

We thank Dr. Kirby for his detailed review and critical but overall constructive and positive comments. In the following, we would like to respond to his main points:

1. Rigorous water accounting

The authors refer to the Australian Bureau of Statistics national water account (ABS 2004, 2006), but miss the rather different and far more comprehensive new Australian Water Accounting Standard (Water Accounting Standards Board, 2010). The draft standard was applied to eight regions in Australia in the web-based 2011 account, accessible on the web <http://www.bom.gov.au/water/nwa/2011/index.shtml>: one of the regions was the Murray-Darling Basin. The objective of the National Water Account is to disclose information about the total water resource, the volume of water available for abstraction, the rights to abstract water, and the actual abstraction of water for economic, social, cultural and environmental benefit, for geographic regions of national significance. The Murray-Darling Basin account has detailed statements about Water assets and liabilities, changes in water assets and liabilities, and physical water flows (including urban and rural water diversions) (Bureau of Meteorology, 2011). The accounting standard and the accounts relate to the detailed nature of Australian water rights and the tradeable nature of both the rights to water and actual volumes of water. However, they differ greatly to the water account of the authors in that neither rain (except on water surfaces) nor land based ET are considered. The account statements in the Australian 2011 Water Account are a stocks and flows account, and do not extend to matters such as productivity which the authors consider in their productivity sheet. My main point in drawing attention to this standard is the rigour behind it. The standard and the accounts represent a rigorous approach to water accounting, and include continuous water accounting. I feel that this level of rigour is lacking in the authors' presentation, with its confusion over terms and equations (more below).

Response: We are thankful for drawing attention to the new Australian Water Accounting Standard (AWAS), which indeed is a major step forward from the ABS method. We revised the paper to include this valuable contribution to the water accounting discourse, in our brief review on exiting water accounting method. However, we do not agree that the presented approach to water accounting in WA+ lacks in rigor. There simply exists rather diverging views on the essence of accounting, and both need to be respected. While the focus of AWAS is on physical water flows “i.e. flow accounting” (which include withdrawals, water rights, etc. and indeed are important) WA+ looks into depletion of water (ET) and in doing so it provides a much needed link between land use and water depletion without a need to record ground data on flows. In water scarce basins, it is all related to depletion and the measurements of that. WA+ is based on direct measurements of depletion by using satellite measurements of ET. This enables users to break down accounts to their area of interest, be it administrative boundaries or hydrological units. AWAS is based on measuring flows and diversions, and has therefore an entirely different procedure to describe accounts and way to regulate this, technically and legally. Both systems have their merits. AWAS is closer related to the Withdrawals sheet than to the Resource Base Sheet of the WA+. We believe WA+ moves past classic data-intensive-flow-accounting, and provide direct information on the depletion of water with a rigorous and well-grounded approach that can be used in many developing countries that do not have a hydrological observatory. We

agree that a better presentation of used water balance method/equations in the paper could be helpful to reveal the rigorous nature of WA+ approach. We revised the paper to address this issue (more below).

2. Inconsistencies and errors in equations and explanation of terms;

The paper is muddled in its presentation of water balances. Starting with Equation 1 and 2:

$$ET = ET_{prec} + ETQ \quad (1)$$

$$ET_{prec} = P - R \quad (2)$$

where P is gross precipitation, R is the return flow (and described as surface runoff, lateral subsurface drainage and deep percolation) ET is the total ET, ET_{prec} is ET from natural processes, ETQ

is variously described as the incremental ET, net withdrawal, and the difference between gross withdrawals and return flow. Equation (2) is described as approximate. So, what is the actual equation?

The total (soil) surface water balance implied by Figure 1 is:

$$P + QW_{Sw} + QW_{Gw} - ET_{prec} - ETQ - R_o - P_{deep} + \Delta SS = 0 \quad (22)$$

(I have labelled this equation as 22, to distinguish it from equations in the paper) where P is precipitation, QW_{Sw} and QW_{Gw} are surface and groundwater withdrawals, ET_{prec} and ETQ are as above,

R_o is runoff, P_{deep} is percolation to groundwater, and ΔSS is the change in soil water storage. If we deal with averages, $\Delta SS = 0$. Using equation (3) in the paper to equate the return flow, R, from (2) above with $R_o + P_{deep}$, we rearrange (22) to get:

$$ET_{prec} + ETQ = P + QW_{Sw} + QW_{Gw} - R + \Delta SS \quad (23)$$

and hence eliminating terms using (2)

$$ETQ = QW_{Sw} + QW_{Gw} + \Delta SS \quad (24)$$

which is not what the authors describe it as – incremental ET, net withdrawal, or the difference between gross withdrawals and return flow. If we accept equations (1) and (2) and Figure 1 in the paper, ETQ is actually the gross withdrawal plus the change in soil water storage.

On the other hand, figure 5 of the paper implies that:

$$ETQ = QW_{Sw} + QW_{Gw} - QRSw - QRGw - \Delta SP \quad (25)$$

where QR_{Sw} and QR_{Gw} are surface and groundwater return flows, and $\square\square SP$ is a sink, which is not explained. This figure uses symbols for return flow that differs from that in equation (3) of the paper. Accepting figure 5, ETQ is what the authors describe it as, a net withdrawal, but because of the sink term it is not strictly the difference between gross withdrawals and return flow. However, on this interpretation, Figure 1 is wrong and equation (2) is either wrong or R has not been defined properly (it could be defined to include only those flows to surface and groundwater which do not originate from a withdrawal – though that’s a rather arbitrary and un-measurable distinction). Following equation (3) in the paper, the authors write “The key point is that ETQ can be determined from ET and ET_{prec} , without any flow measurement (not further demonstrated in this paper)”. But equation (2) demands that R be known in order to evaluate ET_{prec} , which means that some estimate or measurement of a flow or flows is required. The statement in the paper appears to be wrong, and the claim should certainly be further demonstrated.

