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An assessment of the water use associated with Australian diets using a planetary boundary framework

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Abstract

Objective: Agriculture accounts for around 70 % of global freshwater withdrawals. As such, the food system has been identified as a critical intervention point to address water scarcity. Various studies have identified dietary patterns that contribute less to water scarcity. However, it is unclear what level of reduction is necessary to be considered sustainable. The pursuit of unnecessarily aggressive reductions could limit dietary diversity. Our objective was to assess the sustainability of water use supporting Australian dietary habits and the adequacy of current dietary guidelines.
Design: Dietary intake data were obtained from the National Nutrition and Physical Activity component of the Australian Health Survey. For each individual daily diet, the water scarcity footprint was quantified, following ISO14046:2014, as well as a diet quality score. Water scarcity footprint results were compared with the planetary boundary for freshwater use downscaled to the level of an individual diet.
Setting: Australia.
Participants: 9341 adults participating in the Australian Health Survey.
Results: Dietary water scarcity footprints averaged 432·6 L-eq (95 % CI 432·5, 432·8), less than the 695 litres/person per d available to support the current global population of 7·8 billion, and the 603 litres/person per d available for a future population of 9 billion. Diets based on the Australian Dietary Guidelines required 521 L-eq/d, or 379 L-eq/d with lower water scarcity footprint food choices.
Conclusions: Diets based on the Australian Dietary Guidelines were found to be within the freshwater planetary boundary. What is needed in Australia is greater compliance with dietary guidelines.

Keywords
Australian Health Survey
Dietary guidelines
Discretionary food
Life cycle assessment
Sustainable diet
Water footprint

Public health nutrition challenges have become more complex in recent years because diets are not only expected to support health and well-being, but there is an increasing expectation that they are also environmentally sustainable[1–4]. Part of the responsibility rests with the systems of food production, processing and distribution. However, population shifts to diets that are lower in environmental impacts could also contribute to improving sustainability, based on the notion of sustainable lifestyles expressed in Sustainable Development Goal 12[5]. The largest body of evidence relating to sustainable diets concerns greenhouse gas emissions[2]. An alarming finding is that many lower greenhouse gas emission dietary patterns are linked to poor nutritional and health indicators[6,7], highlighting the need for lower environmental impact diets to also consider nutritional adequacy and support longstanding public health nutrition objectives[8]. Evidence in relation to the impacts of diets on water scarcity is also beginning to emerge[9–13]. Water scarcity reflects the availability of water relative to the natural rate of replenishment. As water scarcity increases, the availability of water for human uses and for the environment diminishes. Water scarcity is a major international environmental concern[5]. The food system is critically relevant to resolving water scarcity since agriculture alone accounts for around 70 % of global freshwater withdrawals[14].

In Australia, a large (>9000) sample of self-reported adult daily diets were recently assessed for diet quality and water scarcity footprint that assesses contribution to water scarcity[13]. Using a quadrant analysis approach, a

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subgroup of diets was identified with both higher diet quality and lower water scarcity footprint. This subgroup had an average water scarcity footprint 43 % lower than the current average diet and 64 % lower than the subgroup of diets with both lower diet quality and higher water scarcity footprint. These findings demonstrate that large reductions in dietary water scarcity footprint are possible. However, the question remains as to whether such reductions are adequate, or necessary, to be considered sustainable. The pursuit of unnecessarily aggressive reductions could limit dietary diversity.

To guard against major and potentially irreversible earth system change, a variety of planetary boundaries[15,16] or absolute environmental limits[17,18] have been proposed. These boundaries represent thresholds for natural resource use and emissions to the environment that should not be exceeded. This approach to sustainability assessment has emerged in recognition that with the global population increasing and standards of living generally rising, marginal improvements in eco-efficiency may not be enough to avert serious environmental change[19]. For example, a major study of EU consumption, supported by international trade, recently concluded that environmental impacts exceed a fair share of the so-called 'safe operating space' within which humanity's footprint is within the planetary boundaries[20]. Critically, food consumption was identified as one of the main drivers of environmental impact.

