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Short communication

Making waves – Are water scarcity footprints of irrigated agricultural commodities suitable to inform consumer decisions?

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ABSTRACT

Fresh water is a limited global resource. Water scarcity footprints (WSF) have been developed to guide the choices of consumers and supply chains to reduce unsustainable fresh water consumption. The Available WAter REmaining (AWARE) method, which is the only method to have gained global consensus, assigns WSF for a commodity or product relative to the scarcity of water in the catchment in which production occurs. This results in products from water-stressed catchments that have a higher WSF than a similar product, using a comparable amount of water, in water-abundant catchments. The characterisation of water stress is developed using the WaterGap global hydrological model. Here, we use the Murray Darling Basin (MDB) to highlight how WaterGap does not reflect the impacts that legislation and infrastructure have on the relative volumes of water available for agriculture and the relationship between when (and where) water enters a catchment and when it is used for agriculture. Given that these issues are not unique to the MDB, it is likely that the AWARE WSF misrepresents the water stress experienced in other regulated catchments around the world. We conclude that for a WSF to be a useful indicator to guide consumer and supply chain decisions in supporting sustainable water consumption, it needs to reflect responsible management, such as setting aside water for the environment, placing caps on extractions, and the ability to hold water or transport water well beyond when and where it enters a catchment. Ultimately, WSF should also include a mechanism to assess burden shifting, especially if consumer or supply chain decisions were to mean that production moved to another catchment.

1. Introduction

Irrigation of agricultural lands to produce food, fibre and biofuel is a key consumer of water. Siebert et al. (2013) reported that, globally, 307 million ha of agricultural land is used for irrigation, with water primarily sourced from surface water (*i.e.*, rivers and lakes). The majority of irrigated agricultural land can be found in Asia (~ 69%), with Australia irrigating on average ~ 2.5 M ha annually. In Australia, over two-thirds of all irrigated agriculture occurs in the Murray Darling Basin (MDB), which covers an area of 1.06 million ha, and produces $24 billion worth of food and fibre (DAWE, 2020). Irrigation water is extracted from rivers, lakes, streams and groundwater aquifers or diverted from overland flows. Extracting water from these sources can be associated with negative environmental impacts such as changes to wetland ecology (Kingsford, 2000), and a decline in waterbird populations (Kingsford and Thomas, 2004). Impacts such as these have resulted in consumers and businesses becoming increasingly aware of the effects their consumption has on the environment. These concerns have led to the development of indicators such as water scarcity footprints to assess impacts, with the intention of guiding purchases and procurement to more sustainable products.

Footprints have been advocated as a method for assessing environmental impacts of products and supply chains with the most recently developed AWARE water scarcity footprint (WSF) the preferred approach to assess water impacts (Boulay et al., 2018). Recent work has re-calculated the WSF of MDB with a focus on cotton production (Bontinck et al., 2022) however in this paper we provide additional critique of the AWARE water scarcity index in the context of its suitability to assess the sustainability of irrigated agricultural products that are produced in the MDB with respect to water impacts. We first provide an

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overview of the AWARE WSF and explore how accurately this sustainability indicator reflects real world water use, where legislation regulates water extractions for agriculture and water infrastructure regulates river flows. We also discuss the need for prospective analyses to inform consumer decisions with a focus on key issues that make retrospective analyses unsuitable. These points are discussed within the context of a corporation using the water scarcity footprint of two or more substitutable agricultural products (*e.g.* dairy milk and soy milk) to inform a purchasing decision based on reducing the water impacts associated with their supply chain.

