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Article

Estimating Green Water Footprints in a Temperate Environment

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Abstract: The "green" water footprint (GWF) of a product is often considered less important than the "blue" water footprint (BWF) as "green" water generally has a low, or even negligible, opportunity cost. However, when considering food, fibre and tree products, is not only a useful indicator of the total appropriation of a natural resource, but from a methodological perspective, blue water footprints are frequently estimated as the residual after green water is subtracted from total crop water use. In most published studies, green water use (ET_{green}) has been estimated from the FAO CROPWAT model using the USDA method for effective rainfall. In this study, four methods for the estimation of the ET_{green} of pasture were compared. Two were based on effective rainfall estimated from monthly rainfall and potential evapotranspiration, and two were based on a simulated water balance using long-term daily, or average monthly, weather data from 11 stations in England. The results show that the effective rainfall methods significantly underestimate the annual ET_{green} in all cases, as they do not adequately account for the depletion of stored soil water during the summer. A simplified model, based on annual rainfall and reference evapotranspiration (ETo) has been tested and used to map the average annual ET_{green} of pasture in England.

Keywords: CROPWAT; effective rainfall; England; green water footprint; pasture

1. Introduction

In England almost all agricultural grassland is rainfed. Weatherhead [1] estimated that only 3,671 ha of grassland in England received any irrigation in 2005, representing less than 0.1% of the national

area of managed grassland. Therefore the contribution of grass to the water footprint of raising livestock is entirely associated with 'green' water—*i.e.*, rainfall that is used by the vegetation at the place where it falls [2].

Often, the green water footprint of a good or service is considered of low importance, as green water has a low or negligible opportunity cost. In the case of a crop, if the crop were not grown, the green water would not be available for other users (such as domestic water supply or industry) in the catchment. Assuming the field is not kept bare or sealed by an impermeable surface, if the crop in question was not grown, some other vegetation (e.g., 'natural' vegetation) would use a similar amount of water. However, estimation of the green water component of the water footprint is important for four reasons;

1. It is important to show the total water use of a crop in order to estimate the total impact of crop production on the aquatic environment.
2. It serves to demonstrate the importance of rainfed agriculture on global agricultural production and food security [3].
3. The renewal of surface and groundwater resources is dependent on the difference between precipitation and evapotranspiration in the catchment. Changes in land cover and land use will lead to changes in the evapotranspiration (and green water footprint) thus affecting the availability of "blue" water for other uses. Rost *et al*. [4] for example, have estimated that global agriculture has resulted in 5% increase in global river discharge compared to the potential natural vegetation due to the generally lower evapotranspiration of agricultural crops and pastures compared to natural vegetation.
4. Most calculations of blue water use are based on the difference between estimated total crop water use and green water use. Many studies explicitly estimate the irrigation requirement to fulfil the deficit between crop water requirement and that which is supplied by rainfall. Any error in the estimation of green water use is therefore transferred directly to the estimate of blue water use.

For rainfed cropping systems, the green water footprint (GWF) is equivalent to the volume of water consumed by evaporation and transpiration (ET_{green}) over the period between planting and harvest (or in the case of a perennial crop like pasture, an entire year) plus the volume of water physically embedded in the harvested product (and technically the water consumed in photosynthesis). GWF may be expressed as volume, representing the total impact of an activity or an entity, or as a volume per unit of production. As ET accounts for the majority (>99%) of the water use in most agricultural systems, the GWF is usually estimated from the depth of evapotranspiration (ET) converted to a volume. Apart from occasional lysimeter or local water balance studies very little data exist on actual ET rates from rainfed crops and therefore in water footprinting studies ET is generally modelled from climatic data.

One approach is to estimate ET_{green} from monthly effective rainfall – defined, in this context, as the proportion of gross rainfall that is available to be evaporated or transpired from the crop after losses due to runoff and deep percolation have been taken into account [5]. For each month of calculation, the ET_{green} is the minimum of the potential evapotranspiration for the chosen crop and stage of growth, ETc, and the effective rainfall, P_{eff} [6]. ETc can be estimated from climate data using the Penman-Monteith equation and appropriate crop coefficients [7] but estimating effective rainfall is more difficult.

Many water footprint studies (e.g., [8-10]) have used the CROPWAT v8.0 model [11] to estimate monthly effective rainfall. Although the software offers several alternative methods, the method referred to as the "USDA SCS method" has generally been used [6] due to its simplicity; being only a function of monthly precipitation and not requiring local calibration. However, the implementation in the CROPWAT model [12] is a simplified version of the USDA SCS model based on an assumed average consumptive use (ET) of 8"/month (≈200 mm/month) and a "useable" soil water storage of 3" (≈75 mm). Although this may be an appropriate simplification for irrigation system design in semi-arid environments, it is clearly inappropriate for estimating green water use in English conditions; where ET rates in the peak months of the year may only average 100 mm/month.

The original USDA SCS method estimates monthly effective rainfall from gross rainfall, soil water holding capacity and ETc. It was calibrated on 50 years of rainfall records at 22 locations throughout the United States [13] and has been shown to perform well in well-drained soils in the USA [14]. However, Mohan *et al*., [15] found that it under-predicted effective rainfall in India compared to other methods. No evidence could be found of the original USDA SCS method being used in water footprinting studies.