Our study involved evaluation of the water scarcity footprint of Australian adult diets in relation to proposed planetary boundaries for global freshwater use, that is freshwater withdrawals for agriculture and industry. Our objective was to assess the absolute sustainability of water use supporting Australian dietary habits and the adequacy of current dietary guidelines[21] if they are to support sustainable water use in addition to health and well-being. To our knowledge, this is the first study to assess the water scarcity footprint of individual self-reported diets within a planetary boundary framework.

Methods

Dietary intake data

Dietary intake data, covering 9341 adults (19 years and above), were obtained from the National Nutrition and Physical Activity component of the Australian Health Survey[22]. This survey, conducted by the Australian Bureau of Statistics over the period 2011–2013, using a 24-h recall process and a complex sampling method[23], remains the most detailed and nationally representative source of dietary intake information in Australia. For each individual, the data describe quantities of foods and beverages consumed on the day prior to a face-to-face interview with a trained assessor.

As described elsewhere[13], mixed dishes were disaggregated into their basic components and cooked food portions were converted to equivalent raw quantities. In addition, adjustments for under-reporting were made using estimates of the under-reported food energy from the Australian Bureau of Statistics[23]. For each individual daily diet, total energy intake was determined using data obtained from the Australian Food Composition Database[24], along with the number of serves of each of the food groups described in the Australian Dietary Guidelines[21]. A diet quality score (out of 100) was also quantified, using an index that describes degree of compliance with the guidelines[25]. A higher score reflects higher compliance with the Guidelines.

Water scarcity footprint modelling

The evaluation of water use across a food system is complex as water scarcity can vary greatly from one geographic region to another. Water use from regions of scarcity and abundance cannot be simply aggregated as this is not environmentally meaningful[26]. Instead, a water scarcity footprint needs to be quantified, as described in ISO14046:2014[27], taking into account the spatial distribution of water use and the local water scarcity conditions. In Australia, the water scarcity footprint of the major agricultural commodities has been assessed[28], as well as processed food products of local and imported origin[13].

That said, water scarcity is a human construct. Water scarcity footprint results obtained using different water scarcity models are typically highly correlated[13,29]; however, they can differ in magnitude. Therefore, in this study, an ensemble method was used, as is common when working with climate data from a variety of models[30]. To characterise the water scarcity footprint of foods consumed in Australia, a multi-model ensemble was calculated as the arithmetic mean of results obtained from three different water scarcity models reported previously[13]. Data for almost 150 separate food items are presented in the Supplementary Material. Water scarcity footprint results were scaled relative to water use at the global average level of water scarcity (i.e. litres equivalent, L-eq) to enable direct comparison with the planetary boundary for water use.

Planetary boundary analysis

The authors of the planetary boundary concept initially proposed a boundary for global freshwater consumption of 4000 km^3/year, with a zone of uncertainty extending to 6000 m^3/year[15]. By allocating 70 % of this available water use to the food system[14] and sharing it equally among the 7·8 billion global citizens, the maximum water use to support an individual daily diet is in the range of 983–1475 L (Table 1). Subsequent analysis, based on more complex modelling, has revised downwards the planetary boundary to 2800 km^3/year, with a zone of uncertainty of 1100–4500 km^3/year[31]. Anticipation of higher future global populations also constrains the water use available to support an individual daily diet (Table 1).

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Table 1 Downscaling the planetary boundary for freshwater consumption to define a boundary for water use to support an individual daily diet that is sustainable

Planetary boundary (km^3/year)	Range (km^3/year)	Food system share (%)	Pop (billion)	Dietary share (l/person per d)	Lower limit (l/person per d)	Upper limit (l/person per d)
4000[15]	4000–6000	70[14]	7·8	983	983	1475
4000[15]	4000–6000	70[14]	9·0	852	852	1279
2800[31]	1100–4500	70[14]	7·8	695	274	1120
2800[31]	1100–4500	70[14]	9·0	603	237	971
2800[31]	1100–4500	90[3]	7·8	878	351	1405
2800[31]	1100–4500	90[3]	9·0	761	304	1218

As dietary water scarcity footprint results presented in this study are expressed relative to water use at the global average water scarcity, they can be directly compared against the planetary boundary for water use downscaled to the level of an individual diet. We assessed the average (i.e. mean) Australian adult daily diet. In addition, a quadrant analysis was undertaken for the 19- to 50-year age group used in the Australian Dietary Guidelines[21] to define a higher diet quality/lower water scarcity footprint subgroup and a lower diet quality/higher water scarcity footprint subgroup. For this age group, the water scarcity footprint of a recommended diet based on the Australian Dietary Guidelines[21] was also quantified.