2. The AWARE water scarcity footprint

Assessing water impacts in life cycle assessment has been through many iterations moving from withdrawal to availability and consumption to availability ratios, to ecosystem and human demand to availability ratio and finally a global consensus that ultimately resulted in the AWARE method to characterise water scarcity. The purpose and development of the AWARE method can be found in Boulay et al. (2018). AWARE represents the "relative Available WAter REmaining per area in a watershed, after the demand of humans and aquatic ecosystems has been met. It assesses the potential of water deprivation, to either humans or ecosystems, building on the assumption that the less water remaining available per area, the more likely another user will be deprived." Global consensus was that this approach is a more appropriate indicator of impacts than consumption or withdrawal-based methods. A key component of the AWARE method is the development of a characterisation factor (CF_{AWARE}) which represents the inverse of the availability of water minus demand (*i.e.*, water required for ecological purposes and consumed by humans) on an area basis, normalised for global values. A catchment where demand $>$ availability is given a maximum CF_{AWARE} of 100, while a catchment where water is abundant is given the minimum CF_{AWARE} of 0.1. Calculating the WSF of an agricultural commodity is achieved by multiplying the water used in the production of an agricultural product by the relevant CF_{AWARE} with the result indicating the scarcity of the water used relative to global water availability. A more in-depth overview of the data inputs used to calculate CF_{AWARE} is provided in Bontinck et al. (2022). Just one example of this is that cotton grown in the northern part of the MDB with 8 ML of water per ha would have a water scarcity impact (WSF) of 800 m^3 H_2O-e due to the maximum CF_{AWARE} being applied to this catchment, whilst cotton grown with the same amount of water in the Ganges catchment in India would have a water scarcity impact of 141 m^3 H_2O-e. These results suggests that sourcing cotton grown in the Ganges river catchment for a supply chain would result in superior environmental performance than sourcing cotton from Australia despite rivers in the MDB receiving an environmental water allocation (discussed below) and the Ganges river experiencing regular summer no-flow events in recent years (Mukherjee et al., 2018). This apparent inconsistency is because the WaterGap model does not adequately estimate water supply and demand for these catchments. Briefly, WaterGap estimates water availability based on the rain that falls over a river catchment and extractions for agriculture based on land use derived from monthly satellite images of agricultural land. The flow of water through the system is validated by measured water flows in the system. This short communication highlights how the method to determine availability and extractions in the WaterGap model, and therefore the calculation of CF_{AWARE}, misses some of the fundamental processes that determine water availability and extractions in the MDB. We argue that this can lead to erroneous conclusions on the sustainability of agricultural production that relies on water extractions in this catchment.

3. Water legislation

3.1. Extraction caps

Legislation is used to manage water extraction in many countries and one key method to regulate water extraction is the use of a cap and trade (C&T) system. Cap and trade systems are commonly used to limit environmental damage by limiting the emissions of pollutants to the environment. In the context of irrigated agriculture, however, a C&T system places a maximum upper limit on the water that can be extracted from a system. A water market then allows users to trade water within the system, with the intention that the water will be directed to the highest value use. In some locations the cap is fixed (*e.g.*, the Ord River Scheme (Australia) which has abundant water flows and is capped at 348 GL annually, or 8% of total water available) or, as is the case for the MDB, the cap can be adjusted annually based on inflows to the system. An example of how this adjustment occurs for the Gwydir River basin, a sub-catchment of the MDB, is that only once inflows have been sufficient fulfil environmental requirements and supply essential users (*e.g.,* livestock, domestic use, and high security water users such as permanent agricultural crops such as nuts) for a period of 24 months, is water allocated to general security users such as cotton, dairy and rice producers. Although not considered environmental flows, the delivery of water to water users can sustain base environmental flows between the release and extraction points and avoid the need to use water dedicated to the environment. Issues around the AWARE method considering C&T legislation is not limited to the MDB, globally many other irrigation sources have C&T mechanisms in place. Notable examples include the Ord River Scheme in Australia, Aflaj irrigation systems of Oman, the Texas Edwards and Fox Canyon Aquifers, and the Colorado-Big Thompson (C-BT) irrigation project in the United States, all hydrological systems in South Africa and the Shiyang River Basin in China. Of particular note, the success of the C&T programme in limiting extractions from the Shiyang River Basin has resulted in the Chinese central government implementing a nation-wide water rights and water market system (Wang et al., 2019).

