HESSD-12-9915 "Identifying hydrological responses of micro-catchments under contrasting land use in the Brazilian Cerrado" R. L. B. Nobrega, A. C. Guzha, G. N. Torres, K. Kovacs, G. Lamparter, R. S. S. Amorim, E. Couto, G. Gerold

RESPONSES TO RC-C4218 [W. Dawes (Referee #1)]

We appreciate the time the reviewer spent reading the manuscript. We have considered the comments and below (in blue) we present our responses to the points raised.

This is a frustrating piece of work, as it only really reports on some annualized data, with line graphs showing the patchy nature of some of the continuous data, and cannot show uniquely the effects of land-use compared to all other factors.

We regret that the reviewer finds our work in that way. However, it is the same frustrations we face working and collecting data in remote areas with limited access. For example, reliable soil and geologic information are missing for this region; there are only data in scales such 1:250 000 on soils (SEPLAN, 2001) and 1:2 500 000 on geology (Bizzi et al., 2003). In other words, research in such regions could bring up some unexpected and unpleasant surprises due to the lack of data with a sufficient resolution and quality. While the data gaps are entirely for reasons that we could not anticipate or avoid, such as instrument damage from vandalism and wild animals interference, we believe that the data presented in this manuscript is sufficient to draw conclusions on the behavior of the study catchments. Especially, since the data is as yet a unique time series for this region.

The lack of data in the Cerrado biome is more prevalent in its Northern portion, where we performed our study and which at the same time is part of the current Amazon agricultural frontier. We would like to emphasize that beyond the hydrological characterization, we present an extensive soil hydro-physical analysis. This, by itself, has been the focus of other studies in the tropics (e.g.: Bruno et al., 2006, Zimmermann et al., 2010; Hassler et al., 2011; Scheffler et al., 2011). Furthermore, our objective in doing a catchment study was directly oriented to support two research demands: study the Cerrado biome itself, and improve our understanding of effects of different land uses related to the agriculture expansion in the Amazon Agricultural Frontier. While we could not entirely show the unique effects of the land-use compared to all other factors, as mentioned by the reviewer, we tested our data for hydrological controls such as surface-water hydrology in the modified Cerrado landscape, which were not pointed out yet in other hydrological studies at catchment scale.

Despite these challenges, we have attempted to explain the variation in water balance components as influenced by land-use change using the available data. Following suggestions by reviewer #2, we have also extended our efforts to include the use of remote sensing techniques, improving the quality of our E_T estimation. We therefore believe that our work is adding considerable to the scientific understanding of the region and is therefore valuable to publish.

The conclusion that different land covers produce different water balances is in no way controversial, and this work fails to argue why the Brazilian Cerrado landscape is any different.

While we agree that there are no controversies concerning the changes in the water balance due to differences in the land cover, to assume that the Cerrado biome reacts in the same way as other regions in the world would be a potentially incorrect generalization. The combination of highly adapted natural vegetation and deeply weathered soils in the Cerrado (Hunke et al., 2015) is a particular hydrological situation that deserves attention. We present observed impacts in the Brazilian Cerrado, which is considered one of the most important biomes for Brazilian water resources. The limited data currently available makes our study an important contribution to the hydrological understanding of this biome, especially in the light of the debate about the continuing agricultural expansion versus the maintenance of the remaining cerrado vegetation.

The water balances are clearly encapsulated in Tables 6 and 7, but show only that 30 to 35% of the water balance is in "lost water" not measured or inferred.

We acknowledge the reviewer's concern about the fact, that we did not quantitatively measure groundwater recharge in discrimination to water balance residuals (15–35%). Yes, lumping the groundwater recharge together with residuals, may lead to propagation of large error terms from the other components into the groundwater flux and cause systematic over- or underestimations. However, we would like to state that we could not install piezometers to monitor groundwater level fluxes due to farm management restrictions in the cropland area and fieldwork limitations. In the Cerrado biome, Oliveira et al. (2015) estimated the soil water storage change until the water table level at a plot scale with a well 42 m in depth, and show an accumulated soil water storage change of about 25% of the precipitation for a hydrological year (October to September, Fig. 5 in Oliveira et al., 2015).