Results

Using the multi-model ensemble approach, the water scarcity footprint of the average Australian adult daily diet was 432·6 L-eq (95 % CI 432·5, 432·8, *n* 9341). Average energy intake was 10 458 kJ. As has been reported elsewhere[13], the largest contribution to the water scarcity footprint was from discretionary foods (26·1 %). These foods, sometimes also referred to as indulgence foods, are energy-dense and nutrient-poor foods high in saturated fat and/or added sugars, salt or alcohol. The Australian Dietary Guidelines[21] recommend that these foods are consumed only occasionally and in small quantities, although most Australians consume these foods excessively. Concerning the core food groups defined in the Australian Dietary Guidelines[21], fruits made the largest contribution to the water scarcity footprint of the average Australian adult diet (20·0 %), followed by dairy foods and alternatives (14·4 %). The Australian Dietary Guidelines[21] group dairy foods like milk, cheese and yogurt, together with non-dairy alternatives such as soya, cereal and nut beverages. Fresh meats (beef, lamb, poultry and pork) and alternatives (fish, eggs, tofu, legumes/beans) contributed 12·1 % of the water scarcity footprint; cereal/grain foods and vegetables contributed 11·8 and 7·7 %, respectively.

The water available to sustain a daily diet depends on the estimated planetary boundary for water use, as well as the share that is apportioned to the food system and the global population. The smallest estimate for a current population of 7·8 billion is 695 litres/d (Table 1). On this basis, the average Australian daily diet is well within the planetary boundary for water use (Fig. 1). Considering the large 19- to 50-year age group (*n* 5157), diets that were both higher in diet quality and lower in water scarcity footprint required only 245 L-eq/d (95 % CI 244·7, 245·0), below even the lowest zone of uncertainty for the planetary boundary (Table 1). Only diets that were both lower in diet quality and higher in water scarcity footprint reached the boundary (699 L-eq/d; 95 % CI 698·9, 700·9).

Compared with the current average diet, a recommended diet[21] requires substantially reducing the number of servings of discretionary foods and increasing the number of servings from all the five core food groups (Table 2). If the current diet was scaled accordingly, the water scarcity footprint would increase to 521 L-eq/d. However, with lower water scarcity footprint food choices (as exhibited by the higher diet quality and lower water scarcity footprint subgroup), the recommended diet can be achieved with less water use (379 L-eq/d; Table 2). Either way, the recommended diet was also found to be within the planetary boundary for a current population of 7·8 billion and a future population of 9 billion (Fig. 1).

Discussion

The evidence base supporting sustainable diets mainly describes the potential reductions in environmental impact that are possible through adoption of one dietary pattern compared with another[2]. This is a valuable information. However, it does not address the question of absolute limits of resource use and emissions to the environment. In this regard, planetary boundaries have emerged as an important analytical framework for evaluating absolute environmental sustainability[32–34], especially across the global food system[35–37]. That said, for the freshwater planetary boundary, there is considerable uncertainty regarding its definition (Table 1). Also, there exists a variety of value choices regarding the distribution of available water to economic sectors and individuals[38–39]. In this study, 70 % of the available water was allocated to food production, based on the historical share[14]. In contrast, when developing the EAT-Lancet Commission global reference diet[3], 90 % of water resources were allocated to food production, having the effect of increasing the water available to support diets, but significantly constraining water available for domestic and industrial uses.

