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Green-blue water accounting in a soil water balance

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ABSTRACT

It has become common practice to speak about ‘green’ versus ‘blue’ water consumption, in order to distinguish between consumption of rainwater versus groundwater or surface water. The two sources of water differ in terms of possibilities for storage and use. Whereas industrial, municipal and livestock water supply primarily depend on blue water, crop cultivation relies on both green and blue water. Discriminating between green and blue water consumption in a crop field is not straightforward: consumption refers to evapotranspiration (ET) and water contained in the harvested crop, which both appear in undifferentiated form. One cannot see which part of ET or the water in a plant originates from rainwater and which part from irrigation water. In this paper I propose a generic and physically based method to differentiate green and blue evaporation (E) and green and blue transpiration (T) by daily accounting of the fractions green and blue water in each soil and vegetation layer. The green and blue fractions of all water fluxes leaving a soil or vegetation layer in a day depend on the average green and blue water fractions in that soil or vegetation layer during that day. This method allows for an accurate assessment of irrigation efficiency (the ratio of blue water transpiration to the irrigation water applied), and for a precise estimation of green and blue water footprints of crop production (the ratio of either green ET or blue ET to the crop yield).

1. Introduction

Freshwater availability essentially depends on the precipitation over land. On land, precipitation partitions into two components: evapotranspiration and runoff. The traditional focus of water resources planning and management has been on how to best divert, store and redistribute the runoff flow for use in agriculture, industries and households (Falkenmark and Rockström, 2006). This, however, has proven to be a limited focus, because it ignores the other water flow that is highly relevant to our economy as well (Schyns et al., 2019). The conventional engineering approach of optimizing the allocation and use of groundwater and surface water resources (the runoff flow) results in a form of sub-optimization if the efficient allocation and use of the evaporative flow is not included in the considerations as well. An estimated 67% of the world’s crop production still comes from rainfed agriculture (Portmann et al., 2010), where crops take up rainwater that is stored in the soil to subsequently transpire most of it. In croplands there is, next to the beneficial transpiration by crops, which contributes to their biomass growth, unproductive evaporation of water as well, from rainfall that falls on the leaves and from the soil surface. Efficient use of rainwater is as important as efficient use of irrigation water. In order to generate the necessary debate on the efficient use of the evaporative flow from rainwater stored in the soil versus the efficient use of groundwater and surface water resources, Falkenmark (1995) coined the terms green versus blue water use. Green water use refers to the use of rainwater in the soil and blue water use to the use of groundwater and surface water resources.

Even though the distinctions between green and blue water resources and between green and blue water use are commonly employed these days, we still struggle to use them in precise unambiguous ways. Regarding green water, as Schyns et al. (2015) point out, the term is often loosely used, sometimes to refer to rainwater *storage in the soil*, while other times to rainwater *evaporation* (Falkenmark and Rockström, 2006; Falkenmark, 2013). Furthermore, the term ‘green water flow’ is usually defined as ‘the evaporative flow from land’, but often it remains unclear whether this includes only evapotranspiration (ET) from rain stored in the soil or total ET, which includes ET from irrigation water and evaporation from other forms of blue water use as well. Falkenmark (2007) speaks about the blue-to-green redirection that occurs when part of blue water resources that are abstracted subsequently evaporate. This idea of blue water flow becoming green water flow contrasts with the common and logical usage to speak about blue water consumption when referring to evaporation of abstracted blue water resources. Furthermore, the terms green and blue water are sometimes used to refer to water resources *availability*, while other times to water resources *use*. All these ambiguities may play a role in the hesitance in the hydrological community to use the green-blue water terminology, since we should use clear definitions of stocks and flows and keep track

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of water balances over time. Whatever colour terms are used, it should always be clear how a term matches an identifiable stock or flow in the water cycle. In fact, for understanding hydrology we can suffice working with well-established hydrological terms; we don't need colour coding for that. The colour coding, however, fulfils a practical function in discussions on the efficient allocation and use of different water sources (Rost et al., 2008; Hoekstra, 2014). What is needed though is a stricter formalization of the use of the green-blue water terminology, in a way clearly linked to hydrological terminology.

