Direct and indirect water use within the Australian economy

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Abstract

We present the first analysis of water use in the Australian economy to account for inter-state trade, exports and consumption patterns, across all economic sectors and incorporating a temporal analysis. This is achieved by using the environmentally extended input-output technique, combining state-level input-output and water accounts from the Australian Bureau of Statistics. Results show that the three big eastern economies (New South Wales, Victoria, Queensland) rely mostly on water used within their jurisdictions. Approximately one-third of water consumption is for exported commodities, with the biggest export flows of virtual water being associated with agricultural production. Comparing results across the years (2000–2011), the water consumption associated with the provision of goods and services has decreased by 32% for exports, and by 38% for domestic markets. To date in Australia, the focus for improved trans-boundary water management (within Australia) has been on improved mechanisms for sharing physical allocation of water; these results provide the trans-boundary economic dependencies related to water availability. Recent innovations in the compilation of economic input-output models create an opportunity to progress this analysis, exploring in detail the economy–water interlinkages. It is our intention that the paper shows the value of analysing water flows using the multi-regional input-output techniques.

Keywords: Blue water; Environmentally extended input-output; Input-output; Water footprint

Introduction

As the driest inhabited continent, with one of the highest levels of per capita agricultural production anywhere in the world, the Australian economy has a somewhat unique relationship with water. Australia’s water availability varies significantly between years, seasons and regions (Prosser, 2011), recently suffering from historic droughts and flooding in the first decade of the 21st century. Water is a fundamental pillar of the Australian economy, with one study estimating that drought in the year 2002–03 caused a 1.6% reduction in national gross domestic product (Horridge et al., 2005).


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Despite Australia’s complex relationship with water use, we have only a fragmented understanding of how water dependence affects different sections of the economy. Water availability and agricultural production systems vary substantially across the country, meaning the flows of ‘virtual water’ embedded in inter-state trade will also likely be heterogeneous. Given that Australian states and territories manage their water independently, the potential exists for state economies to be dependent on the water policies of other jurisdictions.

Quantifying the water footprint (WF) of a product, service or industry sector provides insight into the water dependence of all supply chains required to make that output possible. The measurement of virtual water and water footprints have been regarded as a tool to aid water policy development (Aldaya et al., 2010; Hoekstra & Mekonnen, 2012; Schyns & Hoekstra, 2014).

WF values are most commonly estimated using process-based life cycle assessment (LCA), in which bottom-up mass-balance estimates of water use are generated for specific products (Chenoweth et al., 2014). Because of the effort involved in generating such estimates, these tend to have fragmented coverage and are difficult to update. In Australia, high-quality process-based WF for Australian agricultural products are being compiled through the AusLCI database (AusLCA, 2017), although equivalent data is much less available for other industries.

An alternative approach is to combine national water accounts with national economic accounts, using established input-output analytical techniques that translate water use by industry into the water footprint of products and services (Daniels et al., 2011). This top-down methodology inherently provides complete coverage of all economic sectors and is therefore useful for macro-scale LCA, such as in a comparison of entire industry sectors, or regions. The appeal of the input-output (IO) methodology is that it directly addresses the interaction between water usage and economic activity, allowing us to trace the flow of ‘virtual water’ through entire supply chains.

The IO approach to water footprinting has great potential to provide valuable insight for policymakers and industry groups, but, unfortunately, such analysis in Australia is sparse and may lack currency, given the major climatic shifts that have occurred over the last 15 years. Lenzen & Foran (2001) provide such analysis of 118 sectors at the whole-of-nation scale, showing that for the financial year 1994–95 Australia used 30% of its water to provide Australians with food while 30% of water consumption was embodied in exported goods. The economy and its water usage have undergone substantial transformations since that time (Prosser, 2011). Manfred Lenzen (2009) provides updated analysis for Victoria using 2004–05 water use data, but the utility of this for other Australian states and territories is unclear. Both those studies rely on water usage data from before or during the severe droughts that affected most of the country during the first decade of the 2000s, and therefore can’t reflect the substantial improvements in water-use efficiency that were achieved by Australian business over that period.