To further confuse the description of water balances, most of the quantities are described as flows of one sort or another. For example, on page 12886 (first paragraph of section 3.1), the authors write “outflows from a certain river basin are explicitly related to the inflow from rainfall”; in equation (2), R is described as the return flow. Yet on page 12892 (3rd paragraph of section 4.1) we are told that “The rate $P - ET (L T^{-1})$ from a discrete area ($L2$) represents a flow ($L3 T^{-1}$)”. So, rain and ET are no longer volumetric flows, and cannot be equated with R in equation (2). Given the confusions above, I think it might be better if the authors were to start with a complete, rigorous water balance equation which contains all the terms they will use, and then relate all terms.

Response: The confusion on the credibility of the water balance equation is due to the fact that we have not defined R properly (R in equation 2 is return flow from precipitation only, which we have mistakenly have not indicated) otherwise the equation holds. We took the thoughtful advice of the reviewer and revised the paper and started the discussion with a , rigorous water balance equation which contains all the terms that will be used. We also revised the used symbols to make sure that they are consistent with other figures and equations in the paper. We have separated the water balance for the total basin (“external”) and also for a particular withdrawal (“internal”).

There are number of empirical equations/method to estimate effective rainfall, including effective rainfall over irrigated area (e.g. USDA, FAO). Therefore it is possible to separate ET from Rainfall and ET from irrigation without measurement of flow or flows. Considering that this is a detail soil physical process, we have not given further attention to it in this more general framework. However we have included a statement that says that this issue needs to be explored in future research.

Rain and ET are both volumetric quantities. Indeed the statement in the paper “The rate $P - ET (L T^{-1})$ from a discrete area ($L2$) represents a flow ($L3 T^{-1}$)” creates confusion as all terms are volumetric based. We revised the paper accordingly. .

We revised the whole section to address the constructive criticism that Dr. Kirby has provided on this and used his advice and suggestions in restructuring it.

3. Other specific comments

Basin closure should be explained further. According to equation (7), the basin closure fraction is utilized flow / available flow, but available flow is only a fraction of the total flow. Thus a basin could have substantial discharge but a closure fraction of 1 – this arises when utilized flow = available flow < total flow. Depending on what one views as closure (actual closure, economic closure), one might not regard such a situation as a closure fraction of 1.

Response: If all outflows are committed, a basin is closed even though it has significant discharge. We understand that there are several definitions for a closed basin (actual closure, economic closure, etc.) depending on one's point of view, but in our terminology basin closure is explicitly related to available water (outflow minus reserved outflows and non-utilizable outflows) and not actual basin outflow. This definition for basin closure is in line with IWMI WA terminology has been around and has been used in many studies in the past.

The reserved flow fraction should be explained further. According to equation (7), the reserved flow fraction is reserved flow / surface water outflow (Q_{outSW}). However, figure 2 shows the outflows to be both surface and groundwater but makes no distinction between surface and groundwater in the reserved and utilizable flows that contribute to the outflows. Is the reserved flow intended to refer to surface water flows only? (There could be groundwater reserved flows to maintain groundwater dependent ecosystems.) If not, then equation (7) makes sense only in terms of the surface water part of the reserved flow.

Response: This is a sharp observation, and we have corrected the equation and the reserved outflow definition to include groundwater reserved outflows.

On page 12901 (2nd paragraph of section 5), the authors write: “Except for the withdrawal sheet that is more related to the classical water accounting processes, the input data for the other WA+ sheets can be estimated through satellite measurements”. Not all the input data can be so estimated: the resource datasheet has surface and groundwater inflows and outflows, which cannot be estimated from satellites, at least, not currently with any degree of precision.

Response: We agree with the reviewer. Majority of input data can be space-born but the WA+ may require limited ground data too. The paper was revised accordingly to correct the statement and make the readers more aware of this issue.

In section 6, the authors write that all rivers and tributaries are regarded as being one single bulk river and all aquifers as one single bulk aquifer. It need not be so. As the Australian Bureau of Meteorology's Murray-Darling Basin 2011 account shows, an overall basin account can be an aggregation of sub-accounts for different elements, whether they be geographic elements such as catchments, or use or process elements such as irrigation or urban water use. Thus, each of the resource, consumption, productivity and withdrawal sheets described by the author could have subaccounts at finer geographic or use

resolution. Finer geographic resolution implies considerably greater measurement or modelling of flows than is contemplated by the authors. This approach was taken by Kirby et al (2010), who describe dynamic (monthly for many years) water accounts that deal with precipitation, dryland and irrigated ET from a range of land uses (including natural vegetation), runoff, river flow, withdrawals from both surface and groundwater for irrigation and other use, and return flows from irrigation. The approach is based primarily on modelling, and thus provides a complement to the more satellite based methods that the authors describe, and it does not distinguish beneficial uses except insofar as withdrawals are intended for beneficial use.

Response: We agree with the reviewer. The WA+ accounts for a basin can be broken down to tributary basins (hydrological units) and overall basin accounts can be an aggregation of sub-accounts for different geographic elements. We revised the paper to elaborate on this point.