To contextualize our results in this frame of differences in soil water storage and recharge, we take into account the reviewer's comments and we included the following text replacing the lines between P9938L17–L21 in the revised manuscript: "In our study, water balance errors are likely to exist owing to the lack of measurements on groundwater levels and soil water storage. However, our dS/dt results (15–35%) are consistent with previous studies. Oliveira et al. (2015) reported that ca. 25% of the water balance was soil water storage in a hydrological year (October through September) in an area covered by cerrado sensu stricto vegetation. Wendland et al. (2007) observed a variation in the underground storage representing up to 19% of the precipitation in some places of a watershed (ca. 6500 ha) in the Cerrado biome with most of its natural vegetation converted into agricultural lands."

In classical terms, monitoring of catchments of any size for changes in behaviour, either natural variation or sudden land-use changes, was done with pairs of catchments. Then a baseline could be established where all factors matched, or were taken into account by the relationships between their behaviour. Any changes in flow, evapotranspiration, deep recharge, etc., were monitored following land-use change so that the effects of this single variable could be locally quantified. This current work, in an admittedly relatively unstudied biome, has no baseline. There are no relationships between daily or monthly flows established under Cerrado vegetation prior to changes to cropland or pasture.

Our study makes use of the space for time substitution approach, a method chosen specifically because of the absence of historical data. This is an approach that has been used in various other studies such as Broxton et al. (2009), Geroy et al. (2011), Heidbuchel et al. (2013), and Strauch et al. (2015). Therefore, we believe that this is a scientifically logical methodology as an alternative to the method the reviewer describes. Troch et al. (2015) note how this method has yielded significant insights in the hydrologic response of landscapes with different patterns. Although we acknowledge that this is more valid for the cerrado and pasture catchments, we believe that the investigation of the cropland micro-catchment, as a typical representative of agricultural catchments in this area, helps to characterize areas where a baseline can be observed neither via historical nor space for time approaches.

The catchments are not similar enough topographically meaning that rainfall-runoff-throughflow processes are a confounding effect. The cropland micro-catchment is clearly the most interesting and counter-intuitive, but has only half the average slope, for example, and we do not know what the prior stream flow dynamics were to say how different they are now. This catchment also has ~50% clay/~25% sand content in the top 60cm, compared to ~10% clay/~85% sand for the other two micro-catchments (Table 4).

We acknowledge the reviewer concerns on catchment similarity. However, in our study, the cerrado and pasture catchments share common and similar physical characteristics, and they are certainly sufficient to show the hydrological differences due to the different land cover characteristics as other studies in this region have shown (Rodriguez et al., 2010; Germer et al., 2010). However, considering that more efforts are demanded on other important replacement land covers besides pastures in the humid tropics (Wohl et al., 2012), we added the cropland catchment in our analysis to represent the reality of the land-use change in the Cerrado areas of the Southern Amazonia.

At our study scale, the information on prior streamflow is indeed inexistent. Therefore, we avoided relating the differences between the catchments to the land-use change, although we know that the majority of this watershed (*das Mortes* watershed) was covered by cerrado vegetation some decades ago (Schlicht, 2013) and has already been extensively converted to croplands (Fig. below). Naturally, cropland was developed on soils and topography with the most potential for economic gain (e.g. low slopes, and high clay content (Buol, 2009)) and therefore these areas differ from the remaining ones, which have sandy soil texture and are either covered by native cerrado vegetation or used for cattle ranching. We understand that this background information is important to explain the lack of similarity of the cropland catchment to the others. Therefore, we added this background and the importance of including this catchment, as aforementioned, in the study area description in the manuscript after P9922L12. Furthermore, the cropland catchment results are supporting parameterization of hydrological models in this region regarding cropland attributes (Lamparter et al., submitted).