Two key developments in recent years provide a new opportunity to interrogate the water performance of the Australian economy. Firstly, the Australian Bureau of Statistics (ABS) now produces annual water accounts for all Australian economic sectors, at both national and state level (ABS, 2016). Secondly, the innovative IELab software is now available to produce contemporary, multi-regional IO tables for Australia, integrating a range of ABS and other economic datasets (Lenzen et al., 2014). While this has been used for a range of analyses, it has not yet been applied to water footprinting analysis in Australia.

Combining those contemporary data sources, this paper presents the first analysis of water use in the Australian economy to account for inter-state trade, exports and consumption patterns, across all economic...
sectors and incorporating a time-series analysis. It is our intention that the paper shows the value of analysing water flows using the multi-regional input-output techniques, using Australia as an example. Results herein presented could be updated once more detailed contemporary data is available.

Methodology

This paper maps the flows of virtual water through the supply chains of the entire Australian economy, tracing inter-sectoral and inter-regional dependencies on water availability. This is achieved by combining state-level input-output (IO) tables with a complete set of state-level water accounts from the ABS (2013a), covering all eight of Australia’s states and territories. The IO methodology (described further below) essentially translates all direct water use by all Australian industries into water footprints for all products and services generated, capturing both the direct and indirect (or ‘virtual water’) contributions to the WF for each economic output.

We identified the virtual water flows of water physically utilised in Australia by all economic activities, regardless of where the final product was used. We also identified physical water used by households. The exercise categorises whether the product is consumed within Australia or if it is exported, but does not identify the importing country. This paper concerns itself only with the relationship between local water supplies and the economy. Hence we do not estimate, nor account for, the WF of products that are imported into the country.

Several discussions are available in the literature about the relevance of including a measure of water scarcity when performing water footprinting exercises in order to better understand the environmental significance of water extractions (Chenoweth et al., 2014). This paper does not contribute to this discussion, nor does it consider any water scarcity index in its account for water consumption.

Results are generated for four years (2000–01; 2004–05; 2008–09; 2011–12) to consider the implications of water efficiency improvements through the first decade of the 2000s. The year 2011–12 is the most recent year for which the ABS provides state-level data with a high level of sectoral detail, therefore this is the most contemporary year for which our analysis could be performed without losing accuracy. For more recent years, the ABS state-level accounts provide estimates with less disaggregation in the non-agricultural sectors of the economy. While national water accounts are available for earlier years, the ABS warns that the quality of those estimates prior to 2001 is lower (ABS, 2006). For simplicity, we would refer to the year 2000–01 as 2001, and so forth for all years analysed. Yearly accounting starts from July 1.

Defining the ‘water consumption’ measure

The metric for water quantity used in this work matches the definition of ‘Water Consumption’ used in the ABS Water Accounts, whereby:

\[
\text{Water consumption} = (\text{self} - \text{extracted use} + \text{mains water use} + \text{water reuse}) - \text{mains water supply} - \text{instream use}
\]

The ‘self-extracted use’ (sourced directly from the environment) and ‘mains water use’ (supplied by another industry) include water sourced from groundwater, surface water bodies and desalinated
seawater. The ‘water reuse’ term includes the use of wastewater, stormwater or drainage water that has been treated to some extent. The ‘water consumption’ definition excludes instream flows such as hydro-power generation, cooling or fisheries (‘instream use’) and water supplied to other users (‘mains water supply’). The use of seawater directly by industries is not included in the ABS accounts. It is worth noticing that this definition of water use does not account for rainfall water used by agricultural production, and that the concept is applied consistently across all economic sectors and household water use.

Subject to the data gap noted above, these estimates are equivalent to the overall consumptive water demand for each sector, regardless of where that water currently comes from. Therefore, the term used does not reflect the total actual extractive use from freshwater sources, but rather the total demand on freshwater sources that would be required should there be no availability of desalinated or reuse water. We choose this metric for analysing water–economy interactions, as it is not affected by policy vagaries that dictate whether or not desalinated or reuse water is made available in any particular jurisdiction.

The ABS Water Accounts include an estimate of losses from water utility distribution networks, most notably the evaporative or infiltration losses from irrigation distribution channels. Evaporative losses from in-stream or farm dams are not captured in the ABS estimates. Whereas the ABS accounts allocate their loss estimates to the ‘consumption’ of the water industry, in this paper those losses are prorated to all water users in proportion to their relative use of reticulated water.