Another challenge is that differentiating between green and blue water consumption is not that simple as it may seem. Consumption refers to ET and water contained in the harvested crop, which both appear in undifferentiated form; one cannot see which part of ET or the water in a plant originates from rainwater and which part from irrigation water. This raises the question then how to estimate irrigation water consumption. Even though many scholars report figures on irrigation water consumption (e.g. Haddeland et al., 2014; Hoff et al., 2010), it often remains unclear what precisely they refer to, since hydrological or crop growth models help to simulate the soil water balance, thus providing estimates of total ET, possibly distinguishing between evaporation (E) and transpiration (T), but these models do not distinguish between green and blue ET. Since irrigation water consumption refers to blue ET, the question is how these scholars handle this problem.

One method that has been practised is to estimate blue ET as the difference between ET under irrigated conditions and ET under rainfed conditions (e.g. Mekonnen and Hoekstra, 2010, 2011; Liu and Yang, 2010; Siebert and Döll, 2010; Hoogeveen et al., 2015). This approach is problematic since the rooting depth under rainfed conditions can substantially differ from the rooting depth under irrigated conditions, affecting the water uptake by plants, so that what is green E and T under rainfed conditions is not the same as green E and T under irrigated conditions. Mekonnen and Hoekstra (2010, 2011) partially solved this by simulating the rainfed case with a rooting depth as it would be under irrigated conditions, but this approach is still unsatisfactory, because irrigation affects the overall soil moisture dynamics over time, so that green E and green T under irrigation are not necessarily the same as green E and T under rainfed conditions. Another problem with this approach is that in many regions, rainfed agriculture is not even an alternative to irrigated agriculture, so that the reference rainfed case is not available. The approach of estimating blue ET as total ET under irrigated conditions minus total ET under rainfed conditions has also been followed by Romaguera et al. (2014), who used remote sensing products for estimating total ET under irrigation conditions and model simulations without irrigation. This approach faces the same problem as the studies that compare two different model simulations.

Another method to distinguish between green and blue ET is to estimate blue ET based on the relative addition to the soil of irrigation water and rainfall over time (Rost et al., 2008; Hanasaki et al., 2010; Fader et al., 2011). This is a better way to pursue, but the way this has been implemented has thus far been a bit simplistic, ignoring the full dynamics within the soil. Drops of irrigation water or rainwater are not really followed along their pathways through the soil moisture and finally to E or T. Rost et al. (2008) and Fader et al. (2011), for example, distinguish different soil layers without accounting the green-blue ratio in the layers separately, and lack a full accounting of all green and blue water fluxes leaving each soil layer. Hanasaki et al. (2010) consider evapotranspiration as a whole, not distinguishing transpiration specifically, thus unable to estimate the part of irrigation water applied that benefits the crop. Furthermore, all three studies neglect the contribution of capillary rise to soil water.

In this paper I propose a generic and physically based method for green and blue water accounting in crop cultivation. The basis is formed by the underlying soil hydrology that determines the changes in soil water stocks and flows over time. The method comprises a partitioning of soil moisture and all water fluxes leaving the soil into a green and blue component, for instance on a daily basis when that is the time step considered in the hydrological or crop growth model. In the generic framework I will also include capillary rise as a particular source of water for crop growth, which comes in addition to rainwater and irrigation water. The green-blue water accounts form an extension to the usual hydrological water accounts of changes in stocks and flows. The essence is that we trace the different origins of the water contained in the soil and in each flow leaving the soil. The novelty of the paper is that it proposes a theoretically sound method to distinguish between green and blue transpiration and between green and blue soil evaporation, by tracking the pathways of rainwater and irrigation water, to replace the proximal methods as discussed above and employed until now.

First, I will address the question why having such green-blue water accounting system is useful at all. Second, I introduce the principle of tracing green and blue water in the soil water balance. Third, I provide an illustrative example of green-blue water accounting, in a simple case of a one-soil-layer model. Fourth, I reflect on the practical use of the accounting method for the estimation of irrigation water consumption, irrigation efficiency and green and blue water footprints. I will conclude by showing how the method presented here solves the ambiguities in green-blue water accounting as mentioned above, and I will recommend to integrate green-blue water accounting in soil-water balance models as a standard routine.