The CROPWAT model also offers an option to estimate actual evapotranspiration from a water balance based on average monthly rainfall and ETo data (using the irrigation schedule function with the option to select "no irrigation"). Hoekstra *et al*. [6] recommend using this method as the model includes a dynamic soil water balance. They presented an example of the estimation of the water footprint of growing a crop of sugar beet in Spain and found that the effective rainfall method, based on Smith [9], gave an estimate of ET_{green} that was only 40% of that derived from the water balance. This brings into question the validity of the effective rainfall method for calculating water footprints.

Actual ET is affected by many local factors including plant cover, soil water holding capacity, the reference evapotranspiration (ETo) and the interval between rainfall events. The same monthly rainfall total may contribute very differently to crop water use if it falls as many small storms compared to a single large storm. Therefore, a more realistic estimate of ET_{green} can be derived from a water balance simulation using local daily rainfall and ETo data over a long time period. This was the approach used to calibrate the USDA SCS method in the 1960s [13] and to test its performance [15]. Although the CROPWAT model has the facility to use daily rainfall and ETo data, it can only run simulations for discrete, individual years. This makes it difficult to account for any carry-over of soil water from one year to the next. In contrast, the Wasim model [16] is a one-dimensional soil water balance model that operates in a similar way to the CROPWAT scheduling option, but it can be run for long-term, continuous time series, allowing a more meaningful estimation of long-term average ET_{green}.

This paper, aims to compare the estimates of ET_{green} (and therefore green water footprint) based on effective rainfall from Smith [9] and the USDA SCS [13] method, with estimates based on a soil water balance using monthly (CROPWAT Schedule) and daily (Wasim) meteorological data, in order to test the suitability of each approach for use in water footprinting studies in a temperate environment. Pasture in England will be used as a case study as grassland is the largest agriculturally managed land use in the country and therefore has the greatest potential impact on water resources.

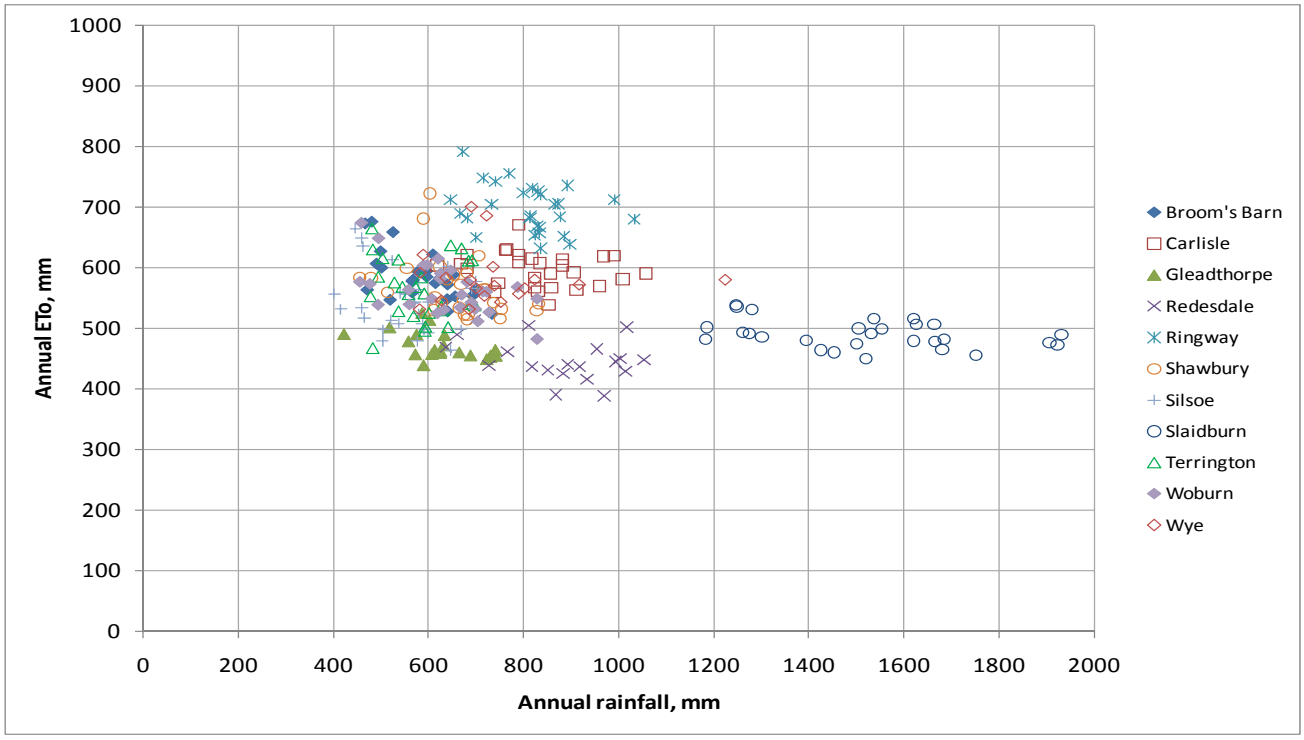
2. Materials and Methods

Eleven meteorological stations were chosen as being representative of the range of agroclimatic conditions in England. For each, daily rainfall and ETo were collated for as many years as possible within the 30-year climate baseline period (1961 to 1990). In all, this represented 291 station-years of data (Table 1). This data set included years with an annual rainfall ranging from 400–1,900 mm and annual ETo ranging from 390–790 mm (Figure 1).

