

Interactive comment on “Review article: Quantifying the human impact on water resources: a critical review of the water footprint concept” by J. Chenoweth et al.

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We would like to thank all of the reviewers for their detailed and useful comments on our paper. A number of extremely constructive comments were made which when implemented will improve this review article considerably. Allow us to respond to some general remarks before moving on to address specific comments individually.

General comments

The comments made by the four referees can be grouped broadly into four categories:
1) The “critical” aspect is missing, with Referee #2 making some practical suggestions

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on how we could address this point. 2) The paper is rather long, but at the same time
3) Additional literature is suggested to enhance the arguments 4) The authors lack understanding/shallow analysis of cited literature

In terms of comments surrounding (1), we acknowledge that based on the Referees' understanding of "critical", the paper is indeed not brand new or novel criticism, but tries to provide the broad spectrum of positive and negative perspectives on water footprinting in an up-to-date review. Thus the very critical perspective on water footprinting of Wichelns and others, who seems to see little or no use at all for water footprinting as a methodology, is balanced with more positive perspectives on the methodology. Essentially this bridges the gap in the literature between the hydrological / crop modellers who see water footprinting as bringing little or nothing to water resources management (and indeed see it as simply confusing the issue), and the water policy and sustainability researchers who see water footprinting as a useful tool for helping people, companies or countries to reduce their environmental impact by providing complex information in a simple to understand format. While few of the concepts outlined in the paper are new, as is to be expected in a review paper, the bringing together of such a diverse and contradictory literature in a systematic fashion, while seeking what common ground there is, has not been done before and is what is new in this paper.

Regarding points 2 and 3, all referees find the paper rather long but at the same time they suggest extra literature. In part, the length of the paper is due to the fact that it outlines the basics of the water footprint concept and how it has developed, thus making the paper suitable for new practitioners of water footprinting and those interested in the concept but relatively unfamiliar with it. This means that the paper inevitably has to include some "obvious" arguments and examples, as they were described by Referee #1. At the same time, the paper is reviewing all the methodologies applied thus far, including those which have relatively recently been proposed (as well as those belonging to the LCA community) and are still under development. This is one of the strong points of the paper, as is acknowledged by Referee #2. While striving to keep

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the comprehensiveness of the review, some further editing based upon the excellent suggestions of the referees should improve the paper and allow a reduction in length.

In preparing this review, we have strived to produce a review that remains as unbiased as possible. None of the authors of this paper are directly related to WFN or other groups that strongly encourage or discourage the water footprint concept. Rather, we are researching in the area of water resources management and as a result we know the water footprint concept well. We are thus aware of the concept's limitations and its advantages, both of which we have strived to bring out fairly in this review. Inevitably, however, this was going to be impossible to do in such a way that would satisfy fully both the proponents and opponents to water footprinting. On the one hand there is the Water Footprint Network, whose mission is, as stated on their website, "to promote the transition towards sustainable, fair and efficient use of fresh water resources worldwide by [...] advancing the concept of the 'water footprint'" . At the same time, there are researchers such as Wichelns (2011b, p643) who says in relation to water footprints (and virtual water) that "there is no conceptual or empirical basis for using these notions to determine optimal strategies or beneficial policies" and that "[m]any of the statements put forth by authors describing virtual water and water footprints are inaccurate and misleading". Unfortunately, referees #1 and #3, in particular, seem to equate presenting criticisms from the literature of the water footprint concept as bias despite the fact that a full range of perspectives from the literature are discussed in this review. While to them the review may come across as unfairly critical of the water footprint concept, to the other referees it comes across as insufficiently critical. Nevertheless, it cannot be both more critical and less critical simultaneously. One of the objectives of the paper, as set out at the end of the introduction, was to stimulate a constructive debate, and we believe that the referees opposing views with respect to the paper demonstrate that it has been successful in this respect.