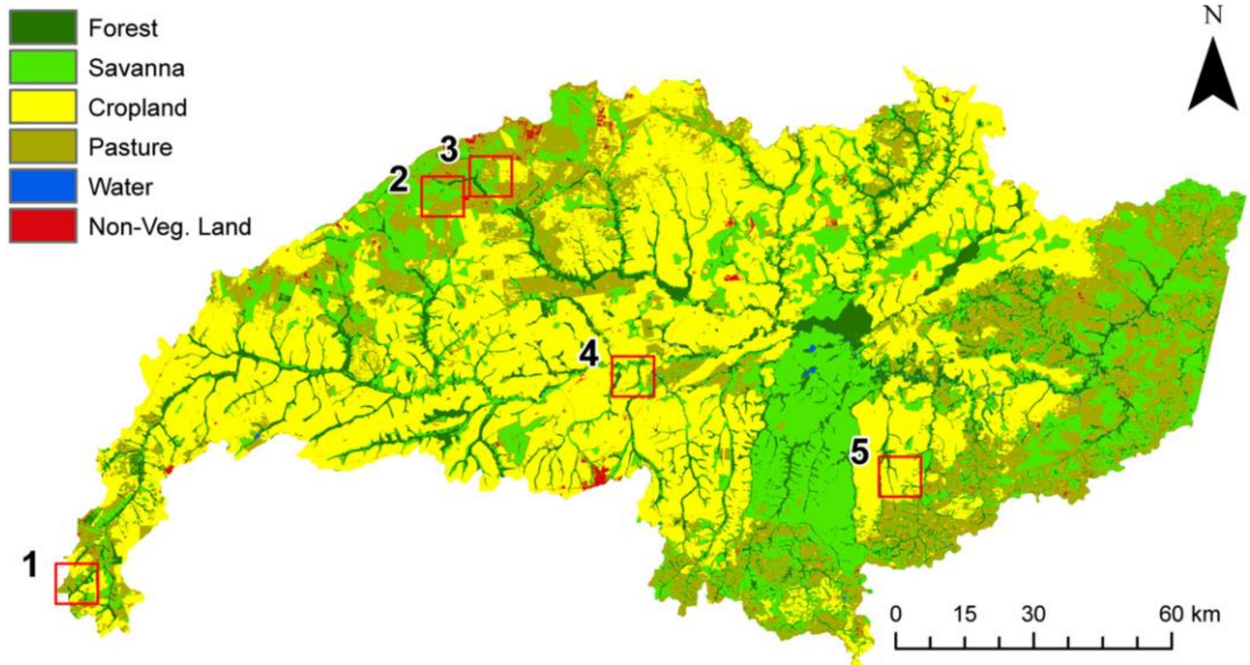

Figure. Classification results of the *das Mortes* watershed (17 555 km²) based on Landsat imagery analysis. Our study catchments are located within the red square number 1 (source: Müller et al., 2015).

Both cropland and pasture micro-catchments lose about one-third of rainfall in unmeasured losses but with very different mixes of stream flow and evapotranspiration. Table 6 shows that more than 96% of stream flow under each of the land-uses is inferred to be throughflow rather than direct runoff, yet the authors discuss differences in quick- flow for nearly 2-pages. This is clearly not the first-order process of interest where the biggest changes are expected to occur.

Concerning this comment, we acknowledge that quickflow contribution is minimal in these catchments compared to near surface lateral flow contributions. The lengthy discussion reflects on the presumption that overland flow is relevant in areas where natural vegetation is removed. The lack of overland flow again shows the relevance of the collected data and the uniqueness of the study region. In the revision, we added a discussion of the prevalence of subsurface lateral flow compared to quickflow, citing other studies in this region after P9938L14: "In a 2-year study in the cerrado landscape, Hayhoe et al. (2011) observed that the well-drained soils, in a pasture and cerrado catchments promote near surface lateral flow. Crespo et al. (2011) also observed that, in comparison to direct flow, subsurface throughflow plays a significant role in rainfall runoff generation in tropical catchments."