Table 1. Location, altitude, data range and average annual rainfall and reference evapotranspiration (ETo) for the 11 meteorological stations.

Station	Latitude	Longitude	From	To	Altitude (m)	Average annual Rainfall (mm/y)	ETo (mm/y)
Brooms Barn	52.26 °N	0.57 °E	1964	1990	75	588	585
Carlisle	54.93 °N	2.96 °W	1961	1988	26	832	596
Gleadthorpe	53.22 °N	1.12 °W	1970	1990	60	628	470
Redesdale	55.25 °N	2.26 °W	1971	1990	235	874	448
Ringway	53.36 °N	2.28 °W	1963	1990	69	811	697
Shawbury	52.79 °N	2.66 °W	1963	1990	72	653	567
Silsoe	52.01 °N	0.41 °W	1963	1990	59	547	541
Slaidburn	53.99 °N	2.43 °W	1963	1988	192	1,515	487
Terrington St. Clement	52.75 °N	0.29 °E	1963	1990	3	587	564
Woburn	52.01 °N	0.64 °W	1963	1990	89	632	564
Wye	51.18 °N	0.45 °E	1972	1990	56	738	582

Figure 1. Distribution of annual rainfall (mm) and ETo (mm) for 291 station-years of data for 11 stations in England.



Four methods of estimating the green water use of pasture were compared. Two were based on "effective rainfall" estimated from monthly rainfall and potential evapotranspiration, and two based on a simulated water balance.

2.1. Smith (1992) Effective Rainfall Method

For each station-month, effective rainfall (P_{eff}) was estimated using the USDA SCS method as implemented in the CROPWAT v8.0 software [12];

$$P_{eff} = P\frac{(125-0.2P)}{125} \text{ for P} \leq 250\text{mm/m} \quad (1)$$

$$P_{eff} = 125 + 0.1P \text{ for P} > 250\text{mm/m} \quad (2)$$

where P is the gross monthly rainfall, and ET_{green} is determined from,

$$ET_{green} = min(ET_c, P_{eff}) \quad (3)$$

Where ETc is the potential evapotranspiration ≈ ETo for the case-study grass surface.

2.2. USDA SCS (1993) Effective Rainfall Method

Following USDA [10] and converting the units of inputs from inches to mm,

$$P_{eff} = 25.4SF(0.04931P^{0.82416} - 0.11565) \times 10^{0.000955ETc} \quad (4)$$

and the soil factor,

$$SF = (0.531747 + 0.011621 \cdot \text{D} - 8.943 \times 10^{-5} \cdot \text{D}^2 + 2.321 \times 10^{-7} \cdot \text{D}^3) \quad (5)$$

where D is the "usable soil water storage", mm, equivalent to approximately half the available water capacity [13]. As above,

$$ET_{green} = min(ET_c, P_{eff}) \quad (6)$$

2.3. CROPWAT Schedule Monthly Water Balance Method

The irrigation scheduling option in CROPWAT is designed to be used for irrigation system design and evaluation. It works by calculating a daily soil water balance and scheduling an irrigation event when pre-defined soil water status criteria are met. If the irrigation criterion is set to "no irrigation" it performs a rainfed water balance. Actual evapotranspiration is estimated from ETo, a crop coefficient and a stress factor related soil moisture. Average monthly rainfall is distributed over the month in six events and decadal (10 day) average ETo is interpolated from the monthly averages. The CROPWAT schedule option was run for each station using the averages of monthly rainfall and ETo for the periods shown in Table 1. As the pasture is not irrigated,

$$ET_{green} = ET \quad (7)$$

where ET is the modelled actual evapotranspiration.

2.4. Wasim Daily Water Balance Method

Wasim is a one-dimensional, daily, soil water balance model that simulates the soil water storage and rates of input (infiltration) and output (evapotranspiration, runoff and drainage) of water in response to weather. Although originally developed as a teaching and learning tool [16], its value in hydrological research has been demonstrated in several applications including estimation of irrigation requirements [17], runoff estimation [18], drainage performance [19] and groundwater recharge potential [20]. Full details of the modelling approach are given in Hess *et al*. [21].

For a grass surface (with an assumed 100% ground cover), ET, is estimated from;

$$ET = ETo Ks \tag{8}$$

Where Ks (dimensionless) is a stress factor used to account for dry soil conditions. Ks is equal to 1.0 when the root zone soil water content is between field capacity and 50% of the available water capacity. For restricted water supply, it decreases linearly to zero at permanent wilting point and remains zero thereafter. For excess water, it decreases linearly to zero when the root zone soil water content reaches saturation. This has been shown to be an acceptable simplification [22]. Adjustments are made for days with rain that falls when the soil at <50% of available water.