The extent of and the pace at which the literature relating to water footprinting is growing, as well as the arguments for and against the concept, are indicative of the contro-

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versies and complexities surrounding the WF. It is practically impossible to exhaustively discuss every single argument raised in the literature, thus, inevitably some papers and concepts will be discussed in more depth than others, and some papers which add little new to the concept are not discussed at all. It is thus perhaps inevitable that despite including 148 papers in this review, all of the referees commented that we either did not cite particular papers or did not discuss in sufficient depth papers which they thought were key to the topic. At the same time, all of the referees except Vanham suggest that the review is too long. This contraction is more profound in the comments of Referee #3, who finds the paper rather long, and at the same time suggests exhaustive evaluation of the cited literature. Fortunately, both Vanham and Referee #2 provide the practical suggestion of moving some of the text to tables, thus permitting a more comprehensive listing of the literature relating to key concepts while allowing the amount of text to be reduced somewhat. We would like to thank both of them for this invaluable advice and would like to assure them that we will pursue this option in due course.

Specific referee comments

Referee Vanham

Vanham suggests that it is positive that the review brings together both the LCA approach to water footprinting and the volumetric approach of the WFN. He suggests however, the review is not complete, concise nor critical enough, and is not supported by figures or tables. Unfortunately, he seems to have missed the three figures which were included in the article. However, his suggestion of using tables is excellent and should help improve the completeness of the review and its conciseness.

Vanham suggests that we do not discuss in the review the concepts suggested by Vanham and Bidoglio (2013) sufficiently, in particular the need for water footprint sustainability assessments. Their paper is policy-oriented, raises some of the major limitations, and has some suggestions on how it can accompany policy formulation at regional/national level. We would be happy to make further reference to their paper

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when revising the review.

Referee #1

This referee strongly suggests that we cite the paper Verma, S., D.A. Kampman, P. van der Zaag and A.Y. Hoekstra, 2009. Going against the flow: A critical analysis of virtual water trade in the context of India's National River Linking Program. *Physics and Chemistry of the Earth* 34: 261-269. The above paper discusses one of the major shortcomings of virtual water trade, i.e. that non-water factors (and specifically water endowments) often have a key role in determining trade within and across countries. Attempts to present WF results alongside economic productivity or explain if virtual water trade is justifiable from a scarcity perspective have been done before, as noted in our review when we cite the work of Aldaya et al (2010b). If the referees agree that there is a need to extend the discussion in the paper on this issue further we could also add in references to Novo et al., 2009 and Garrido et al., 2010, as well as including Verma et al., 2009.

Referee #1 has an issue with the review because in their view it is “neoclassical” in its approach. The referee does not at any point specify what they mean by the term “neoclassical”, a term which varies widely in its meaning depending upon the precise discipline in which it is applied. Presumably they mean that the review is conventional in its approach rather than adopting an alternative framework which is “based on the evidence/commentary available in the literature” as they go on to suggest. However, basing the review on the evidence available in the literature, as the review currently does, requires it to examine the evidence and arguments put forward in the literature by both the proponents and opponents of the concept. It cannot both build upon the evidence and commentary available in the literature and at the same time adopt an alternative framework not drawn from the literature.

Referee #1 goes on to suggest that a more structured assessment would allow a more transparent review. Adopting the more specific suggestion of Vanham and Referee #2

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of tabulating some of the information presented in the review should allow this. Without more specific recommendations from this reviewer about how they would like the paper to be structured it is difficult to propose how better to address this suggestion.

The final request of Referee #1 is that the counter arguments against the criticism of Wichelns and others are brought more to the fore. Unlike the criticism put forward by some researchers, who can see no merit in the water footprint concept, this review clearly does not dismiss the concept outright but highlights both its strengths and weaknesses in relation to different purposes. Thus, the uses suggested by the proponents of water footprints are examined together with arguments against using water footprints for these uses. We very clearly note that the concept has succeeded in stimulating widespread discussion on the links between water, food, diet and consumption of consumers, as well as considerable interest at the corporate level. However, in attempting to produce an unbiased review, we have to rigorously analyse the concept, its underlying assumptions and the literature both in favour and against the concept.

Referee #2

This reviewer begins by noting that the paper presents a useful overview of the water footprint concept and related approaches such as LCA, and as such is a valuable summary. We would like to thank the reviewer for acknowledging this as a strength of the paper, as it was our attempt to bring the LCA literature closer to the debate, considering the interest of this research community on water footprinting.