2. Why differentiate between green and blue water consumption?

The main reason to explicitly distinguish between 'green' and 'blue' water consumption – that is consumption of rainwater versus groundwater or surface water – is that the two sources of water differ in terms of possibilities for storage and use. Whereas rainwater is stored in the soil and is primarily used in-situ for biomass growth (food, feed or energy crops, production forest), groundwater and surface water are stored in natural aquifers, lakes and rivers, but can also be abstracted or diverted, transported, and stored in artificial reservoirs, and can be used for a variety of purposes, from irrigating crops or trees (to supplement rainwater) to water supply for households, municipal purposes and industries. The range of beneficial uses for blue water is thus larger than for green water, but this does not mean that green water is not beneficially used for our economy. There are various reasons why we want to know how much green and blue water resources we consume, for what, and how efficient.

Let me start with the relevance of irrigation efficiency. When we are interested in the question which part of the irrigation water applied to the field benefits the crop, we need to know blue T. The irrigation efficiency at field level is defined as the fraction of the applied irrigation water volume that benefits the plant (Burt et al., 1997). The volume of irrigation water that benefits the plant is blue T, hence we need to be able to estimate that. Total water consumption in crop production is defined as the ET over the growing period (from planting to harvest). In irrigated crop production, the source of soil moisture and ET is partly rainwater, partly irrigation water, and partly capillary rise. With hydrological or crop growth models we are used to estimate total E and total T, but for assessing irrigation efficiency we really need to know blue T, the part of T that stems from irrigation.

Another reason for our interest in blue T, as well as blue E, is the impact of blue water use on groundwater tables, river flows and remaining blue water availability in a catchment, which is not captured by the measure of irrigation efficiency (Perry, 2007; Contor and Taylor, 2013; Grafton et al., 2018). When we are interested in the question how much of the irrigation water gets lost from the catchment – that is the part of the irrigation water that evaporates or transpires and does not infiltrate to groundwater or run off to streams again – we need to know blue ET. Blue water abstractions are not changing the water available in the catchment as long as we return the water after use to where we abstracted it. Blue water scarcity in a catchment depends on the volume of blue water consumption in comparison to blue water availability.

We are also interested in blue water consumption (blue ET), as well as in green water consumption (green ET), to evaluate how much water we consume per unit of crop produced. In other words, we may be interested to quantify the blue and green water footprint of crop production and analyse the extent to which we can reduce the blue and green water footprint per unit of product by either consuming less water while producing the same or producing more with the same amount of water (Hoekstra et al., 2011). Note that reducing the green and blue water footprint per unit of crop is the same as increasing water productivity, which is expressed as the amount of crop produced per unit of water consumed (Molden, 2007). In irrigated crop production, one may aim to increase production per total amount of green and blue water consumed, while in rainfed farming, the focus can simply be the increase of production per drop of green water consumed.

Yet another reason why we may be interested in estimating green and blue water consumption is to analyse the trade-off between the two. Adding irrigation water to a crop field changes the water balance as a whole, affecting the evaporation and water uptake and transpiration by plants as well. Chukalla et al. (2015), for instance, show how adding some irrigation water to an originally rainfed crop can increase green ET, but increase crop yield even more, thus reducing the green water footprint per unit of crop produced. Perry et al. (2009) refer to the case whereby one crop is replaced by another crop with a deeper rooting depth, so that more water can be tapped from the soil profile. If the crop was irrigated, less irrigation (blue water) will be needed to achieve the same yield, but the volume of rainwater (green water) that will be consumed will increase. There are also trade-offs at larger scale, typically when shifting in a river basin from rainfed to irrigated production or vice versa, or when shifting production from a basin with mainly rainfed agriculture to another basin with mostly irrigated farming or vice versa. Yet another example of shifting between green to blue water consumption is when changing from the cultivation of a rainfed winter crop to growing an irrigated spring crop or the other way around.