There is insufficient length, or depth, of soil moisture measurement to help delineate differences between recharge and soil water storage changes.

We agree with the comments of the reviewer, therefore we did not use the soil moisture measurements to delineate differences between recharge and soil water storage changes in the water balance. Instead, we used these measurements to help to understand the soil moisture seasonality in the upper soil layer and its relations to surface processes.

I want to encourage the authors to continue to monitor and study these sites, however what is presented is some short-term preliminary data which cannot clearly articulate what is happening within and between the three micro-catchments.

We thank the reviewer for the encouragement. However, while we wanted to continue monitoring these catchments, currently in this region more efforts and resources are put in research on agricultural production (The Economist, 2010), than environmental monitoring and protection (Mongabay, 2011), making it difficult to convince landowners of the importance of long-term monitoring. As of now, we do have limitations on project funding, and also monitoring of the pasture catchment is no longer possible due to land ownership changes, where the new landowners are not supportive of this research work.

While we understand the importance of longer-term continuous data sets, our study fits in well with recent published studies in which short-term data are used to characterize catchment hydrological characteristics. These include data collected with 2 year or less (Germer et al., 2010; Hayhoe et al., 2011; Recha et al., 2012; Muñoz-Villers et al., 2012; Salemi et al., 2013; Ogden et al., 2013; Clark et al., 2014; Oliveira et al., 2015).

For the Cerrado and pasture catchments with similar soils and topography, comparisons of evapotranspiration and stream flow using standard annualised water balance techniques is fully justified, e.g. Schreiber, Budyko, Pike, Choudhury, Milly, Fu, Zhang. This might show their similarity to other international catchments, or highlight why they are different enough from standard models of catchment hydrology to be more intensively studied.

We acknowledge the reviewer's endorsement of our methodology.

Variations between micro-catchments with greater differences might be explored using the simplest of daily-time-step water-balance models such as SIMHYD, with only 7 parameters, that has been applied at both local and regional scales, and for hundreds of catchments (Chiew x 3).

While we appreciate the simplicity of the suggested models, we would like to state that our goal with this manuscript is to quantify soil and hydrological characteristics based on empirical data in this biome. Nevertheless, we do understand the reviewer's concern. In this context, we are using hydrological models (SWAT, WaSiM, and Mike SHE) in association with climate and land-use scenarios to explore and better understand the hydrological dynamics in different scales of the Brazilian Cerrado. This paper is part of a wider research effort on the understanding the Cerrado biome under land-use changes, and we do expect that our results support parameterization of hydrological models in this region regarding to the cerrado, pasture, and cropland land-use attributes.

We conducted analysis on the *das Mortes* catchment using long-term discharge data, available only for drainage areas of ~5000 and ~17500 km². Trend analysis (Guzha et al., 2013a) showed that discharge in this macro-catchment increased more significantly in the 1970's and 1980's, despite the ongoing agricultural expansion associated to land-conversion in later decades. We suspected that those results are explained by the initial land-use conversion (dominantly cerrado to pasture in this region). This impact was found to be more evident than in other tropical regions, and it suggests that the effects of deforestation on hydrological fluxes in this region are more pronounced immediately after clearing with a decline in the subsequent years. For a better evaluation of hydrological fluxes, land-use scenario models on macro-scale were developed (Guzha et al., 2013b; Meister, 2014) and these applications reaffirmed the considerable lack of knowledge regarding the basic small-scale hydrological processes in this region.

Some mundane referencing issues:

Other minor observations:

P9919 L9: Silva Junior et al (1999) not in references, may be Silva et al (1999)?
Thank you for the attention. We added the correct reference: “Silva Junior, M. C., Furley, P. A., and Ratter, J. A.; Variations in tree communities and soils with slope in gallery forest, Federal District, Brazil, in: M. G. Anderson and S. M. Brooks (eds.), Advances in Hill Slope Processes, John Wiley & Sons, Chichester, 451–469, 1996.