If the soil water content is between the field capacity and saturation then water is lost to drainage following an exponential decay function according to the soil permeability. Surface runoff due to the intensity of rainfall is estimated using the SCS Curve Number method, adjusted for antecedent conditions [23]. Any rain falling on saturated soil is assumed to run off and any rain that does not run off is assumed to infiltrate.

The model was parameterised for a loam soil with an available water capacity of 162 mm/m and a grass cover with a maximum rooting depth of 0.7 m. Free-drainage conditions were assumed and the water table simulation options within Wasim were disabled. The model was then run for each of the 11 climate stations and the monthly estimated actual evapotranspiration was recorded. As the pasture is rainfed the irrigation options of Wasim were disabled. ET_{green} is equivalent to the actual ET as in equation 7 above.

2.5. Spatial Variability of Green Water Use

When comparing models there is always a need for an independent, data based reference against which to compare them. There are few data on actual evapotranspiration rates available to validate the two approaches; however, actual evapotranspiration can be inferred from annual catchment-scale water balances. Gustard *et al.* [24] used long-term river discharge, rainfall and potential evapotranspiration data to estimate annual catchment scale "losses". Based on a study of 687 catchments in the UK, they showed that losses could be estimated from;

$$losses = ETo(0.00061R + 0.475) \text{ for } R \leq 850 \text{ mm} \tag{9}$$

$$losses = ETo \text{ for } R > 850 \text{ mm} \tag{10}$$

Where *losses* is the difference between annual rainfall and annual runoff expressed as a depth, mm, and R is the average annual rainfall, mm. As the dominant loss at the catchment scale is through evapotranspiration, the losses estimated from the water balance is a good estimator of annual

evapotranspiration. Although this represents the evapotranspiration from a range of land cover types, less than 10% of the land area of England is woodland [25], and less than 1% of the agricultural area is irrigated [1], so the estimate of catchment ET should be broadly representative of rainfed grassland, agricultural and natural vegetation. This can be approximated to be equivalent to the total ET_{green} of the catchment and therefore provides an independent benchmark against which to test the validity of the other methods.

The UK Climate Impacts Programme has generated 5km gridded datasets of long-term average annual rainfall and ETo for the baseline (1961–1990) period for the UK. If the Gustard *et al*. [24] method is in good agreement with the site-specific estimates of green water use of pasture, it can be used with this dataset to estimate the green water use of pasture in different parts of the country.

3. Results and Discussion

Figure 2 shows the average ET_{green} for pasture at each climate station in comparison to the estimates of catchment scale losses. The Wasim model has the best fit with the catchment losses with a root mean squared error (RMSE) of 32 mm compared to 130 mm and 204 mm for the effective rainfall methods of Smith [12] and USDA SCS [13] respectively. The method of Smith under estimated ET_{green} by 13–34% with the greatest difference in the drier locations (Figure 3). This is compatible with the findings of Hoekstra *et al*. [6]. Surprisingly, the USDA SCS method performed worse than Smith's simplification, perhaps reflecting the differing rainfall characteristics of England compared to the USA. The CROPWAT schedule approach performed better than either of the two effective rainfall methods with a RMSE of 38 mm and an average underestimate of 5%.

Figure 2. Comparison between average annual catchment losses and ET_{green} estimated using four alternative approaches showing the 1:1 line (dotted).