For various reasons we may thus be interested in knowing blue T, blue E or blue ET as a total, to be distinguished from green T, green E and green ET as a total. In reality, however, E and T appear undifferentiated, so green and blue E and green and blue T cannot be measured directly; they can only be inferred indirectly. Green and blue E and green and blue T aren't conventional hydrological concepts, because for understanding hydrology it's logic and sufficient to work with total E and total T. Separating E and T into their green and blue components is useful though, as this split unveils the origin of the water that evaporates or transpires. Green-blue water accounts as extension to hydrological accounts thus tell something about the origin of stocks and flows. Most in particular for E and T or for ET as a total it is highly relevant to know which parts come for rainwater and which parts from added irrigation water.

3. The principle of tracing green and blue water in the soil water balance

The accounting method proposed here is built on the idea that a valid question for any water flux leaving the soil and vegetation is: what is the source? Particularly for (nonbeneficial) soil evaporation and (beneficial) crop transpiration we may want to know how much of that was irrigation water and how much rainwater or capillary rise from the groundwater.

In order to estimate green and blue E and T we need to trace the origin of E and T. The E and T flows originate from soil water or water intercepted by vegetation. These water stocks in turn originate from either precipitation or irrigation, and sometimes partly from capillary rise as well. If we know how much of the water in the soil and how much of the water intercepted by vegetation comes from precipitation or irrigation, we also know the fractions of green and blue water in E and T. Therefore I propose a simple accounting method to keep track of the fractions green and blue water in the different soil and vegetation layers, on a daily basis, as a basis to estimate green and blue water fractions in all fluxes leaving each layer. The method is as follows:

1. A systematic recording of the green-blue water composition is done per soil and vegetation layer. The amount of green water in a soil or vegetation layer increases when rainwater enters that layer. The amount of blue water in a layer increases when irrigation water or capillary rise enters that layer. The green-blue composition of the water storage in a layer is continuously updated based on the colours of the various inflows.
2. At a certain point in time, each water flux (e.g. E or T) from a specific soil or vegetation layer is composed of a green and a blue fraction equal to the green-blue composition of the water storage in that layer at that point in time. This assumes a homogeneous distribution of green and blue water in a layer.

The extended accounts are not necessarily limited to green and blue water. The blue water accounts can be done separately for blue water originating from different sources (Hoekstra et al., 2011), including for example: irrigation water from surface water; irrigation water from renewable groundwater; irrigation water from fossil groundwater; irrigation water from harvested rainwater; irrigation water from domestic wastewater; irrigation water from desalinated seawater; and capillary rise from renewable groundwater. At catchment scale it could be interesting to know how much blue water is consumed in crop production from these different water sources. At the minimum level – because of the essentially different soil water dynamics – it is recommended to distinguish between blue water from irrigation water added to the field and blue water entering the soil water from below through capillary rise.

Let me make a note here on the treatment of harvested rainwater. Rainwater harvesting refers to the local capture and storage of rainwater, directly when it falls on the ground or shortly after it already has become runoff. Harvested rainwater is thus blue water (which may be confusing given the use of the term rainwater), because it is not contained in the soil but instead collected in a water reservoir from which the water can be distributed to any use. Using this harvested rainwater is thus blue water use and any consumption following from it will be a form of blue water consumption.

The accounting method presented here is physically based; the outcomes could be empirically tested using tracer methods. For example, if we would add a tracer substance to irrigation water and measure the occurrence of that tracer in the surface runoff, evaporative flows and groundwater recharge, we could establish which fractions of these water flows originate from the added irrigation water. The same is true for the soil water in different soil layers: at any moment in time one could measure the occurrence of the tracer in the soil moisture in a particular soil layer and establish which fraction of the soil moisture in that layer apparently originates from irrigation water (versus other sources like rain and capillary rise).

4. The practice of tracing green and blue water in a soil water balance model

How the accounting of green and blue water in crop cultivation is done precisely depends on the schematization of the vertical into one or more soil and vegetation layers and the schematization of water fluxes entering and leaving the various layers. Here I give a simple example for the case of one soil layer, while distinguishing between three inflows (infiltration of rainwater; infiltration of irrigation water; and capillary rise from the groundwater) and three outflows (evaporation; transpiration; and percolation to the groundwater). Besides, we distinguish an overland runoff flow, which subtracts from rainwater and irrigation water before infiltration into the soil (Fig. 1). Note that water entering the soil through capillary rise is blue water because the water originates from groundwater.

