Reviewer #1

“This work is another timely piece adds to the increased collection of biofuel water footprint studies with consistent methodology in recent years. In particular, the model contributes to the existing water footprint models by using external soil water stock dataset. This platform can be useful for resource management programs and policy makers. The manuscript is well written. I only have few clarification questions and comments.”

Response: Thank you for the compliments. We have hopefully addressed your questions and comments in the following responses and changes made to the paper.

“The section seems loose and relatively lengthy. Somehow it looks like a report format, not a journal article. Some trim-downs to make it concise would be needed.”

Response: We agree that the introduction was to long and loose. As suggested the introduction section has been trimmed down and content was merged with duplicate information elsewhere in the paper.

“This section only reviewed one method – Penman-Monteith. There are several methodologies exist but not mentioned. For the models, WETT is soil erosion model and there are other models of this type. An online water footprint model WATER (http://water.es.anl.gov/) is another example of the models.”

Response: Section 2 is intended to focus solely on methods and models related to a complete biomass water footprinting and not partial footprints or other related issues such as water quality or soil erosion. We mention the WEPP model as an example of other water related models that we are not covering in detail. We added text to make this clearer in section 2.

We added text and a link to ANL's model in this section as suggested. The ANL online water footprinting model should have already had a link to the online tool in the original publications, but the footnote must have been accidently deleted prior to submission.

“The literature review needs to include more recent publications on water footprint of biofuels which include both green and blue water footprint and at county level (2012 and 2013). For example:

A. Chiu, Y. and M. Wu. 2013. Water footprint of biofuel produced from forest wood residue via a mixed alcohol gasification process, Environ. Res. Lett. Vol. 8, No. 3 (2013). DOI: 10.1088/1748-9326/8/3/035015.

B. Chiu, Y., M. Wu. 2013. Considering water availability and wastewater resources in the development of algal bio-oil, Biofuels, Bioprod. Bioref. (2013) Vol. 7 (4), p406-415. DOI: 10.1002/bbb.1397.

C. Wu, M., Chiu, Y., and Demissie, Y. 2012. Quantifying the Regional Water Footprint of Biofuel Using Multiple Analytical Tools, Water Resource Research. VOL. 48, W10518.”

Response: Thank you for pulling the more recent literature in this research area. As suggested this recent literature has been added to the paper in section 2.

“I agree with the authors that many past water footprint assessments focus on country or state level. It should be pointed out that recent publications have already moved toward county-level modeling and addressed both green and blue water, such as references 32, 39, 42, and others not cited.”

Response: We have made sure that all mentions of the geographic level of existing water footprinting include mentions of more recent county level studies throughout the paper. The paper should also more clearly indicate that while we have set up BioSpatial H2O to analyze the U.S. we are not just limiting our statements in the literature review to U.S. focused water footprinting.

“Many existing water consumption studies have been limited in the scope of crops evaluated, and thus inhibit multi-crop comparisons”. What exactly the authors want to express? In fact, several studies in the reference are multi-crop comparison. Studies with the scope of multiple crops often generate multi-crop comparisons, rather than inhibit the comparisons. Also the scope defines the study. This sentence may need to be clarified or reworded.”

Response: Yes, you are correct that our original wording was not clear in the abstract and section 2.3. We have rewritten this sentence to essentially state the importance of consistent multi-crop comparisons under alternative conditions/assumptions. There are several crops and alternative locations where our original statement is somewhat applicable, but that was really isn’t the core point we wanted to convey.

“Although the limitations of the early water footprint studies have been identified in this manuscript as 1) a lack of high resolution analysis (limited to country, state mostly, which may or may not be true), 2) lack of ability of spatial-explicit modeling of non-historical condition (future scenario), 3) single crop/multiple crops but no comparison (?), and 4) either green water or blue water, which may not be true, the contribution of this model is not clear in abstract and in the main body.

In the abstract, it was stated “We developed a model called BioSpatial H2O to address some of these limitations”.

Lines 10-12 page 13 “BioSpatial H2O improves on existing analysis by addressing several limitations of existing agricultural crop water consumption assessments outlined in previous sections and allowing for potential modifications to address other limitations.” It is unclear what the “several limitations” are and what the “other limitations” are.