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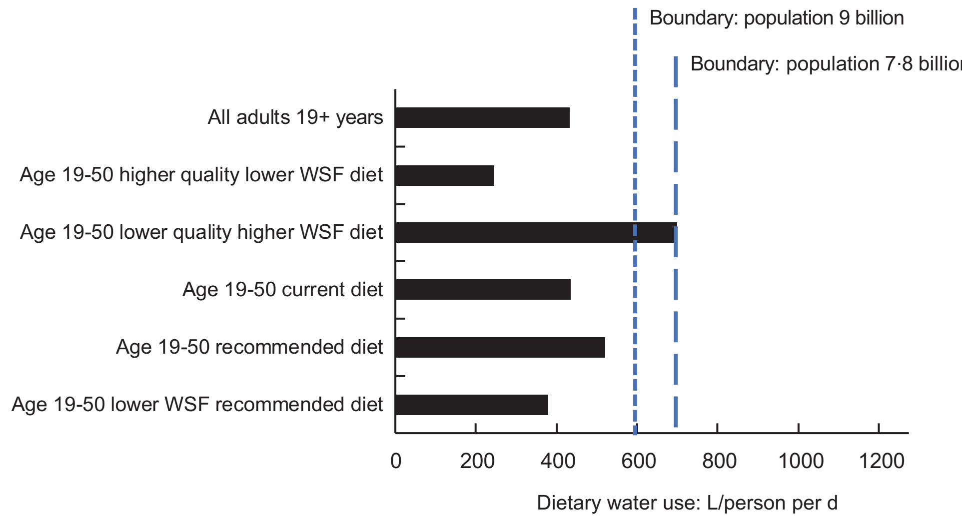

Fig. 1 (colour online) Water scarcity footprint (WSF) of Australian adult dietary patterns compared with planetary boundaries for dietary water use for a current global population of 7·8 billion and a future global population of 9 billion

Table 2 Food intake and water scarcity footprint (WSF) for the current adult daily diet (19–50 years), the current diet scaled to the recommended servings in the Australian Dietary Guidelines[21], and a recommended diet with improved WSF intensity based on the higher diet quality and lower WSF subgroup. Food groups are as defined by the Australian Dietary Guidelines. The recommended number of servings is based on the average for men and women. WSF are expressed relative to water use at the global average water stress

	Current diet (*n* 5157)		Recommended diet with average WSF intensity		Recommended diet with improved WSF intensity	
Food group	Servings/person per d	WSF L-eq/person per d	Servings/person per d	WSF L-eq/person per d	Servings/person per d	WSF L-eq/person per d
Fruit	1·38	104	2·0	151	2·0	81
Vegetables	2·47	27	5·5	61	5·5	52
Breads and cereals	4·57	64	6·0	84	6·0	47
Fresh meat & alternatives	2·32	51	2·8	62	2·8	45
Dairy and alternatives	1·46	58	2·5	99	2·5	95
Discretionary foods	7·42	104	2·8	39	2·8	36
Miscellaneous foods		24		24		24
Total		434		521		379

It is evident that, in Australia, the opportunities to reduce dietary water scarcity footprints are large (Fig. 1). However, as discussed elsewhere[13], the opportunities to achieve this through amended dietary guidance are limited as the largest variations in water scarcity footprint are between different foods within a food group. For example, in Australia, apples have a water scarcity footprint approximately 20 times less than stone fruit (Supplemental Table 1). Two slices of bread made from wheat have a water scarcity footprint around 80 times less than a cup of cooked rice. Diversity is an important principle in nutrition. Dietary guidelines in Australia emphasise eating a wide variety of healthy foods within each food group as each food contributes different nutrients. Given the prevalence of discretionary food consumption in Australia, it could be harmful to discourage certain healthy food options (such as summer fruits, nuts) on account of their water footprint. Fortunately, this study has shown that diets based on existing Australian Dietary Guidelines[21] are within the freshwater planetary boundary, even if the available water is equitably shared across a future global population of 9 billion (Fig. 1).

Much has been written about the challenge of meeting dietary needs within sustainable water use limits[40–41]. While on average the water use associated with Australian diets is within the planetary boundary, this does not mean that there are not parts of the food system located in water-stressed areas. However, this points to the need for strategic action to address water scarcity at the level of the individual supply chain and at the level of local water resources management. The same foods can have very different water scarcity impacts depending on where and how they are produced[29,42,43]. In conclusion, diets based on the Australian Dietary Guidelines were found to be within the freshwater planetary boundary. What is needed in Australia is further public health nutrition effort to encourage compliance with dietary guidelines.