Boulay et al. (2018) state that where demand $=$ availability, then the maximum CF_{AWARE} of 100 is given to the catchment however this does not consider the purpose of legislation in water management of C&T systems, for example the MDB, where all available water is allocated to either the environment, conveyancing or extraction. We argue that where demand $=$ availability and where a cap on extractions for human use (including agricultural production) is in place, then CF_{AWARE} does not accurately reflect the sustainability of water use in that catchment. This is because a cap on extractions means that any additional production in a system that operates under a C&T scheme must come at the expense of other production, not an increase in extractions for that purpose. Hence, demand will necessarily equal availability in any system that operates under a C&T scheme. Contrary to the AWARE method, we argue that production that occurs in a system that operates under a C&T scheme is more sustainable than production in a catchment where no cap on extractions exists. The example of the MDB *vs* the Ganges river catchment is a case in point. Whilst some rivers in the MDB cease to flow only in times of drought, the Ganges river has experienced regular periodic drying under normal rainfall conditions in recent years due to over extraction (Mukherjee et al., 2018), yet based on CF_{AWARE}, irrigated agricultural production in the Ganges river catchment is classified as being more sustainable than the MDB. We propose that any catchment that operates under a C&T scheme and where water is allocated to the environment should receive the minimum CF_{AWARE} possible.

3.2. Carryover

Another element of legislation that potentially impacts the usefulness of current WSF methodologies is the concept of "carryover". Carryover is the ability to retain at least some undelivered water allocations in an upstream impoundment (*i.e.,* dam) from one year to another. When the water is required in the year after the water is captured, the water is released from the impoundment and flows to the point of extraction. This is an available mechanism in regulated rivers of the MDB. The effect of carryover is that W_{avail} in dry years can be vastly underestimated when based on extractions, and irrigated crop production, as estimated by the WaterGap model. This discrepancy would be greatest when a very dry year follows a very wet year, during which little to no allocations were used, resulting in the water stress of a catchment being overestimated. For example, the holders of general security water entitlements in the Murray River sub-catchment of the MDB were given no extraction allocations for 2019 – 2020 due to in-flows being extremely low. However, the official water accounts for the catchment (Burrell et al., 2020) show that 313,978 ML, or enough water to grow ~ 35,000 ha of cotton, were available to farmers who had carryover water from the previous year. As such, the method used by the WaterGAP model overestimates the CF_{AWARE} because the WaterGap model does not consider carryover in the water balance of a catchment. Integrating carryover into the WaterGap model would be challenging because it would require the incorporation of not only the timing of releases from impoundments but also the location of extractions from the system associated with each release.

3.3. Monthly CF_{AWARE} in regulated river systems

The issue of monthly values for CF_{AWARE} in regulated rivers face a similar issue to carryover. In unregulated river systems, a relatively large area of irrigated crop being grown during months of low W_{avail} (*i.e.*, periods of low inflow) would strongly suggest that the river system from which the water was being extracted would be stressed. However, calculating a monthly CF_{AWARE} is problematic in regulated river systems because inflows are captured in an impoundment when they are highest and released to users when required, usually at times of low inflows. Hence, irrigated crops grown in periods of low W_{avail} using water that was stored in impoundments would result in an overestimate of CF_{AWARE} for those periods.

3.4. Water transfer schemes

CF_{AWARE} is calculated based on a water balance of a catchment using the WaterGap model. A key deficiency in using the WaterGap model to calculate CF_{AWARE} is that the WaterGap model does not necessarily include water that is transferred between catchments, or systems, in the final water balance (Müller Schmied, 2021. pers. comm.). In the WaterGap model, global hydrology is simulated in 55 × 55 km grids (at the equator) and water from a neighbouring grid can be used to satisfy water use even if it is outside the catchment. In some instances, such as the Snowy Mountains Scheme in Australia where water is transferred between the Snowy catchment and the MDB, water is transferred *via* existing rivers over distances of hundreds of km so the WaterGap model does not have the capacity to consider these transfers. This is critical, as in some instances (*e.g.*, 2019–2020 financial year) water transfers from the Snowy River can provide nearly 50% of the water used to irrigate agricultural crops in the MDB (ABARES, 2020; Snowy Hydro, 2020). The effect of this is to overestimate the CF_{AWARE} in the system that receives the water because extractions are greater than W_{avail} and underestimate CF_{AWARE} in the system that provides the water because W_{avail} is over-estimated. This issue with respect to the AWARE method, is not limited to the MDB as there are other extremely large transfer systems such as the South–North Water Transfer in China and Pattiseema Lift Irrigation Projects in India, where the distance of water transfers exceed the grid size used in WaterGap.