P9922 L9: EMBRAPA (1998) not in references, may be EMBRAPA 1997?
Thank you for the attention. The correct reference is: “EMBRAPA: Centro Nacional de Pesquisa de Solos: Sistema Brasileiro de Classificação de Solos, Brasília, 2 ed., Rio de Janeiro, 306 pp., 2006.”

P9922 L25: Silva Junior (2005) not in references, may be Silva Junior (2004)?
Yes, it is. We corrected the citation.

P9931 L2: Base et al (2012) not in references
Thank you for the attention. We added the reference: “Bäse, F., Elsenbeer, H., Neill, C., and Krusche, A. V.: Differences in throughfall and net precipitation between soybean and transitional tropical forest in the southern Amazon, Brazil, Agric. Ecosyst. Environ., 159, 19–28, doi:10.1016/j.agee.2012.06.013, 2012.”

P9938 L6: Lima (2000) not in references
It is on P9949L6–8.

P9939 L10: Moraes et al (2006) not in references
Thank you for the observation. We added the reference and corrected the citation (de Moraes et al., 2006): “de Moraes, J. M., Schuler, A. E., Dunne, T., Figueiredo, R. de O., and Victoria, R. L.: Water storage and runoff processes in plinthic soils under forest and pasture in eastern Amazonia, Hydrol. Process., 20(12), 2509–2526, doi:10.1002/hyp.6213, 2006.”

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RESPONSES TO RC- C4297 [Referee #2]

The manuscript investigates some components of the water budget in the Brazilian Cerrado. This biome has been the main agricultural expansion region in Brazil, and therefore are expected several changes in the hydrological processes. To evaluate some of these changes the authors used experimental data from three micro-catchments (< 1 km2) under undisturbed cerrado ("cerrado sensu stricto"), pasture, and cropland (corn-soybean rotation). Several hydrological and hydrometeorological data were measured from October 2012 through September 2014. I recognize the hard work done by the authors to obtain and evaluate all these data; however I did not find in this study a clear objective and a relevant contribution to the literature. I also found some problems in the methodology, results and discussion sections. The manuscript is too long, and in some parts looks like a report. Overall, the manuscript has some potential for publication, but should be substantially improved for its consideration in HESS.

I have some comments/suggestions that hopefully will help the authors to improve the manuscript.

We would like to thank you for the detailed review and constructive criticism that helped us to improve the manuscript. Our responses below (in blue) show how we considered your comments in the revised manuscript.

General comments

Abstract This section should be rewrite. Please find some suggestions below: First: Writing about the GAP found in the literature. Second: Make your study objectives clear and straightforward. What exactly you set out to achieve and why. E.g. The objective of the study was, Here we assessed, The objective of the investigation was, This study evaluated..... Third: Write short phrases about the data and methodology used in the study. Fourth: You should show just the main findings of the study, i.e. findings that will support the study’s conclusion. Fifth. Conclusion: The most important section. What is the study’s contribution for the literature? You should point out the implications for the science here.

We thank the reviewer for the detailed suggestions. We rewrote the abstract (below) following those suggestions and, additionally, the HESS guidelines, which request possible directions for prospective research.