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Supplementary material

For supplementary material accompanying this paper visit https://doi.org/10.1017/S1368980021000483

References

1. Garnett T (2016) Plating up solutions. *Science* **353**, 1202–1204.
2. Ridoutt BG, Hendrie GA & Noakes M (2017) Dietary strategies to reduce environmental impact: a critical review of the evidence base. *Adv Nutr* **8**, 933–946.
3. Willett W, Rockström J, Loken B *et al.* (2019) Food in the Anthropocene: the EAT-Lancet Commission on healthy diets from sustainable food systems. *Lancet* **393**, 447–492.
4. Gheewala SH, Jungbluth N, Notarnicola B *et al.* (2020) No simple menu for sustainable food production and consumption. *Int J Life Cycle Assess* **25**, 1175–1182.
5. United Nations General Assembly (2015) *Transforming Our World: The 2030 Agenda for Sustainable Development*. New York: UN General Assembly.
6. Payne CLR, Scarborough P & Cobiac L (2016) Do low-carbon-emission diets lead to higher nutritional quality and positive health outcomes? A systematic review of the literature. *Public Health Nutr* **19**, 2654–2661.
7. Ridoutt BG, Baird D & Hendrie GA (2020) The role of dairy foods in lower greenhouse gas emission and higher diet quality dietary patterns. *Eur J Nutr* Published online: 10 April 2020. doi: 10.1007/s00394-020-02245-w.
8. Ridoutt B, Hendrie G & Noakes M (2017) Dietary strategies to reduce environmental impact must be nutritionally complete. *J Clean Prod* **152**, 26–27.
9. Hess T, Andersson U, Mena C *et al.* (2015) The impact of healthier dietary scenarios on the global blue water scarcity footprint of food consumption in the UK. *Food Policy* **50**, 1–10.
10. Hess T, Chatterton J, Daccache A *et al.* (2016) The impact of changing food choices on the blue water scarcity footprint and greenhouse gas emissions of the British diet: the example of potato, pasta and rice. *J Clean Prod* **112**, 4558–4568.
11. Notarnicola B, Tassielli G, Renzulli PA *et al.* (2017) Environmental impacts of food consumption in Europe. *J Clean Prod* **140**, 753–765.
12. Goldstein B, Hansen SF, Gjerris M *et al.* (2016) Ethical aspects of life cycle assessments of diets. *Food Policy* **59**, 139–151.
13. Ridoutt BG, Baird D, Anastasiou K *et al.* (2019) Diet quality and water scarcity: evidence from a large population health survey. *Nutrients* **11**, 1846,
14. Food and Agriculture Organization of the United Nations (2020) AQUASTAT - FAO's Global Information System on Water and Agriculture. http://www.fao.org/aquastat/en/overview/methodology/water-use (accessed July 2020).
15. Rockström J, Steffen W, Noone K *et al.* (2009) Planetary boundaries: exploring the safe operating space for humanity. *Ecol Soc* **14** 32.
16. Rockström J, Steffen W, Noone K *et al.* (2009) A safe operating space for humanity. *Nature* **461**, 472–475.
17. Bjørn A, Chandrakumar C, Boulay A-M *et al.* (2020) Review of life-cycle based methods for absolute sustainability assessment and their applications. *Environ Res Lett* **15**, 083001.
18. Sandin G, Peters GM & Svanström M (2015) Using the planetary boundaries framework for setting impact-reduction targets in LCA contexts. *Int J Life Cycle Assess* **20**, 1684–1700.
19. Bjørn A, Diamond M, Owsianiak M *et al.* (2015) Strengthening the link between life cycle assessment and indicators for absolute sustainability to support development within planetary boundaries. *Environ Sci Technol* **49**, 6370–6371.
20. Sala S, Benini L, Beylot A *et al.* (2019) *Consumption and Consumer Footprint: Methodology and Results. European Commission JRC Technical Report 113607*. Luxembourg: Publications Office of the European Union.
21. National Health and Medical Research, Council (2013) *Australian Dietary Guidelines Summary*. Canberra: NHMRC.
22. Australian Bureau of Statistics (2014) *4364.0.55.007—Australian Health Survey: Nutrition First Results—Foods and Nutrients, 2011–2012*. Canberra: ABS.
23. Australian Bureau of Statistics (2017) *4363.0—National Health Survey: Users' Guide, 2014–2015*. Canberra: ABS.
24. Food Standards Australia New Zealand (2019) Australian Food Composition Database. https://www.foodstandards.gov.au/science/monitoringnutrients/afcd/Pages/default.aspx (accessed January 2019).
25. Golley RK & Hendrie GA (2014) The Dietary Guidelines Index for children and adolescents: what is the impact of the new dietary guidelines? *Nutr Diet* **71**, 210–212.
26. Pfister S, Boulay AM, Berger M *et al.* (2017) Understanding the LCA and ISO water footprint: a response to Hoekstra (2016) "A critique on the water-scarcity weighted water footprint in LCA". *Ecol Indic* **72**, 352–359.
27. International Organization for Standardization (2014) *ISO 14046:2014 Environmental Management—Water Footprint—Principles, Requirements and Guidelines*. Geneva: ISO.
28. Ridoutt BG, Hadjikakou M, Nolan M *et al.* (2018) From water-use to water-scarcity footprinting in environmentally extended input-output analysis. *Environ Sci Technol* **52**, 6761–6770.