Water footprinting methodology

Monetary input-output (IO) tables provide a synthesis of industry inputs and outputs (in $ terms) for all sectors of the economy, and in doing so provide a map of supply chain transactions. IO tables are produced by statistical agencies in a manner that is consistent with their other national accounts. Multi-regional IO tables also include the extra dimension of inter-regional trade between industry sectors.

IO tables can also be integrated with accounts of physical parameters, such as volumetric water consumption. To do this, an estimate for consumption (in ML) by each industry sector, in each region, is aligned with the economic sector classification of the monetary IO table.

Standard mathematical techniques (Leontief’s equation) can then be used to trace the (effectively infinite) supply chains that are captured in IO tables (Leontief, 1966). For the provision of any particular good or service to consumers, aggregating all the upstream supply chains will provide an estimate of the total allocation of economic ($) or physical (ML) inputs to that particular good or service (Murray & Wood, 2010; Kitzes, 2013).

An IO table coupled with water use data allows us to calculate the total WF of each good and service, capturing both the water used directly by the industry producing that output and also the water used (indirectly) at all points in the upstream supply chains servicing that industry. IO analysis can, therefore, be thought of as a methodology of LCA, one particularly suited to perform macro-scale analysis of whole regions, whole industry sectors or whole economies (UN, 1999).

For this study, all physical water consumption accounts are aligned directly with the end user of the water, regardless of whether or not they extracted the water directly from the environment, or purchased the water in an economic transaction. To then trace that virtual water through supply chains, the IO footprinting methodology assumes that the WF of any specific industry can be allocated across its customers on the basis of total sales (in $ terms) to each customer.
Data sources

**IO tables.** The online IELab software (https://ielab-aus.info) was used to generate an Australian IO table for each year, identifying eight distinct regions (one for each Australian State and Territories). That compilation provides a higher spatial resolution and more comprehensive time series than the official ABS release of IO tables for years between 2001 and 2012 (ABS, 2013c). A description of the IELab methodology is provided by Lenzen et al. (2014).

The IO tables used for this paper identify 43 sectors, more aggregated than the 109 sectors used for the official IO tables produced by the ABS (ABS, 2013c). This choice of sectoral classification is based on alignment with the resolution of the ABS water data, as the uncertainty introduced by disaggregating the water data into a higher number of sectors would be of little benefit for the analysis provided here. Supplementary information A.1 (available with the online version of this paper) provides details of parameters used to build the IO table.

**Water consumption data.** The ABS release of state-level water accounts for 2012 (ABS, 2013a) contains information on water consumption for the entire economy and is considered the most complete and accurate water use estimate for the whole Australian economy for the years 2009 and 2012. The account identifies 31 industry sectors. In this work we have disaggregated the 31 industry sectors identified into 43 sectors, to improve the estimates of virtual water embedded in inter-regional and export trade. This has been done using different data sources. Estimates for the water-intensive and highly traded crops of rice, cotton and sugarcane were separated out of the ‘Other Crop Growing’ data, prorated according to the relative scale of water use for each crop as estimated in other ABS estimates for the same year (ABS, 2013b). A similar approach was used to separate a consumption estimate for grapevines out of the ‘Fruit and tree nut growing’ data. This was because grapevines predominantly serve the wine sector, hence their supply chain and trade (inter-state and international) characteristics will be very different from other fruit and nut crops. Finally, the ‘Other industries’ data was split into a range of different service and non-service sectors, to distinguish better those activities related to food provision. The only available ABS data useful for this task is the state-level water accounts for 2000–01, taken from the updates provided with the 2004–05 release (ABS, 2006).

To complete the picture of Australian Water Consumption, state-level estimates for direct water use by households are also taken from the ABS Water Accounts (ABS, 2013a).

The ABS Water Accounts were also used to provide state-level data for the years 2000–01 and 2004–05 (both from ABS, 2006); they were disaggregated to the same set of 43 sectors. As the ABS sectoral classification varies between each release of the Water Accounts, each year required a different approach to translating the source data into water consumption estimates for the 43 sectors for the IO calculations. The 2000–01 water accounts have the highest level of sectoral detail, therefore requiring the least modification. The 2004–05 water accounts also provide complete data for the economy, but lack detail in the service sectors (as in the 2011–12 data) and also in the mining and manufacturing sectors. For more information on disaggregated sectors and data sources, see supplementary information A.2 (available with the online version of this paper).