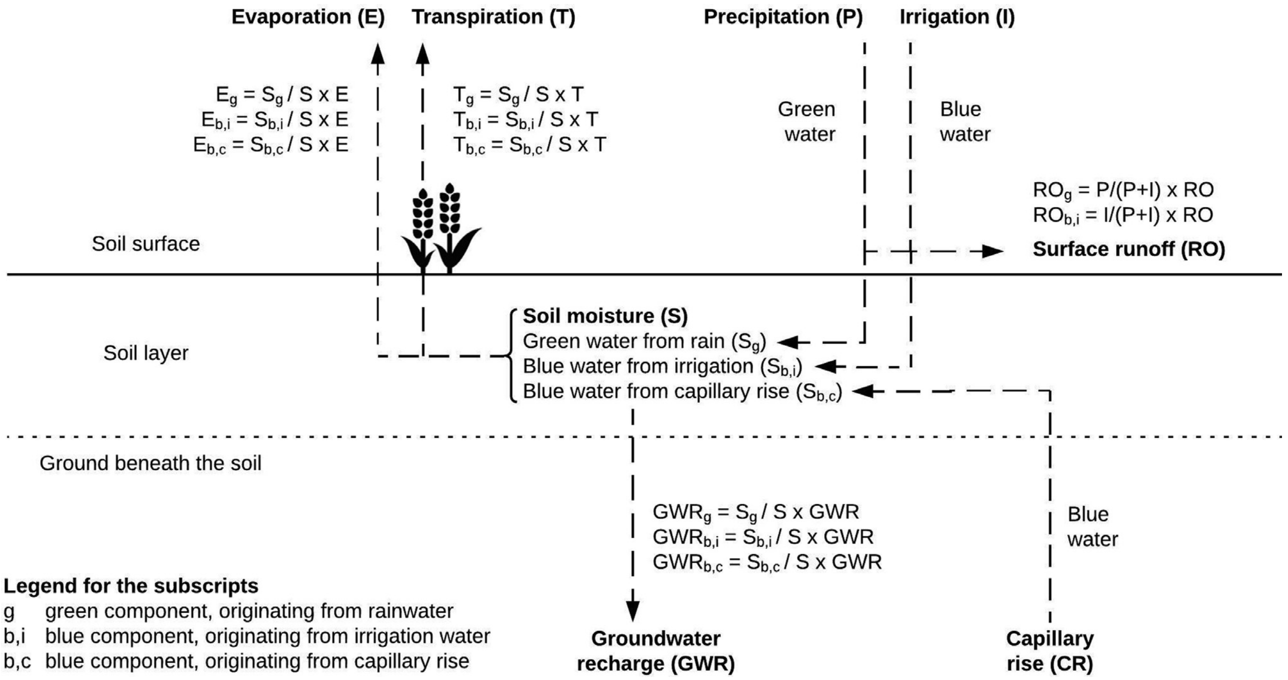

Fig. 1. Green-blue water accounting of soil moisture and water fluxes entering and leaving the soil moisture in case of one soil layer. The 'colour codes' in the form of subscripts refer to the origin of the water.

In the soil water balance model as shown in Fig. 1, the changes in the different components of the soil moisture are given by:

$$\frac{dS_g}{dt} = P - \left(\frac{P}{P+I}\right)RO - \frac{S_g}{S}(GWR + E + T) \tag{1}$$

$$\frac{dS_{b,i}}{dt} = I - \left(\frac{I}{P+I}\right)RO - \frac{S_{b,i}}{S}(GWR + E + T) \tag{2}$$

$$\frac{dS_{b,c}}{dt} = CR - \frac{S_{b,c}}{S}(GWR + E + T) \tag{3}$$

The symbols refer to the stocks and flows as shown in Fig. 1. When implemented in a numerical model, this gives;

$$S_g(t) = S_g(t-dt) + P(t) - \left(\frac{P(t)}{P(t)+I(t)}\right)RO(t) - \left(\frac{S_g(t-dt)}{S(t-dt)}\right)(GWR(t) + E(t) + T(t)) \tag{4}$$

$$S_{b,i}(t) = S_{b,i}(t-dt) + I(t) - \left(\frac{I(t)}{P(t)+I(t)}\right)RO(t) - \left(\frac{S_{b,i}(t-dt)}{S(t-dt)}\right)(GWR(t) + E(t) + T(t)) \tag{5}$$

$$S_{b,c}(t) = S_{b,c}(t-dt) + CR(t) - \left(\frac{S_{b,c}(t-dt)}{S(t-dt)}\right)(GWR(t) + E(t) + T(t)) \tag{6}$$