29. Ridoutt B & Hodges D (2017) From ISO14046 to water footprint labeling: a case study of indicators applied to milk production in south-eastern Australia. *Sci Total Environ* **599**, 14–19.
30. Flato GJ, Marotzke B, Abiodun P *et al.* (2013) Evaluation of climate models. In *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, pp. 741–866 [Stocker TF, Qin D, Plattner GK *et al.*, editors]. Cambridge: Cambridge University Press.
31. Gerten D, Hoff H, Rockström J *et al.* (2013) Towards a revised planetary boundary for consumptive freshwater use: role of environmental flow requirements. *Curr Opin Environ Sustain* **5**, 551–558.
32. Ryberg MW, Owsianiak M, Richardson K *et al.* (2018) Development of a life-cycle impact assessment methodology linked to the Planetary Boundaries framework. *Ecol Indic* **88**, 250–262.
33. Chandrakumar C & McLaren SJ (2018) Towards a comprehensive absolute sustainability assessment method for effective Earth system governance: defining key environmental indicators using an enhanced-DPSIR framework. *Ecol Indic* **90**, 577–583.
34. Bjørn A, Richardson K & Hauschild MZ (2018) A framework for development and communication of absolute environmental sustainability assessment methods. *J Ind Ecol* **23**, 838–854.
35. Springmann M, Clark M, Mason D'Croz D *et al.* (2018) Options for keeping the food system within environmental limits. *Nature* **562**, 519–525.
36. Gerten D, Heck V, Jägermeyr J *et al.* (2020) Feeding ten billion people is possible within four terrestrial planetary boundaries. *Nat Sustain* **3**, 200–208.
37. Conijn JG, Bindraban PS, Schröder JJ *et al.* (2018) Can our global food system meet food demand within planetary boundaries? *Agric Ecosyst Environ* **251**, 244–256.
38. Lucas PL, Wilting HC, Hof AF *et al.* (2020) Allocating planetary boundaries to large economies: distributional consequences of alternative perspectives on distributive fairness. *Glob Environ Chang* **60**, 102017.
39. Häyhä T, Lucas PL, van Vuuren DP *et al.* (2016) From planetary boundaries to national fair shares of the global safe operating space: how can the scales be bridged. *Glob Environ Chang* **40**, 60–72.
40. Jägermeyr J (2020) Agriculture's historic twin-challenge toward sustainable water use and food supply for all. *Front Sustain Food Syst* **4**, 35.
41. Harris F, Moss C, Joy EJM *et al.* (2020) The water footprint of diets: a global systematic review and meta-analysis. *Adv Nutr* **11**, 375–386.
42. Page G, Ridoutt BG , Bellotti B (2012) Carbon and water footprint tradeoffs in fresh tomato production. *J Clean Prod* **32**, 219–226.
43. Ridoutt BG, Sanguansri P, Freer M *et al.* (2012) Water footprint of livestock: comparison of six geographically defined beef production systems. *Int J Life Cycle Assess* **17**, 165–175.