**Allocation of distribution losses.** The ABS Water Accounts identifies water losses as water that enters the water system but does not reach the final user. Such losses could occur by leakage, seepage, evaporation from distribution systems, meter inaccuracies, or theft. In the ABS Water Accounts, all losses are
allocated to the water supply sector. However, for this analysis where the focus is on understanding the water footprint of consumer products, we allocate losses to each industry in proportion to their total primary ‘consumption’ of water.

Data on distribution losses were taken from the state-wide ABS estimates for distribution networks from rural and urban water utilities (ABS, 2013a). The ‘rural’ estimates were allocated to agricultural and mining sectors, with the ‘urban’ estimates assigned to all other sectors plus household use. In both cases, the overall loss estimates were prorated across the relevant sectors in proportion to an estimate of that sector’s use of water distributed from utilities. For details see supplementary information A.2.

Results and discussion

The effect of inter-regional and export trade

A clear distinction can be drawn between the regional economies, regarding their connection to, and therefore reliance on, water use in other jurisdictions (Figure 1; Table 1). Water dependency within, or between, states is mostly explained by water consumption for agricultural production. As food products are transported across state borders, so too is the virtual water associated with those products. The three big eastern economies, New South Wales (NSW), Victoria (Vic) and Queensland (Qld), rely mostly (~65%) on water used within their jurisdictions. Those states are big agricultural producers; most of their food consumption is sourced from regions within the same state. They are also significant exporters of food (inter-state and internationally), making other Australian states reliant on their production.

All other State and Territory economies rely as much, or more, on water use outside their borders, as they do on consumption from streams which they manage directly. This suggests a degree of vulnerability to external factors, such as climate variability or drought in other parts of the country, or water policy changes in other jurisdictions. The three smaller states, Western Australia (WA), South Australia (SA) and Tasmania (Tas), have a more limited range of agricultural output, hence are more reliant on the production of certain food in other regions. Approximately half of the water needed to underpin their state activities is extracted from catchments outside their boundaries. The Australian Capital Territory (ACT) and the Northern Territory (NT) have very little agriculture, therefore more than 75% of their regional water footprints is associated with water use in other states.

Approximately one-third of water consumption in most jurisdictions is for exported commodities (Figure 1; Table 1); the biggest export flows of virtual water are associated with livestock and sugar from Queensland; grains and cotton from NSW; and dairy and sheep, beef cattle and grain from Victoria. Tasmania has a notably higher fraction (43%) of its domestic water associated with exports, which are composed of dairy farming and sheep, beef cattle and grain products. The ACT exports very little agricultural produce, hence the majority (88%) of consumptive water use within the ACT borders is for Australian domestic consumption. Very little of Australia’s water use is associated with the export of value-added products (Figure 2). Overall, for the years studied, between 24% and 30% of water consumed in Australia is embodied in exports (Figure 4). This opens the question of whether the environmental damage caused by water consumption is worth the socio-economic benefits (Lenzen & Foran, 2001; Foran & Poldy, 2002).
Sectoral dependencies

Figure 2 provides a simplified representation of the complex web of virtual water dependencies through Australia’s supply chains. This illustrates the importance of the agriculture sector as a direct water user, and as the major contributor to the embodied water of Australian exports and final demand.
The domestic water use needed to provide goods and services for Australian consumers is more than four times greater than its direct use from household taps (Figure 2). This provides perspective on the relative impact that efficiency measures at a household level could achieve. Efficiency measures for the household are not the only way that consumers can help reduce water stress in Australia. Since food provision contributes the majority of virtual water to Australian domestic consumption, a change in diet (Hadjikakou, 2017) or reduction of food waste (Reutter et al., 2017) could be valid measures taken by consumers to reduce their water footprint. The water footprint of non-food goods and services of Australian consumers is similar in scale to direct residential use, suggesting that efficiency in these industries could also help to reduce water stress in Australia.

Table 1. Inter-regional water dependencies, listing for each of the eight States and Territories for 2009: (a) the allocation of that region’s direct water use to the different flows of virtual water; and (b) the State of origin of the virtual water use per state.