“Understanding the environmental impacts of land-use change on landscape hydrological dynamics is one of the main challenges in the Northern Brazilian Cerrado biome. This is the location of the Amazon agricultural frontier, where most of the conversion of cerrado vegetation to agricultural land has occurred. Motivated by the vast gap in the literature concerning these changes, our principal objective is to quantify the predominant hydrological responses of the main land-use types of the Brazilian Cerrado, with focus on the water balance components (i.e. streamflow and evapotranspiration) and the soil hydro-physical properties. We used experimental data from field measurements in three first-order micro-catchments (< 1 km^2). These catchments were selected on the basis of their predominant land use: cerrado sensu stricto vegetation, pasture for extensive cattle ranching, and cropland (soybean-maize rotation) with no-till treatment. We monitored precipitation, streamflow, soil moisture, and meteorological variables from October 2012 to September 2014. We also determined the hydraulic and physical properties of the soils, conducted topographic surveys to develop high-resolution digital elevation models, and applied remote sensing techniques to estimate evapotranspiration. We used these data to quantify the water balance components of the study catchments and to relate these water fluxes to land use, catchment physiographic parameters, and soil properties. Our results show runoff coefficients of 0.27, 0.40, and 0.16 for the cerrado, pasture, and cropland catchments, respectively. Baseflow plays a major role in streamflow generation, with a baseflow index of more than 0.95 in all three study catchments. We found that evapotranspiration is smallest in the pasture (597 mm yr^{-1}) compared to the cropland (808 mm yr^{-1}) and the cerrado catchments (1017 mm yr^{-1}). Compared to the cerrado catchment, the pasture catchment exhibited greater discharge (55%) while the discharge in the cropland catchment was smaller (57%). The cerrado and the pasture catchments have similar climatic, soil, and topographic characteristics, therefore we attribute the observed hydrological differences to their distinct land-use. Our results also show significant differences in soil hydro-physical properties between the cerrado and pasture catchments, and between the preserved riparian vegetation areas and the areas with converted land-cover of the pasture and cropland catchments. This suggests the deterioration of soil properties due to land-use conversion and management in the disturbed land-cover areas, as indicated by the greater bulk density and smaller total porosity. We recommend further research to understand the subsurface water movement in order to quantify the role of groundwater fluxes on streamflow and recharge, and the influence of the gallery forests on the hydrological processes in the Brazilian Cerrado."

High and Low. Overused and misused when large or great and small are more appropriate. High and low are in essence, degrees of elevation. Please change these words through the text.

We thank the reviewer's suggestion. We reviewed the text and replaced these words as suggested in the following locations: P9916L20-23, P9922L19, P9929L13, P9930L11, P9930L14, P9931L9, P9931L12, P9931L14, P9932L4-6, P9932L14-15, P9932L17, P9933L2, P9933L13, P933L16, P9933L22, P9934L6, P9934L10, P9934L12-13, P9934L15, P9934L19-20, P9935L6, P9935L8, P9935L11, P9935L12, P9935L17-18, P9935L24, P9935L26, P9936L3, P9936L7, P9936L10, P9937L13, P9937L14, and P9937L19.

You should avoid using unnecessary words through the text. Be clear and straightforward. Some examples: P9916L5. "This study uses empirical data from field measurements" = We used experimental data; P9916L15. "The results of this study show" = Our results show

We changed: P9916L7 to "We used experimental data …" and P9916L15 to "Our studies show runoff coefficients of ...". Additionally we changed P9916L19 to "Our results also…", P9939L18 to "Our studies do not… ", and P9940L23 to "Although our results… ".

Why do the authors use a constant Kc=1 for the cerrado? What are the uncertainty in this approach? The approach used to compute ET can works well to croplands and pasture; however, I'm not sure to use it for the undisturbed cerrado. The authors also can compute ET using other approaches such as by remote sensing data (see Mu et al., 2011; da Silva et al., 2014; Oliveira et al., 2015). I also suggest computing the uncertainty in the ET estimation.

As there are several uncertainties in all computed water balance components I suggest inserting an uncertainty analysis section in this study.

We used the K_c=1 based on Lima (2001), as mentioned in Table 1, who stated that in this vegetation the plants are in a balance between their growth and senescence, therefore the K_c should be constant and adopted as 1 when associated to the water stress coefficients.

We agree with the reviewer that the approach used to compute E_T is acceptable for croplands; therefore, we kept the E_T method associated to the crop and water stress coefficients due to the well-known parameters for its ET estimation. However, we understand that we should improve our methodology to reduce the associated uncertainty as much as possible for the undisturbed cerrado.