Authors should state the limitations have been addressed through this work and to what extent, in both abstract and in the section 3. It is OK to address only few at a time with available technology and knowledge. I can see that this work has its own contribution to address the limits but just need to state it clearly.”

Response: As suggested we more clearly and concisely state the limitations of the existing literature and the novelty of our paper in the abstract and throughout the paper (e.g., starting on line 400). In summary, we are interested in developing a spatial explicit multicrop water footprinting tool for scenario analysis.

“One point was missing in the methodology is how the Cligen station/STASGO2-based data are distributed to county level, because STATSGO2 contains mostly state-based data. Results in Figure 6 show county level coverage but it is not clear how it was derived.”

Response: Our methods should have been clearer and is described more thoroughly in section 3.2. In summary, map unit composition was determined by transecting or sampling areas on the more detailed maps and then statistically expanding the data to characterize the whole map unit. " http://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/home/?cid=nrcs142p2\_053629. The spatial dataset is distributed in state, territorial, and national extents, we used the soil mapping unit at the national extents level.

“We joined crop planning. (typo?)”

Response: Yes this is a typo. We made the needed correction.

“Line 15, page 18 “Behind the crop coefficient curve and reference surface calculations are climate and soil input data and other user-determined assumptions.” It is not clear what these “other assumptions” are. If the crop coefficient estimate is the key improvement in this study which distinguishes this work from others that based on static curves, these are critical assumptions and should be spelled out and values presented. The footnote 3 does not provide enough reference supporting this sentence.”

Response: We used the single crop coefficient method as outlined in FAO paper 56 for each crop assessed. We have added clarifying language around this to the paper starting on line 295.

“By bringing the P-M method into an SD framework, we are calculating the water footprint for each derivative and integrating over the model run”. It is not clear to me what the “derivative” means here. P-M equation does not require derivatives in terms of mathematical definition. Authors may want to present clearly the approach and the difference between this work and the traditional method in applying the P-M equation.”

Response: Yes, this should have been clearer. Language has been clarified to indicate that the P-M equation is calculated on daily time-steps over a 30 year period starting on line 224.

“This section is valuable. It would be good to show the results of verification at site level, county level or state level for the two major crops presented.”

Response: As suggested we added a more succinct verification analysis of green water by illustrating ANL water footprinting results by state alongside our own results. Green water results are shown in Figure 7 and discussed in section 4. Blue water results are less prominently shown in SI materials due to our underlying model assumptions on tolerance for yield loss. Blue water results are only illustrative.

“Why corn and soybean water footprint are limited to eastern half of the U.S?”

Response: Geographic data coverage is limited to the available data as now better described starting on line 253. The underlying SSURGO tabular data used in relationship with the STATSGO mapping unit data contains soil property and crop yield data used in the model. The geographic coverage in the figures is the result of available non-irrigated yields for corn and soybeans from SSURGO that were aggregated to the soil mapping units. We have the needed climatic data for the western U.S. so in theory results for the western U.S. could be produced using another soil and yield dataset or making generic assumptions about soil and yields.

“Similar to Introduction, these sections look like a report. Section 4 is lengthy.”

Response: As suggested the results and conclusion sections were trimmed down to essential information. Much of the results text was trimmed now that the major data validation and comparison is in the figures. Conclusions were tightened to focus on the limitations of water footprinting efforts in the literature and

**Reviewer #2**

“The authors of this highly readable manuscript have coupled highly resolved weather data, in conjunction with a stochastic climate simulator, to project hypothetical maximum water consumption, which is reported as a productive water use estimate or water footprint (m3•Mg-1). The background discussion is adequate and well-explained. The authors rightly assert that because water use effects are local, there is a need to create tools to understand highly geographically resolved changes in water resources under different use scenarios and climate effects. Thus, the author's main premise is that tools are needed to develop more localized information is wonderful; however, it is difficult to ascertain if the tool is adequate from the present manuscript.”

Response: Thank you for your comments. As suggested we more clearly and concisely state the limitations of the existing literature and the novelty of our paper in the abstract and throughout the paper (e.g., starting on line 400). In summary, we are interested in developing a spatial explicit multicrop water footprinting tool for scenario analysis. Hopefully, the additional details about the model will also make an assessment of the tool easier.