A time step *dt* of one day will generally be sufficient to capture the dynamics of the soil moisture, and is practical also given that the various input data are generally available on a daily basis.

For any outflow *F* from the soil moisture (*E, T, GWR*), the part of *F* that has origin *x* (precipitation, irrigation or capillary rise) follows at any time from:

$$F_x(t) = \left(\frac{S_x(t)}{S(t)}\right)F(t) \tag{7}$$

The example provided here is for the case of a simple soil water balance model with only one soil layer and has been successfully applied in a few case studies already (Chukalla et al., 2015; Zhuo et al., 2016; Karandish and Hoekstra, 2017; Nouri et al., 2019). In the case of various soil layers, the accounting principle remains the same: the colour composition of each soil layer is to be recorded over time based on the colour compositions of incoming and outgoing water fluxes. The model presented here also doesn't distinguish between evaporation from the soil and evaporation of water intercepted by the leaves and stems of the vegetation. If a vegetation layer and the process of interception is added, the green-blue water accounting principle will need to be applied to this layer as well.

The green-blue water accounting as proposed here does not need any data on top of the data already required for the soil water balance model used. The data required depend on the chosen soil water balance model, not the extended green-blue accounting. The only practical issue when applying the proposed accounting method is that an initial green-blue composition of the soil water needs to be assumed (for each layer when more than one layer is distinguished), just like an overall soil moisture content needs to be assumed. In simulation studies, initialization is a well-known problem and the general solutions often chosen in hydrological studies can also be applied for initialising the green-blue composition of the soil water. One option is to iteratively determine a realistic initial condition (see e.g. Chukalla et al., 2015); another option is to run a model for two or more subsequent years just for initializing (whereby the original assumption does not matter much, because any error will not work through more than a few years) and use only the simulated years after the initialization period (see e.g. Nouri et al., 2019).

5. From the green-blue water accounts to estimating irrigation water consumption, irrigation efficiency and green and blue water footprints

The generic principle introduced here to distinguish between green and blue E and between green and blue T allows us to more accurately estimate irrigation water consumption, irrigation efficiency and green and blue water footprints of crop production than before. Earlier assessments of blue ET in irrigated crop production were rough estimations based on the relative addition to the soil of irrigation water and rainfall over time (Rost et al., 2008; Fader et al., 2011; Hanasaki et al., 2010) or on taking the difference between ET under rainfed conditions and ET under irrigated conditions (Mekonnen and Hoekstra, 2010; Siebert and Döll, 2010). An earlier assessment of blue ET from capillary rise in production forests was similarly based on a rough assumption regarding the contribution of capillary rise without properly keeping track of the composition of the soil moisture (Schyns et al., 2017).

The accounting method presented offers an unambiguous way to estimate irrigation water consumption, which refers to what in the accounts comes as 'blue evapotranspiration from irrigation water' ($E_{b,i} + T_{b,i}$). It is important to know irrigation water consumption, because it is the part of the irrigation water applied to the field that does not return to the catchment (through either runoff from the field or drainage). It is the consumptive part of irrigation that contributes to blue water scarcity, so it is highly relevant to estimate it accurately.

The accounting method also enables the calculation of irrigation efficiency (IE) as the ratio of blue transpiration from irrigation water ($T_{b,i}$) to the applied irrigation water (I) over the growing period of the crop (Zhuo and Hoekstra, 2017):

$$IE = \frac{T_{b,i}}{I} \tag{8}$$

It is to be noted here that if next to the harvested crop there are weeds or other forms of vegetation (e.g. the cover under production trees) as well, one should distinguish between total crop T and weed/other T and compute IE based on crop T.