The use of remote sensing techniques in our study region and especially at the scale of our catchments is not a trivial task. Sano et al. (2007) showed that there are several limitations in the transitional between Cerrado and Amazon rainforest, where our area of study is located, to obtain cloud-free satellite images mainly during the wet season. Moreover, the use of remote sensing at our scale (< 1 km^2) is restricted to the use of some satellites, such as MODIS at 250 m resolution (Bands 1 and 2). Additionally, the nearest reference flux tower integrated into the MODIS Land Product Subsets is located in the Amazon biome, which is ca. 450 km from our study sites and therefore its data could not be used.

Considering the reviewer's suggestions, we have used satellite-based image-processing models to improve our E_T estimation for the gallery forests, pasture and cerrado areas. We used the Surface Energy Balance Algorithm for Land (SEBAL) and Mapping EvapoTranspiration at high Resolution with Internalized Calibration (METRIC) (Allen et al. 2011) for TM-Landsat 7 images, which offer imagery covering our entire study period at 30 m resolution with 13 satellite scenes. Unfortunately, this satellite has a problem, known as the off-SLC (http://landsat.usgs.gov/products_slcoffbackground.php), which restricted the use of some pixels for the ET estimation. Da Silva et al. (2015) applied this method for ET estimation using five Landsat 5 images for a period of 1 year. The manuscript now includes an overview of this methodology and the new E_T estimations. We below briefly describe the method and show in Tables 5 and 7, and Fig. 12 of the manuscript with the respective changes due the new ET estimation.

Due to the sparse temporal scale (from 16 days to nearly 5 months) of appropriate images for this use, we estimated the K_c using the E_T fraction (ETrF) of the SEBAL/METRIC algorithm, which is the same as the crop coefficient K_c (Allen et al., 2011). According to Paço et al. (2014) the use of the crop coefficient based on the METRIC model allows to directly integrate a variety of factors, such as orchard architecture, land use practices and water stress occurrence. Therefore, this method reduces the uncertainty associated to the estimation of the parameters for crop and the water stress coefficients.

The ETrF is calculated as the ratio of the instantaneous E_T (ET_{inst}) from each pixel to the reference E_T (ET_r) computed from the weather data at the time of the image acquisition (Allen et al., 2011). We computed the K_c as the mean of the obtained values for the wet and dry seasons (table below), considering the pixels within the catchment domain.

Table. Kc estimations.

Landsat 7 scene identifiers	**Date**	**Season**	**Kc estimation by using SEBAL/METRIC method**				
			Gallery Forest Cerrado	**Gallery Forest Pasture**	**Gallery Forest Cropland**	**Cerrado**	**Pasture**
LE72260712012283CUB00	09-10-12	Wet	1.15	1.32	0.79	0.98	0.82
LE72260712013061CUB00	02-03-13	Wet	1.29	1.14	-	0.9877	0.68
LE72260712013189CUB00	08-07-13	Dry	0.65	0.68	0.52	0.5388	0.16
LE72260712013253CUB00	10-09-13	Dry	0.65	0.75	0.58	0.39	0.2
LE72260712013269COA00	26-09-13	Dry	0.86	0.79	-	0.5262	0.19
LE72260712013317CUB00	13-11-13	Wet	1.16	1.23	0.986	0.798	-
LE72260712013333CUB00	29-11-13	Wet	-	-	-	1.09	0.54
LE72260712014032CUB00	01-02-14	Wet	-	-	-	1.24	0.545
LE72260712014096CUB00	06-04-14	Wet	1.18	0.97	0.94	0.99	0.62
LE72260712014176CUB00	25-06-14	Dry	1.24	0.99	-	1.01	0.48
LE72260712014192CUB00	11-07-14	Dry	1.28	1.18	1.17	1.03	0.47
LE72260712014224CUB00	12-08-14	Dry	0.94	0.8	0.79	0.704	0.31
LE72260712014256CUB00	13-09-14	Dry	0.88	0.88	0.61	0.63	0.32
Mean for wet season			1.20	1.17	0.91	1.01	0.64
Mean for the dry season			0.93	0.87	0.73	0.69	0.30

Table 5. Area-weighted evapotranspiration in the three micro-catchments and respective totals.