“Without supporting documentation, it is difficult to understand how the biomass yield, a critical parameter, is determined. Figure 4 shows the yield as an exogenous input; however, the source of this input is not clear. The authors do not discuss the yield component at all except to postulate that a comparison of actual vs. 'potential' yield would be useful (p28,line13-14). The references cited on p17, lines 9-11 regarding "harvesting data" seem only to contain information on harvesting dates - not yield.”

Response: We apologize for not being completely clear about the very important yield assumptions. Non-irrigated yields are from the SSURGO tabular data and were used in the model in relationship to the STATSGO soil mapping units. This is more clearly documented starting on line 253. Source: Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Web Soil Survey. Available online at http://websoilsurvey.nrcs.usda.gov/. SSURGOV2.1 MD 2.2.5.

“1) Several facets of the paper hint that perhaps a yield model is being used: the paper is states that it is calculating hypothetical maximum water footprints (p23, line14), they appear to be using only planting and harvest dates as input (p17, line9), and they are showing yields in counties which have no reported yield in NASS (figures 5-6) (e.g. corn acres have not been reported in Chippewa county Michigan in the last 25 years, 15 years for Itasca county Minnesota and more than 30 years for St. Louis county, MN). It is critical to know the source of this input, not only because it determines the denominator of the footprint but because it used in the calculation of the numerator as well....For example, on p. 17 lines 4-5, the authors state that the they are calculating the available water capacity (a parameter required to determine crop yield) to be "calculated from the soil physical properties and the crop yield", thus, the yield parameter is critical to the water use estimate. Further is it stated that the "[n]on-irrigated STATSGO2 crop yields were aggregated..." (p17 line5) and that "BioSpatial H2O is currently based on available agricultural crop data from STATSGO2" (p15, line 4). However, the database, by all appearances refers to geophysical soil characteristics only. Perhaps the database has been updated beyond what is obvious from the website. If so, the authors should cite that update. If not, the authors should be more precise in their description of the yield data sources.”

Response: See additional metadata & figure starting on line 253. Again we apologize for not being completely clear about these assumptions. The crop yields were queried from the Access database "tabular SSURGO" portion of the National Resource Conservation Service download. The crop yields were aggregated to the STATSGO soil mapping units (Musym). The determinate for the individual crop geographic coverage in the model was the layering of the data from different sources. The data model pares locations where data is missing or NULL along the query chain. Several sources were used to fill in the planting and harvesting crop dates at the top layer. In addition, the model is structured such that other sources of the climate and soil data, including yield, could be readily substituted as exogenous inputs if there are better resources.

“2) Like many previous water footprint papers, the authors calculate blue water (irrigation) use as a theoretical maximum. Other authors (notably Hoekstra et al.), calculate a theoretical water requirement based on maximal yield and then derive irrigation water used by subtracting the naturally available water (precipitation or derived soil water) and assigning the deficit as a blue water footprint - whether or not irrigation is actually used. The approach was widely criticized and subsequent versions of the footprint now incorporate more realistic assumptions. This manuscript presents a similar extreme technique, with very thin justification and inadequately described methods.

For example, the manuscript depicts corn and soybean production in some areas where if production occurs, it occurs sporadically at low levels due to short growing season and frost (e.g. upper Michigan and Minnesota), yet here too, irrigation is depicted (Figures 5-6). This approach is extremely misleading in the abstract but is even more so given the highly resolved presentation of this paper (i.e. the appearance of highly resolved data). There is no doubt that one unfamiliar with the agronomy of these crops or regions would look at Figure 6 and conclude that the vast majority of corn in the US is irrigated, despite the authors disclaimer on page 11. The figure on the caption should be adjusted to include "hypothetical maximal" etc. to distinguish model output from being interpreted as actual data

[For the authors' reference, corn yield and water use in corn production are changing due to new varieties and changes in agronomic practice (e.g. increased planting density). From 1980-2011 the volume of water used per irrigated acre decreased 28 percent (1.0 percent compound annually) and volume per incremental bushel produced as a result of irrigation decreased 53 percent (2.4 percent compound annually). The average water use (per irrigated acre) was 12.0 acre inches in 2011 compared with 16.8 acre inches in 1980. During that same time period average yields nearly doubled on irrigated acres - NASS QuickStats 2.0].”

