Australia, green water is the most limiting resource to expansion of food production on the currently available agricultural land. Consequently we contend that green water should be considered as a resource by LCA. As noted by other authors, this is intrinsically linked to land use and further methodology development needs to reflect these linkages, however we believe it should also be treated separately as a water resource.

5. Acknowledgements

Funding for this research was provided by Meat and Livestock Australia.

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