Referee #2, however, is disappointed that the review is not more critical. As noted above, making the review more critical, however, is difficult to do without risking the proponents of water footprinting then claiming a degree of bias in the perspective of the review.

Referee #2 provides a few specific and helpful comments for improving the paper. In particular, analysing the additional concerns about water footprinting raised by Witmer and Cleij (2012) and Wichelns (2010a) is a sensible suggestion in that it will help im-

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prove the comprehensiveness of the review. Witmer and Cleij (2012), despite being grey literature, is interesting because it represents an appraisal of the usefulness of the water footprint concept for policy that has been produced by a National Authority rather than academic researchers. Their conclusions regarding the limitations and usefulness of the concept are along similar lines to those which we bring out in our review, i.e. the water footprint is useful for policy-making when the assessment is narrowed to local/business context (we discuss these issues more precisely in sections 2.5 and 3.1).

The suggestion of tabulating the key points from each paper reviewed is a valuable suggestion as it should help reduce the length of the main text and should also improve the comprehensiveness of the review.

The final main point raised by Referee #2 is that the conclusions of the paper are weak and the two really hard questions raised by the review, namely (a) do we need to develop the water footprint concept further or is the limit of its usefulness reached when it starts to intrude into established water resources management tools, and (b) should sustainable water resources management take more of a global rather than local context, are not adequately addressed. Refocusing the discussion and conclusion around these two questions would strengthen the paper and give the final section a better focus and so is something that we will seek to do when revising the paper.

Referee #3

This reviewer complains that the review is unnecessarily lengthy but then goes in their detailed comments to request that we include quite a few additional references. Referee #3 states that the article “merely lists a number of scientific poor reviewed articles and numerous grey literatures”, thus suggesting that review is not well based upon the core scientific literature due to its extensive use of grey literature. However, it is important to point out that out of the 148 references cited, 109 were refereed journal articles and the majority of the grey literature cited in the paper was in fact produced by

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the WFN and, as such, it was clearly important to include this in the review. We agree with the referee that a certain degree of caution is warranted when citing grey literature in scientific papers. Nevertheless, some grey literature is particularly well written and researched (such as the report by Witmer and Cleij, 2012, suggested by Referee #2) and it can provide invaluable insight with respect to how the water footprint concept is viewed and made use of outside the academic realm.

Referee #3 goes on to state that we cite numerous critical examinations by other authors already published and well cited in the field. This is something, however, that would normally be expected in a review which is trying to be as comprehensive as possible and provide good coverage of the topic from all angles. On the one hand this referee accuses us of merely listing the literature and not reviewing it, then, on the other hand, whenever we attempt to offer our own interpretation and judgements about points made in the literature, this referee suggests that these are unsupported.

The first specific point raised by this reviewer is that there has been a similar paper recently published on this topic by Chapagain and Orr (2012) titled “Water Footprint: Help or Hindrance?” and challenges us about how this review article differs from this paper. Leaving aside the fact that Chapagain and Orr have not published a paper with this title but rather it was Chapagain and Tickner, this paper only examines 84 references relating to water footprinting and thus lacks the comprehensiveness of our review. While it does include some limited criticism of the concept, this paper does not examine in any depth “the numerous critical examinations by other authors” which Referee #3 referred to previously but only mentions a few of them tentatively. Similarly, Chapagain and Tickner mention the link between water footprinting and LCA but do not explore this link in any depth, nor the LCA- based water footprint methodologies. Even their analysis of the standalone water footprint methodologies really only considers the more conventional water footprint methodology of the WFN and does not adequately consider the alternative methodologies put forward by Ridoutt et al. (2009, 2010a, 2012a), Pfister and Hellweg (2009) and Herath et al (2011). Thus, the Chapagain

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and Tickner paper is a very useful contribution to the literature and is more critical of the water footprint concept than most papers previously published by researchers associated with the WFN, but it does not move beyond the framework set by the WFN, something that a critical review on an evolving and contested concept must do.