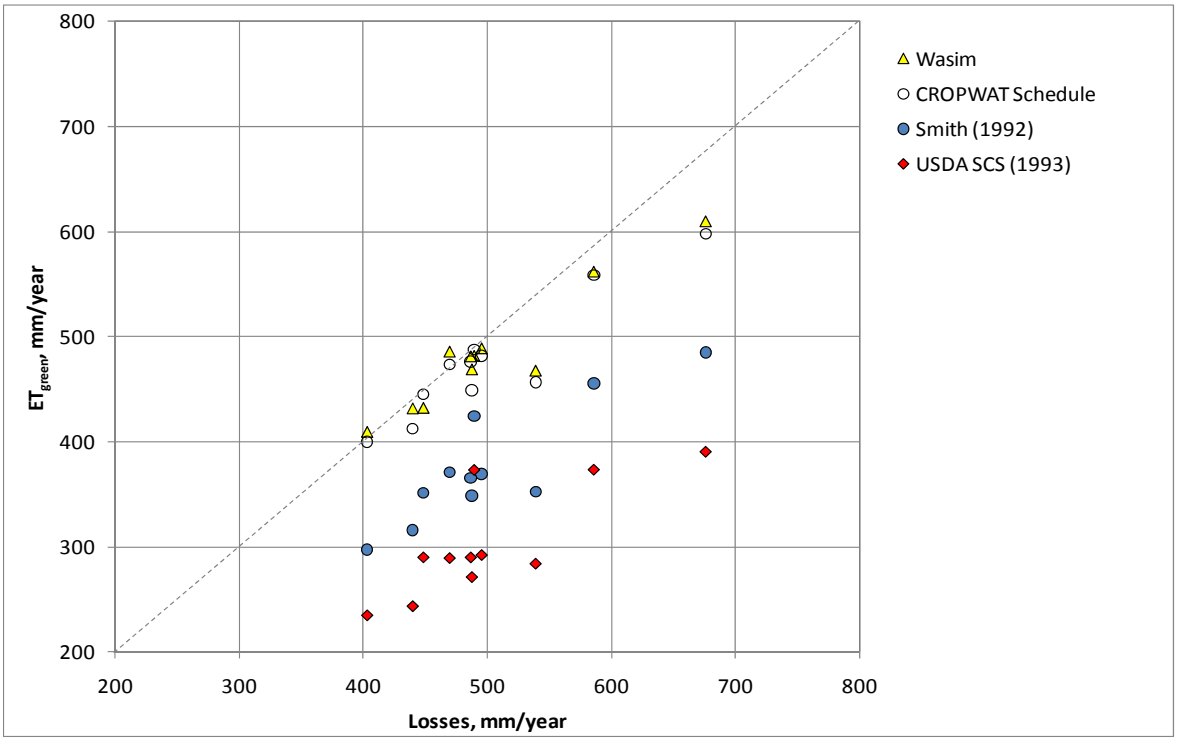
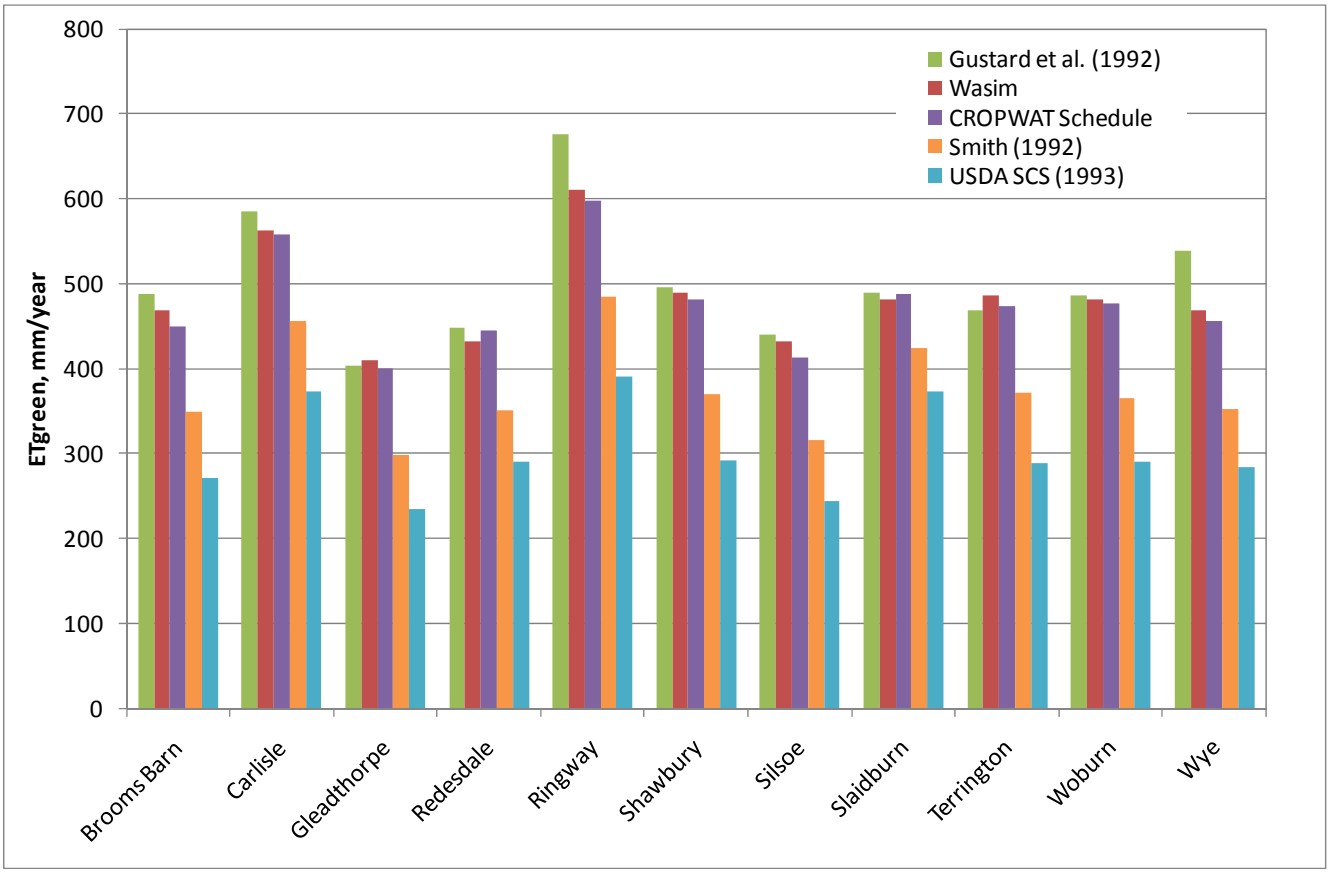


Figure 3 shows the average annual ET_{green} for each station calculated using each method. It shows that the CROPWAT effective rainfall method produced lower estimates of the water use at all stations; ranging from 74–88% of the water use estimated with the daily water balance at Brooms Barn and Slaidburn respectively. In all cases the Wasim and CROPWAT schedule results were closer to the estimated catchment scale "losses" than the estimates based on effective rainfall and on average the Wasim estimate of ET_{green} was 96% of the estimated catchment scale losses. This suggests that the estimate of green water use of pasture derived from a water balance is more appropriate for English conditions than the methods based on effective rainfall.