By providing the distinction between green and blue E and T over the growing period, the proposed accounting scheme easily allows the estimation of green and blue water footprints (*WF*) per unit of crop harvested by dividing the right components of E and T over the growing period by the crop yield (*Y*):

$$WF_g = \frac{E_g + T_g}{Y} \tag{9}$$

$$WF_{b,i} = \frac{E_{b,i} + T_{b,i}}{Y} \tag{10}$$

$$WF_{b,c} = \frac{E_{b,c} + T_{b,c}}{Y} \tag{11}$$

All water footprints are calculated based on the sum of the beneficial consumption of water (T) and the nonbeneficial consumption of water (E) because the water footprint metric intends to show total water consumption related to production, and this includes the 'waste fraction' of consumption, that is the unproductive evaporation from the soil. For the blue WF of irrigation this means that it gets smaller when the unproductive consumption of water gets reduced; measures to shift some of the nonbeneficial E to beneficial T (e.g. through soil mulching), thus increasing Y, will reduce the blue WF (Chukalla et al., 2015). The blue WF related to consumption of irrigation water can be split up into different components if different sources of irrigation water are used and explicitly distinguished (e.g. fossil groundwater, renewable groundwater, rivers/lakes, and harvested rainwater). The blue WF can be split up according to these sources provided that separate tracing is done in the accounting for each of these sources.

6. Conclusion

The confusion in the literature on whether 'green water' refers to rainwater in the soil or to evapotranspiration of rainwater – as was mentioned in the introduction – has been solved here by acknowledging that 'green' and 'blue' do not refer to one particular stock or flow in the water cycle, but are rather labels that tell something about the origin of water. Green and blue are labels that can be used both for water stored in a soil or vegetation layer and for a water flux that leaves from the soil or vegetation (like the evaporation or transpiration flow). 'Green' thus means 'originating from rainwater' and 'blue' means 'originating from groundwater or surface water'. In both cases we refer to the origin in the short-term past, because water keeps circulating, so in the end all water can be traced back in some stage to both rainwater and runoff flows. The issue here is whether, when we trace for instance E, T or soil moisture back to where it comes from, we either end up first with rainfall or with groundwater or surface water.

The proposed green-blue water accounting method helps to improve the estimation of irrigation water consumption, irrigation efficiency and green and blue water footprints in agriculture. Although the emphasis has been on crop production, the green-blue water accounting method is equally applicable for forestry and gardening. For all these purposes we need an accurate partitioning of E and T into a green and blue component. The proposed method provides in a generic and accurate routine for that, while all previous approaches relied on simplistic routines that did not do justice to the soil water dynamics.

The number of papers published in the field of green and blue water consumption in agriculture and forestry is growing quickly; it would be helpful if researchers – instead of relying on simplistic assumptions – adopt the here proposed physically based tracing method, which allows the precise assessment of green and blue fractions of soil moisture and water fluxes leaving the soil. The minimum requirement is that the hydrological or crop growth model used includes a daily soil water balance. Currently there does not exist any hydrological or crop growth model that includes green-blue water tracing, hence researchers have to rely on post-processing of the time series outputs from their model to simulate the colour composition of soil moisture and water fluxes leaving the soil (see e.g. Chukalla et al., 2015). It is to be recommended to integrate green-blue water accounting in soil-water balance models, which requires little effort other than add some additional coding to systematically keep track of the colour composition of soil moisture and soil water fluxes.

The interest in tracing the origins of water consumed in crop production increases. Wada et al. (2014) for instance estimated irrigation water consumption distinguishing between irrigation from surface water and irrigation from groundwater at a global scale, at a spatial resolution of 0.5 arc degree. The next step is to systematically differentiate between irrigation from fossil versus renewable water resources. It will be interesting also to map irrigation water consumption from inter-basin water transfer schemes. Since irrigation water consumption is the largest contributor to blue water scarcity throughout the world (Mekonnen and Hoekstra, 2016) and since increasing water-use efficiency and reducing blue water scarcity are targets in the UN Sustainable Development Goals (Vanham et al., 2018), properly estimating irrigation water consumption is gaining in importance.

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