Response: We address these issues more thoroughly starting on 311. The important thing to note is that in our model the blue water foot print, as calculated in this model, is influenced by an assumed tolerance to crop yield loss. For purposes of illustration only, we have assumed this parameter to be zero. In other words we assume that there is no tolerance to yield reduction and thus the blue water values reported should be viewed as maxima. In practice there will be obviously be some level of tolerance to yield loss based on various economic and behavioral conditions. The model could be easily modified to be water maximizing with the appropriate data, as opposed to a yield maximizing modeling. This could include just using irrigation survey data. The purpose of the modeling in the paper was to only demonstrate the models blue water footprinting capabilities that could be modified by measured data or other research. We do believe it is more appropriate to move most of these blue results to the SI because they are only theoretical maxima when there is no tolerance for yield loss.

“3) Looking at the scale on Figures 5-7, one draws the conclusion that 3-4 times the amount of irrigation water is required for corn and soy than the available precipitation (greenwater) across the entire US. While this makes sense for dry regions such as Wyoming, it is less clear for states with relatively high precipitation. For example, in Illinois and Iowa - two states not generally considered constrained for precipitation - the greenwater footprint ranges from roughly 500-1000 m3/Mg while the blue water footprints ranges from 1000-4000 m3/Mg and 500-3000 m3/Mg, respectively. The authors admit that the BioSpatial H2O footprint is "generally higher" than those in the literature but they understate this. The total range of footprint for corn in this manuscript ranges from 1000 m3/Mg (Iowa low end) to 18,500 m3/Mg for (Wyoming high end). These are 2-4 times higher than calculations by Gerbens-Leenes et al. 2009 - who happen to use a similar method skewed toward a maximum water footprint\*. The utility of such obvious overestimates is doubtful. The literature abounds with doomsday scenarios for bioenergy water use - what is need is more accurate representation of actual water use. If the BioSpatial H2O model is so unconstrained, it's proposed use for future climate scenarios or for fact-checking reported irrigation use seems questionable.

\*[The footprint in Gerbens-Leens et al. is by calculated from the theoretical crop water requirement, assuming irrigation to meet the full requirement (i.e. maximal theoretical water use) divided by the actual (physically constrained) crop yields, which typically are below the maximal theoretical yield - thus giving an inflated total water footprint.]”

Response: Our previous response should mostly also address most this comment.

We would like to add that we would definitely not advocate a blue water footprint with zero tolerance for yield loss as the way we would estimate and try to draw conclusions about actual or future water use. We certainly agree that our theoretical maxima are of limited “utility”. However, building a model for scenario analysis of blue water requires the flexibility be easily altered based on one’s assumptions about economic and behavioral conditions. One obvious leverage point was farmer’s tolerance for yield loses. In theory, we could have just calibrated the tolerance for yield to the most recent irrigation survey, but that would not say anything novel about blue water use. In our paper we still are not saying anything novel about blue water use, but do describe how it is estimated and could be modified for a scenario analysis.

“The authors claim to be calculating the crop co-efficient curve for "each station from exogenous Cligen data instead of just using a standardized crop co-efficient curve". The authors should provide more information as to how they are doing the endogenous calculation (Figure 4).

Typically Kc is parameterized using in-field measurements (see Steele et al. 1996. Transactions of the ASAE 39:931) for an example comparing use of cumulative degree growing days vs. day post planting). Perhaps more detail on the method with citations to the actual equations used\* and parameterizing measurements would clear up the confusion. Since this is a central important feature of the tool, it should be described in more detail. Perhaps an example calculated Kc curve could be shown and compared with literature values.

\*[It would be helpful to see all the math. For example, how is the soil moisture component determining crop water demand (Figure 4) (i.e. what is the relationship used). Are the authors calculating a water balance such as that of Chiuw et al 2002 where ETactual = f(soil moisture, ETpotential)??]”

Response: Additional description of our methods addressing this are included starting on 285. Crop evapotranspiration is calculated based on an evapotranspiration reference surface and an endogenous or exogenous (user-defined) crop coefficient. The reference surface evapotranspiration is calculated using the daily time step method outlined in Chapter 4 of FAO paper number 56. The crop coefficient (Kc) in our model can be either exogenous or calculated endogenously. The illustrative results presented in this paper are based on the endogenous calculation of Kc. For the endogenous crop coefficient calculation, the model uses the single crop coefficient approach as outlined in Chapter 6 of FAO paper number 56. In our model, the Kc curve is constructed to reflect various wetting events, variable growing seasons (spring-summer rotations, winter rotations, and perennial crops), and variable soil textures.