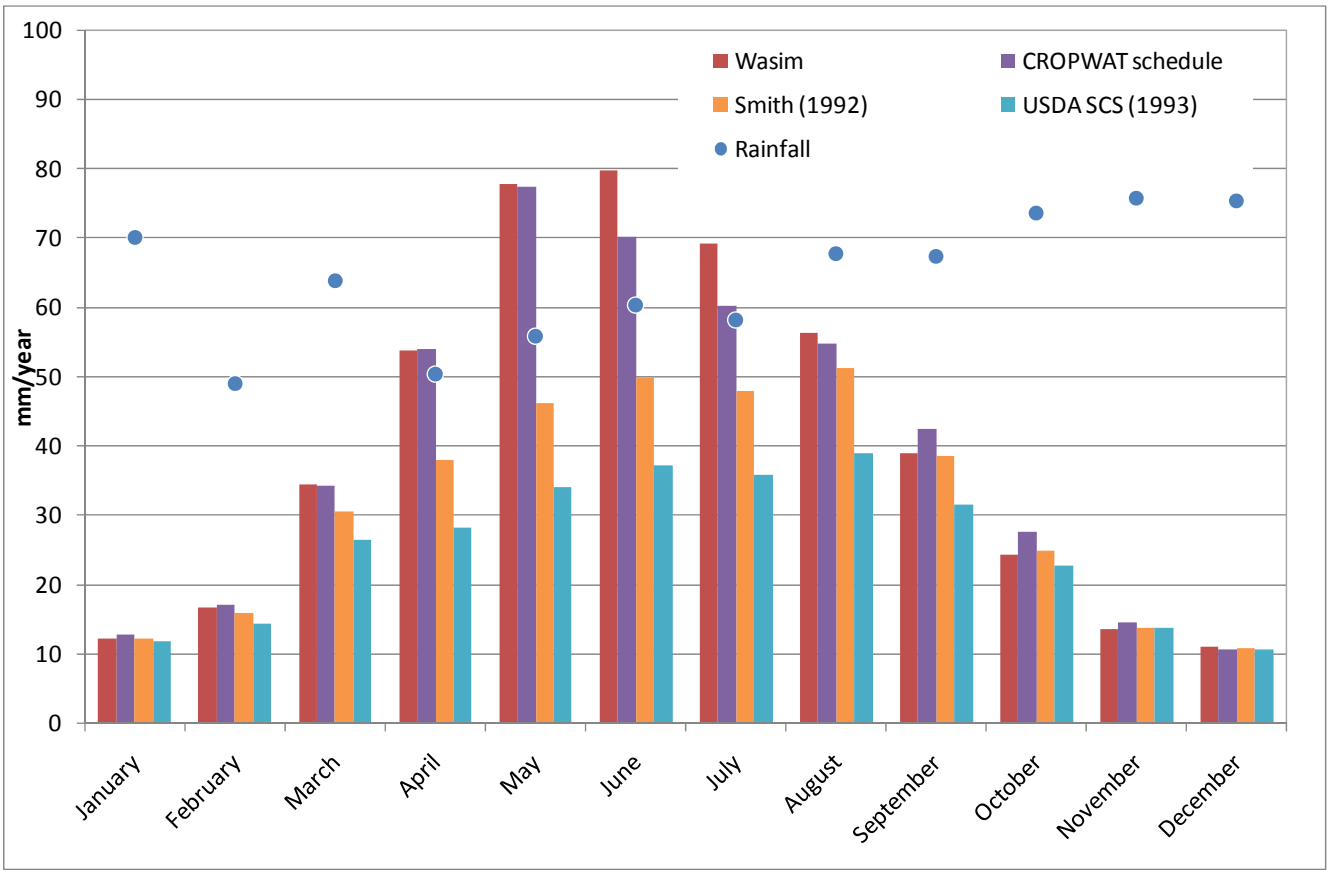
Figure 3. Average annual evapotranspiration, ET_{green}, estimated using four methods for 11 stations in England compared to estimated catchment-scale losses.



When the seasonal distribution of ET_{green} is considered (Figure 4) it is clear that all methods yield similar results in the winter (October to March), when ET is limited by solar radiation and monthly ETc is less than rainfall. However, in the summer months the estimate of ET_{green} from estimated effective rainfall (Smith and USDA methods) is less than that from the water balance methods (Wasim and CROPWAT schedule). By definition, the ET_{green} estimated from effective rainfall must be less than the monthly gross rainfall. From April to August, the average ET estimated using the effective rainfall methods was 75–83% of average rainfall. However, under the English climate, with a cool, wet winter, the soil will typically be at, or close to field capacity by the start of April [26]. Therefore, not only can the crop utilise the rain that falls in each summer month, but it can also draw on stored soil water and a soil water deficit can develop potentially to the limit of the available water capacity. Given

the loam soil used in this example and a 0.7 m rooting depth for grass, this amounts to 113 mm. The daily water balance (Wasim) shows that, on average, ET exceeds summer rainfall by 56 mm, equivalent to half of the available soil water. By September, the soil water deficit will have reached a maximum, limiting evapotranspiration, and in this month the effective rainfall and water balance methods gave more similar estimates of ET_{green}.