It is difficult to understand what the Referee #3 objected to with the title “Water footprinting methodologies – still a work in progress” since they note correctly that there is never an end point in the progression of science. This, in fact, echoes with the concluding sentence of the preface of the water footprint manual (Hoekstra et al., 2011): “We aim to further refine the water footprint methodology so that it best serves the various purposes that different sectors in society see for it, at the same time striving for coherence, consistency and scientific scrutiny”. However, Referee #3 then goes on to claim that the WFN has summarised all the recent developments published in this field in their 2011 manual, implying that an end-point has been reached. As our review demonstrates, while the WFN network has dominated the discourse on the water footprint concept, there is one of a number of methodologies which have been proposed and all methodologies have their strengths and weaknesses, depending upon the purpose they are trying to achieve. This is something which we have tried to bring out in our review.

Referee #3 raises the valid question of who to cite in relation to a concept or idea which has evolved over time in the literature – when a concept is first proposed, where it is first implemented, where it is most extensively discussed? Thus their point that we cited the wrong reference for lines 15-20 of page 9394 is rather unfair as this section is specifically examining the merits of bottom-up versus top-down water footprinting methodologies. The reference cited was Feng et al (2011) whose paper is specifically focused on comparing bottom-up versus top-down approaches to calculating water footprints. While it would be good to be able to trace through the literature how every single concept was developed, the review is already very long (as commented on by all the referees) and thus citing the definitive paper on a concept (rather than all papers)

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is critical for brevity sake. Anyone interested in this concept specifically, can, of course, consult Feng et al. (2011) for further information on the concept's development in the literature. Perhaps the most appropriate way of dealing with Referee #3 concerns about whether the first, most definitive or more comprehensive reference was cited for each particular concept would be to adopt a tabular format to summarise key points from the papers reviewed, as suggested by other referees.

Leaving aside the broader issue raised by Referee #3 at this point about which reference should be cited in relation to a concept which has evolved over time, their statement that we cited the wrong reference in the sentence on product fractions and value fractions as we should have cited Hoekstra and Chapagain (2007) and thus show a “shallow literature review by the authors in preparing the paper” is offensive and shows poor refereeing as the concept was, in fact, not first introduced in the reference they cite. Rather, the concept we are citing at this point was first introduced by Chapagain and Hoekstra (2004, p27) who wrote “To do this we introduce the terms product fraction and value fraction”.

Referee #3 agrees with our comment that grey water footprint was not explicitly included in Chapagain and Hoekstra (2004) but then says that we failed to notice that it was included in Chapagain et al (2006). Chapagain et al (2006) did not use the term “Grey water” anywhere in their paper although they did introduce the term “dilution water”. This point indeed was recently made by a paper published by the Water Footprint Network team – Zhang et al. (2013, p2) who wrote “Chapagain et al. (2006)] introduced the idea of “dilution volume” that evolved into the “grey water footprint” in Hoekstra and Chapagain (2008)”. The wording in our paper should be sharpened here to better reflect the fact that although the term “grey water” was not used in this paper the concept was introduced under a different name.

Referee #3 asks which country is the data in Figure 2 representing. As stated in the Figure caption, the data are from Hoekstra and Mekonnen (2012b) and show global averages to illustrate differences in water consumption. This could be regarded as an

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average (not weighted) country of the world and serves as an example to clarify the terminology and potential outcomes of a national WF assessment. We thank the reviewer for the observation but we do believe that the figures themselves are of secondary importance to the idea being put forward through the use of the figure.

Referee #3 in relation to the statement on page 9398 of our review paper “Furthermore, the inclusion of green water creates inconsistencies between water content figures for agricultural products compared to non-agricultural products (Zhang et al., 2011)” asks that we state what these inconsistencies are that Zhang et al. present. Adding in an extra sentence which states the inconsistencies mentioned by Zhang et al., namely that in agriculture blue and green water can be substituted but with non-agricultural products they cannot, would be useful clarification. It would also be possible to add in the views of Falkenmark and others who highlight the importance of green water to counterbalance those of Zhang et al. Referee #3, however, goes on immediately to argue that, because at this point we do not go on to discuss the purposes of water footprinting, the argument is weak and shows a limited understanding of the water footprint concept. However, clearly the most appropriate section to discuss the purposes of water footprinting is in the later section title “Uses of water footprints” where uses can be addressed systematically.