<table>
<thead>
<tr>
<th>Virtual destination of the region’s direct water use</th>
<th>State of origin of virtual water use per state</th>
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<tbody>
<tr>
<td>To domestic consumption (%)</td>
<td>From local sources (%)</td>
</tr>
<tr>
<td>To interstate trade (%)</td>
<td>To exports (%)</td>
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<td>To exports (%)</td>
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</table>

(a) Virtual destination of the region’s direct water use

(b) State of origin of virtual water use per state

<table>
<thead>
<tr>
<th>Region</th>
<th>To domestic consumption (%)</th>
<th>To interstate trade (%)</th>
<th>To exports (%)</th>
<th>From local sources (%)</th>
<th>From NSW (%)</th>
<th>From Vic (%)</th>
<th>From Qld (%)</th>
<th>From other States and Territories (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NSW</td>
<td>41</td>
<td>25</td>
<td>34</td>
<td>67</td>
<td>–</td>
<td>11</td>
<td>10</td>
<td>12</td>
</tr>
<tr>
<td>Vic</td>
<td>41</td>
<td>25</td>
<td>34</td>
<td>64</td>
<td>14</td>
<td>–</td>
<td>10</td>
<td>12</td>
</tr>
<tr>
<td>Qld</td>
<td>42</td>
<td>26</td>
<td>32</td>
<td>66</td>
<td>13</td>
<td>10</td>
<td>–</td>
<td>11</td>
</tr>
<tr>
<td>WA</td>
<td>34</td>
<td>27</td>
<td>38</td>
<td>42</td>
<td>19</td>
<td>15</td>
<td>14</td>
<td>10</td>
</tr>
<tr>
<td>SA</td>
<td>37</td>
<td>32</td>
<td>31</td>
<td>55</td>
<td>15</td>
<td>12</td>
<td>11</td>
<td>8</td>
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<tr>
<td>Tas</td>
<td>26</td>
<td>30</td>
<td>43</td>
<td>43</td>
<td>18</td>
<td>14</td>
<td>13</td>
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<td>ACT</td>
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<td>51</td>
<td>13</td>
<td>16</td>
<td>26</td>
<td>19</td>
<td>18</td>
<td>20</td>
</tr>
<tr>
<td>NT</td>
<td>23</td>
<td>42</td>
<td>35</td>
<td>27</td>
<td>22</td>
<td>17</td>
<td>16</td>
<td>18</td>
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</tbody>
</table>

Fig. 2. Direct flows of water and indirect flows of ‘virtual water’ through the Australian economy for the year 2009. Virtual water from food agriculture includes all water used to irrigate crops for human and animal consumption.
Agriculture is the biggest direct water consumer, with half of that agricultural water use being for products that subsequently undergo some further processing by the food industry. This processing increases the economic value added by the food sector, thereby increasing the economic profitability of water use to grow those food products. One-quarter of the water used for agricultural products is ‘virtually’ exported with products that undergo no further processing beyond the farm gate.

The relatively small water flows associated with the energy supply and mining sectors, as shown in Figure 2, belie the critical nature of that water to Australia’s economy. As electricity generation underpins all economic activity, and mining is Australia’s biggest source of export income, the water used in these sectors is fundamental to maintain Australia’s prosperity. However, water consumption for these purposes is not exempt from controversy, as water consumption by the mining sector is mostly used in arid or semi-arid regions where water scarcity is a problem and the environment is negatively affected (Prosser, 2011).

Some of these sectors also demonstrate strong regional variation in the water intensity of their production, with the greatest variability being apparent in those agricultural sectors that also have the highest overall water demands (Figure 3 and supplementary information B, available with the online version of this paper). This high variability in water intensity (ML/$-output) for the agricultural sector reflects a complex mix of regional heterogeneity in rainfall patterns, soil conditions and farming practices. For those export-oriented sectors, these results illustrate the importance of providing region-specific water intensity factors for LCA based product, sector and nation-level comparisons. In contrast, the water intensity factors for many tertiary industries, such as construction, education and other services, are both very much lower and differ little across the regions.
To understand the true water demand of different products, the methodology used here may be biased towards those agricultural users most strongly associated with managed irrigation systems. The ABS data includes estimates of losses from such irrigation distribution systems, but not evaporative losses from on-farm dams nor evaporative losses from large water utility dams. Incorporating estimates for those loss flows and also the missing data for industry use of seawater could change the relative intensities of different sectors and regions.