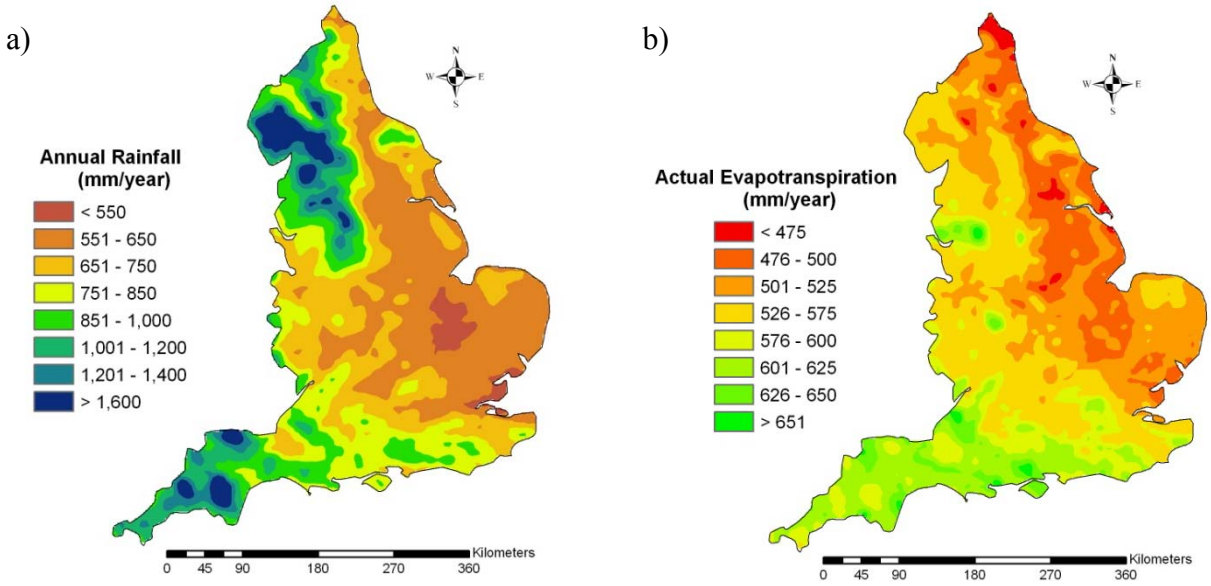
Figure 4. Average monthly evapotranspiration, ET_{green} (mm/month) estimated using each method compared to average rainfall (mm/month).



When comparing the two water balance methods, the Wasim method estimates higher ET_{green} in June and July compared to the CROPWAT schedule method, however the latter approach give higher values for September and October. This suggests that the use of monthly average weather data in CROPWAT results in an over-estimate of the impact of water stress on ET during the mid-summer months and an under-estimate in the early autumn. This may be related to the allocation of rainfall into a few discrete events in the CROPWAT schedule method.

The method of Gustard *et al*. [24], being based only on annual rainfall and ETo, lends itself to national extrapolation. Figure 5 shows the estimated annual green water use of pasture in England. It ranges from <475 mm/year in the north-east, which has high rainfall, but low annual ETo, to >650 mm/year in the south-west of England. In eastern England, although the ETo is the highest in the country, ET_{green} is limited by low annual rainfall.

Figure 5 Map of England showing average annual a) rainfall, mm (Source: UK Climate Impacts Program) and b) estimated ET_{green}, mm for pasture in England.



4. Conclusions

This case study has shown that the commonly used method for estimating ET_{green}, based on monthly effective rainfall, is not appropriate for English conditions as it fails to account for the contribution of stored soil water to summer evapotranspiration. The effect of this will be to underestimate the green water footprint, and in irrigated conditions to overestimate the blue water component of the water footprint. The case study has also shown how a more realistic estimate of ET_{green} can be derived from a daily soil water balance, although using monthly average weather data (as in the CROPWAT schedule method) is adequate for estimating annual green water totals.

Where daily or monthly weather data are not available, a reasonable estimate can be derived from average annual rainfall and reference evapotranspiration using the method of Gustard *et al.* [24]. Using this approach, the average annual green water use of pasture in England has been estimated to range from 475–650 mm/year in the north-east and south-west of England respectively.

The study has also highlighted the simplifications made to the USDA SCS effective rainfall method implemented in the CROPWAT v8.0 software that limit its application to locations and months with high potential evapotranspiration. However, in the English context, the use of the original USDA SCS method results in a less accurate estimate of green water use.