“4) The authors state the Kc, crop co-efficient varies from 0 to 1; however, there are many cases where Kc exceeds 1. e.g. the common accepted Kc for corn from14 leaves through beginning dent is 1.1 and Kc(mid) for maize according the FAO is 1.2. The Kc for soy exceeds 1 from beginning pod through full seed development. Are the authors simply generalizing or are they restricting their calculated Kc?”

Response: We clarified our methods addressing this starting on 285. Kc represents a crop based constant that varies throughout the growing season, refer to FAO paper 56 for common ranges observed across a number of crops. The prior range listed in the paper was in error and did not reflect actual modeling.

“5) The authors may wish to consider whether both Figure 5 and 6 necessary? - Figure 6 seems to simply be an aggregate version of Figure 5. Perhaps, maps of the crop yields and total potential ET would be useful to augment the green and blue water footprints.”

Response: We agree that it did not make sense to include both figures 5 and 6. Figure 6 has since been replaced. A yield figure did not seem to be appropriate since these assumptions pre-exist in the STATSGO2 and have been previously visualized. A total potential ET figure would obscure meaningful results given that we do not assume any tolerance for yield loss when calculating blue water use. In fact, we have moved blue water use result comparison to Argonne National Laboratory data because it is an apples to oranges comparison.

“6) The citation for Cligen on p15, line 5 should be 50 not 49. STATSGO2 should be cited as 49 in the previous line.”

Response: Thank you for catching that. We made the correction in references as suggested.

“7) Allocation methods for the footprint are not addressed. For example, is there allocation for stover and distiller grain or soycake use? Or is the assumed water footprint only for energy purposes as the title implies. Although this is commonly the case for water footprint papers and the authors are not alone in this omission, it is especially misleading for soybean which is not grown as a dedicated biofuel crop, rather it is a protein feed crop from which the oil byproduct may be used for biodiesel or renewable diesel. The authors may wish to clarify this point.”

Response: Additional description of our methods addressing this are included starting on 330. The “product-purpose” allocation approach is used in our model with regard to attributing a given water footprint to an agricultural crop/product. For example, the water footprint attributed to growing corn grain is fully attributed the corn grain. However, if one were to include the harvest of corn grain and corn stover, the water footprint could be easily be allocated among the respective harvested portions of the crop using any number of user-defined allocation methods in BioSpatial H2O.

“8) Unfortunately, since the authors discuss only the water footprint for two mainstay agricultural feedstocks and do not discuss water for conversion for energy, as implied in the title. Other journals may be more appropriate for such a generic discussion of hypothetical agricultural water use.”

Response: The conversion side of the biofuel supply chain has been much better studied and is not nearly as geospatially variable. While this is an analysis area we are interested in and it would be worth pursuing modeling in this area, we think it is beyond the scope of this paper focusing on proof of modeling concept. However, stated this and also added some literature about the conversion side to the paper in the introduction.

With regards to journal appropriateness, there are perhaps better options. However, feedstock focused studies appear to fall into the scope of Biofpr journal articles based on this (<http://onlinelibrary.wiley.com/journal/10.1002/(ISSN)1932-1031/homepage/ProductInformation.html)>. We will defer to what the editor thinks is appropriate.

“9) Finally, like many water footprint papers now commonly accepted - the authors portray greenwater evapotranspiration as "consumption", ignoring the natural ET of the ecosystem in the absence of crop (e.g. forest or perennial prairie) which is equal to or greater than many crop values and which provides vital ecosystem services. Again, while this is the apparently acceptable current trend in the literature, the consideration of a more representative base case would add considerable value to the manuscript.”

Response: Additional description of our methods addressing this are included starting on 285. Crop evapotranspiration is calculated based on an evapotranspiration reference surface (i.e., the ET of a natural ecosystem) and an endogenous or exogenous (user-defined) crop coefficient. The reference surface evapotranspiration is calculated using the daily time step method outlined in Chapter 4 of FAO paper number 56.