Referee #3's says on page C5392 that our statement on page 9398 of the review article that nutrients other than nitrogen “are not usually considered in water footprint assessments”, is incorrect. However, they go on to say that the existing water footprint literature has not taken into account the effect of other pollutants so far. This would seem to support our statement that so far usually only nitrogen has been considered in water footprints to date. While the WFN manual on water footprinting might outline conceptually how to consider other nutrients, so far in water footprint studies usually only nitrogen is considered. Apart from Liu et al. (2012) which considered both Nitrogen and Phosphorus, most, if not all, other studies only consider Nitrogen as a proxy for water pollution and generally explicitly acknowledge the limitations of excluding other

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polluting elements in fertilisers, manure, pesticides etc. In relation to the point that Referee #3 makes about the final sentence of our paragraph analysing the validity of the grey water concept being confusing since it contains two references, we would be happy to split the sentence in two if they believe it would make the sentence read better. However, this “jam-packing a single statement” as they term it was done in the interest of brevity, the need for which all the referees have effectively commented upon in relation to the length of the paper.

Referee #3’s claim on page C5393 that putting together two different water footprints for beef which were derived using different water footprint methodologies and showing how different they are (as we do on page 9399) gives the wrong impression that one can compare the two results and conclude that they are not trustworthy is not the point that is made on page 9399 and the subsequent page. Rather, we are showing here that depending on the assumptions upon which a water footprint is calculated (which could both be valid under certain circumstances), you get dramatically different outcomes. We in no way try to hide the fact that the basis of Ridoutt et al’s (2012a) estimate is calculated differently to that of Mekonnen and Hoekstra (2012b), but rather, this is the very point which we are making –very reasonable but different assumptions lead to very different outcomes because of the different quantification approaches and data/assumptions employed. In the case of Ridoutt et al’s methodology, their water footprint is a stress-weighted footprint (as we note in the text) which also excludes green and grey water, while Mekonnen and Hoekstra a volumetric approach which includes all three components: blue, green and grey. From an academic perspective, both approaches are correctly accepted, but from a policy and consumer perspective, their repercussions could be entirely different. To the non-expert, who does not necessarily understand the methodological reasons for this huge range, the difference creates a possible confusion with respect to the water footprint of beef.

Referee #3 questions why on page 9400 in lines 21-22 there are no references backing up the statement that large differences in estimated water footprints frequently occur.

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We would be happy to repeat the referenced examples given in the previous two paragraphs of the paper (discussed in the preceding paragraph here also) but this would seem like unnecessary repetition for the majority of readers. .

Referee #3 on page C5393 says that the flow of the paper is jerky and inconsistent, suggesting that a concept like “net green” water should be introduced first and then the inconsistencies presented with references. However, we feel that we have indeed introduced the concept of net green water in this way, introducing it in the appropriate section (on water footprinting methodologies based upon estimating the impact of water use), giving a definition of the term with references to the literature before offering a couple of referenced examples of how the concept has been applied.

Referee #3’s point in relation to the text on page 9406 and the final part of the paper that some corporations are engaging in water footprinting to minimise water-related business risk in addition to product labelling, is a very valuable point which needs to be added into the text. Section 3.1 of the paper which assesses the uses of water footprints as a tool for assisting water resources management and managing water scarcity at the national/regional level needs to be enhanced to include the corporate level in addition to the national and regional levels. Referee #3’s point that water footprint assessment allows businesses to understand the impact of their supply chains across different hydrological regions is valid. However, as we argue in the discussion and conclusion, water is a single input to production and the environmental impact of water consumption varies hugely depending upon local circumstances. Incorporating water use into LCA, a more comprehensive tool which does not focus on a single environmental parameter or production input, makes much more sense if a company is seeking to reduce the overall environmental impact of its supply chain.

Closing remarks

In closing, we would, once again, like to thank their reviewers for their time to read our manuscript and their insightful comments. We believe that our paper has succeeded in

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its intention to spark a healthy debate, as evident from the comments and the differing views of the referees. We look forward to further comments and suggestions from the editor and the referees.

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