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References

1. Weatherhead, E.K. *Survey of Irrigation of Outdoor Crops in 2005: England and Wales*; Cranfield University: Cranfield, UK, 2006.
2. Falkenmark, M. Land-water linkages: A synopsis. In *FAO Land and Water Bulletin No. 1. Land and Water Integration and River Basin Management*; Mather, T.H., Ed.; Food and Agriculture Organisation: Rome, Italy, 1995; pp. 15-16.
3. Aldaya, M.M.; Allan, J.A.; Hoekstra, A.Y. Strategic importance of green water in international crop trade. *Ecol. Econ.* **2010**, *69*, 887-894.
4. Rost, S.; Gerten, D.; Bondeau, A.; Luncht, W.; Rohwer, J.; Schaphoff, S. Agricultural green and blue water consumption and its influence on the global water system. *Water Resour. Res.* **2008**, *44*, W09405.
5. Dastane, N.G. *Effective Rainfall in Irrigated Agriculture*; Irrigation and Drainage Paper 25; Food and Agriculture Organisation: Rome, Italy, 1978.
6. Hoekstra, A.Y.; Chapagain, A.K.; Aldaya, M.M.; Mekonnen, M.M. *Water Footprint Manual—State of the Art 2009*; Water Footprint Network: Enschede, the Netherlands, 2009; 1-127.
7. Allen, R.G.; Pereira, L.S.; Raes, D.; Smith, M. *Crop Evapotranspiration: Guidelines for Computing Crop Water Requirements*; Irrigation and Drainage Paper 56; Food and Agriculture Organisation: Rome, Italy, 1998.
8. Chapagain, A.K.; Hoekstra, A.Y.; Savenije, H.H.G.; Gautam, R. The water footprint of cotton consumption: An assessment of the impact of worldwide consumption of cotton products on the water resources in the cotton producing countries. *Ecol. Econ*. **2006**, *60*, 186-203.
9. Galan-del-Castillo, E.; Valazquez, E. From water to energy. The virtual water content and water footprint of biofuel consumption in Spain. *Energ. Policy*. **2010**, *28*, 1345-1352.
10. Chapagain, A.K.; Orr, S. An improved water footprint methodology linking global consumption to local water resources: A case of Spanish tomatoes. *J. Environ. Manage.* **2009**, *90*, 1219-1228.
11. *CROPWAT [computer program]*, Version 8.0; Food and Agriculture Organisation: Rome, Italy, 2009.
12. Smith, M. *CROPWAT—A Computer Program for Irrigation Planning and Management*; Irrigation and Drainage Paper 46; Food and Agriculture Organisation: Rome, Italy, 1992.
13. Irrigation water requirements. In *National Engineering Handbook*, Part 623 ed.; United States Department of Agriculture Soil Conservation Service (USDA): Washington DC, USA, 1993.
14. Patwardhan, A.S.; Nieber, J.L.; Johns, E.L. Effective rainfall estimation methods. *J. Irrig. Drain. E-ASC.* **1990**, *116*, 182-193.
15. Mohan, S.; Simhadrirao, B.; Arumugam, N. Comparative study of effective rainfall estimation methods for lowland rice. *Water Resour. Manag.* **1996**, *10*, 35-44.
16. Hess, T.M.; Counsell, C. A water balance simulation model for teaching and learning—Wasim. In *ICID British Section Irrigation and Drainage Research Day*, Wallingford, UK, 29 March 2000.
17. Knox, J.W.; Weatherhead, E.K.; Bradley, R.I. Mapping the total volumetric irrigation water requirements in England and Wales. *Agr. Water Manage.* **1997**, *33*, 1-18.

18. Hess, T.M.; Holman, I.P.; Rose, S.C.; Rosolova, Z.; Parrott, A. Estimating the impact of rural land management changes on catchment runoff generation in England and Wales. *Hydrol. Process.* **2010**, *24*, 1357-1368.
19. Hirekhan, M.; Gupta, S.K.; Mishra, K.L. Application of Wasim to assess performance of a subsurface drainage system under semi-arid monsoon climate. *Agr. Water Manage.* **2007**, *88*, 224-234.
20. Holman, I.P.; Tascone, D.; Hess, T.M. A comparison of stochastic and deterministic downscaling methods for modelling potential groundwater recharge under climate change in East Anglia, UK: Implications for groundwater resource management. *Hydrogeol J.* **2009**, *17*, 1629-1641.
21. Hess, T.M.; Leeds-Harrison, P.B.; Counsell, C. *Wasim Technical Manual*; Available online: http://hdl.handle.net/1826/2455 (accessed on 26 November 2009).
22. Brisson, N. An analytical solution for the estimation of the critical available soil water fraction for a single layer water balance model under growing crops. *Hydrol. Earth Syst. Sc.* **1998**, *2*, 221-231.
23. Hawkins, R.H.; Hjelmfelt, A.T.; Zevenbergen, A.W. Runoff probability, storm depth, and curve numbers. *J. Irrig. Drain. Engineering-ASCE.* **1985**, *111*, 330-340.
24. Gustard, A.; Bullock, A.; Dixon, J.M. *Low Flow Estimation in the United Kingdom, Report no. 108;* Institute of Hydrology: Wallingford, UK, 1992.
25. *Countryside Survey: England Results from 2007*; CEH Project Number C03259; NERC/Centre for Ecology & Hydrology: Wallingford, UK, 2009; p. 119.
26. Smith, L.P. *The Agricultural Climate of England and Wales*; Technical Bulletin 35; Ministry of Agriculture, Fisheries and Food, HMSO: London, UK, 1976.