Changes over time

Comparing results across the years agrees with previous analysis (ABS, 2016) that the droughts over the first decade of this century have stimulated a change in the water intensity of the economy (Table 2; Figure 4).

The water consumption associated with the provision of goods and services has decreased by 32% for exports, and by 38% for domestic markets. In contrast, the reduction in direct water use by householders (22%) has been much smaller (Table 2). Also interestingly, the balance between water consumption for domestic goods vs. exports has been changing over that period (Table 2). More detailed analysis would be required to determine how much of these WF changes

Table 2. Changing water footprints for the Australian economy, between 2001 and 2012, expressed as a fraction of the equivalent 2001 values.

<table>
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<tbody>
<tr>
<td>Water embodied in Australian exports</td>
<td>1.00</td>
<td>0.66</td>
<td>0.61</td>
<td>0.68</td>
</tr>
<tr>
<td>Water embodied in Australian final demand</td>
<td>1.00</td>
<td>0.78</td>
<td>0.52</td>
<td>0.62</td>
</tr>
<tr>
<td>Direct water use by households</td>
<td>1.00</td>
<td>1.00</td>
<td>0.84</td>
<td>0.78</td>
</tr>
<tr>
<td>Total water use in Australia</td>
<td>1.00</td>
<td>0.77</td>
<td>0.57</td>
<td>0.65</td>
</tr>
</tbody>
</table>

Fig. 4. Changing water footprints for the Australian economy, between 2001 and 2012. For each year, the breakdown (%) of the total WF is shown for [direct household consumption] vs. [consumption associated with domestically consumed products] vs. [consumption associated with exported products].
are being driven by structural shifts in Australia’s agricultural exports, compared with the more obvious reductions in water intensity of production due to technological shifts or rain water availability.

Despite the disparities identified above, the overall breakdown of water consumption in the Australian economy appears to be approximately the same as it was at the turn of the century. The water consumption required to provide goods and services (predominantly food) to Australian consumers is consistently much higher (at least three times) than the direct water use in the home. Adding the indirect and direct water use of Australian consumption shows that Australians are responsible for the consumption of about 70–76% of Australian water. Interesting to note is that water consumption required to underpin Australia’s export market is consistently double the amount of water directly used by householders.

Conclusions

Strong regional variation in water–economy interdependencies suggests that future Australian water footprinting studies should better account for regional differences in production and trade characteristics. To date in Australia, the focus for improved trans-boundary water management has been on improved mechanisms for sharing allocation in the Murray Darling Basin, and other catchments that cross state lines. The results provided here illustrate also the trans-boundary economic dependencies related to water availability – all but the three biggest state economies are potentially vulnerable to changes in water policy or physical availability outside their jurisdictions.

Similarly, approximately one-third of Australia’s water consumption is used for Australia’s exports (predominantly agricultural commodities), suggesting that export income could also be sensitive to water policy choices. Conversely, that strong link is a reminder of the tension between the socio-economic benefits of export activity and the environmental pressure associated with extraction from Australia’s ecologically sensitive freshwater streams. The relationship between exports and water consumption is relatively consistent across all states and territories.

While the water use efficiency of Australian agriculture and business has improved in response to the droughts, the water consumption (indirectly) required to produce goods and services for domestic consumption is far greater than that used directly in households. Changes in buying patterns could, therefore, provide a substantial opportunity for residents to help alleviate Australia’s water stress challenges. Further analysis is required to determine the implications, both for Australia’s water balance and for socio-economic outcomes, of any such changes. Reductions in food wastage are an obvious candidate for consideration, given that the food system accounts for the majority of water consumption in Australia.

Recent innovations in the compilation of economic input-output models create a new opportunity to progress this analysis, exploring in more detail the economy–water interlinkages that will vary strongly across Australia’s regions and sectors. The priorities for such analysis should be to integrate the full suite of water consumption data sources that have become available through Australia’s 20 year water reform process, explore the risk that imports will expose our businesses to growing water stress in other countries, and provide a more nuanced characterisation that better accounts for the marginal economic value of water to critical industries such as electricity generation and mining (Australian Bureau of Statistics, 2010).
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