3.5. Prospective analysis

The AWARE method was developed to assess impacts associated with water consumption, the implication being that an irrigated agricultural product that is produced with a relatively low WSF results in less water stress than a similar product with a higher WSF. We have demonstrated above that this may not hold true for existing production in regulated catchments because the WaterGAP model used to develop CF_{AWARE} misses fundamental aspects of water use and consumption in these catchments. It is even less likely however to represent the consequences of an increase in consumer demand for products with a relatively low WSF produced in catchments with a low CF_{AWARE}. For example, if cotton production were to increase in a catchment with a low CF_{AWARE}, and where no C&T system was in place, then we could expect an increase in environmental impacts due to an increase in demand because additional extractions are allowed. In contrast, increasing demand for cotton grown in the MDB cotton would not result in an increase of environmental impacts associated with increased water extractions in that catchment because, due to legislated cap on extractions, no additional water can be extracted. In addition, the AWARE method does not consider the market effects that may occur in response to an increase in demand for an irrigated agricultural product that is produced in a catchment with a C&T system in place. Market effects have been integrated into recent research assessing the environmental impacts of changes to agricultural production with a focus on land transformation (Simmons et al., 2020; Smith et al., 2019). The need to do so was identified for biofuel, when it was recognised that if agricultural land, a constrained input, used to produce food or fibre was instead used to produce biofuel feedstocks, then additional agricultural land would be required to ensure production of food and fibre were maintained. Further, the shifting of burdens associated with this agricultural production could result in greater overall impacts and is the basis of the argument that not including market effects results in misleading conclusions being drawn (Brandão et al., 2021; Plevin et al., 2013). Like agricultural land, water is a constrained input in irrigated agricultural systems, so we can therefore conclude that using WSFs that do not consider the market effects of changes to demand for irrigation water to guide procurement may also result in misleading conclusion.

3.6. Climate change

The WaterGap model is based on 30 year averages of historical climate and water use data, so current CF_{AWARE} values represent historic impacts, not impacts that can be expected in the future. Climate change has already reduced inflows into the MDB and is expected to continue to reduce inflows in coming years (Adamson et al., 2009). Globally, other catchments are also expected to experience changes in inflows as a result of climate change (Arnell, 2005; Li et al., 2016). If a method were to attempt to assess prospective indicators of water stress then there would need to be a consideration, where relevant, of water that is derived from precipitation and water that is derived from a loss of glacial mass (Ragettli et al., 2016). As for current circumstances however, catchments with a C&T system that limits extractions will be more sustainable under any changes in inflows associated with climate change than those without.

4. Conclusions

- The AWARE WSF method is not suitable to assess the water scarcity impacts of irrigated agriculture in the MDB. The issues highlighted here are not unique to the MDB so it would be prudent that they are also considered when assessing the WSF of other regulated catchments.
- The WaterGap model is not suitable to be used to inform water scarcity in regulated systems because the model does not assess the issues discussed above. This is not a criticism, rather the inherent limitations of the WaterGap require close consideration when using it to develop a globally relevant product labelling to reliably reflect environmental impacts.

- The AWARE WSF methodology is not suitable to inform consumers or policy makers on the sustainability of irrigated agricultural products produced in the MDB.
- We propose that a new indicator to convey the responsible management of water, that includes the impacts of legislation on water sustainability and burden shifting, is developed to support decisions.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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