	Cerrado E_T (mm)			Pasture E_T (mm)			Cropland E_T (mm)		
Hydrological Year	Gallery Forest	PLU area	Total Area	Gallery Forest	PLU area	Total	Gallery Forest	PLU area	Total
2012–2013	~~72~~81	~~907~~952	~~979~~1033	~~66~~79	~~449~~534	~~515~~613	~~108~~86	746	~~854~~832
2013–2014	~~67~~105	~~926~~895	~~993~~1000	~~65~~74	~~484~~507	~~549~~581	~~100~~81	703	~~803~~784
Total E_T	~~139~~156	~~1833~~1847	~~1972~~2003	~~131~~153	~~933~~1041	~~1064~~1194	~~208~~167	1449	~~1657~~1616

Table 7. Annual and total water balance for the study catchments.

	Rainfall (P, mm)			Discharge (Q, mm)			Evapotranspiration (E_T, mm)			Recharge and change in storage (dS/dt, mm)		
	2012–2013	2013–2014	Total	2012–2013	2013–2014	Total	2012–2013	2013–2014	Total	2012–2013	2013–2014	Total
Cerrado	1543	1848	3391	453	461	914	~~979~~1033	~~993~~1000	~~1972~~2033	~~111~~57	~~394~~387	~~505~~444
Pasture	1595	1964	3559	724	692	1416	~~515~~613	~~549~~581	~~1064~~1194	~~356~~258	~~723~~691	~~1079~~949
Cropland	1653	1685	3338	273	252	525	~~854~~832	~~803~~784	~~1657~~1616	~~526~~548	~~630~~649	~~1156~~1197

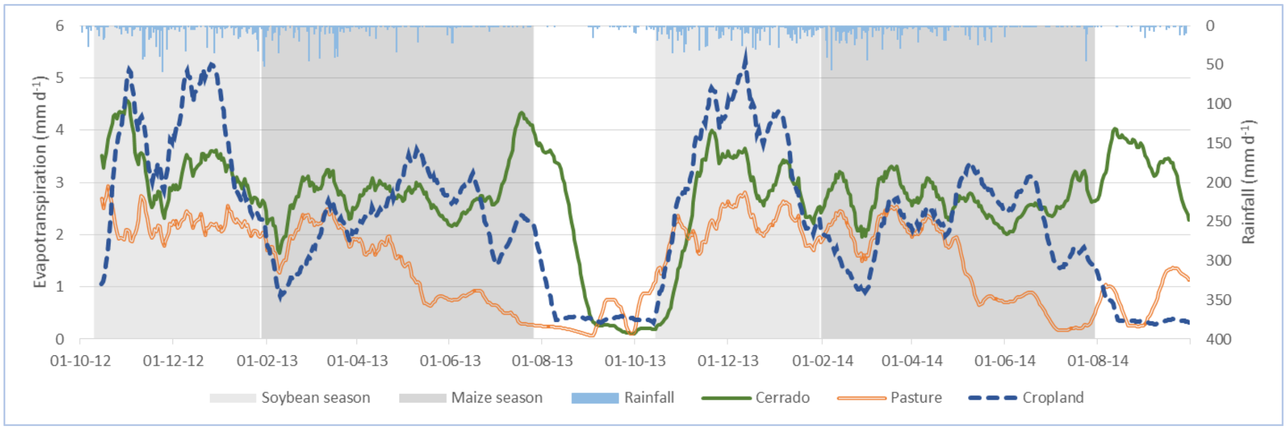

Figure 12. 15-day moving average for evapotranspiration and daily areal average rainfall for the three micro-catchments.

The studied catchments have different characteristics (e.g. soil type, texture, slope steepness, drainage morphometry...) that should be better investigated and discussed.

We made changes in the manuscript based on all referees' comments concerning this topic to address the differences between the catchments in terms of land-use background and also in the discussion section. The changes are pointed out through our responses to reviewer #1 (P9922L12).

Conclusion section should be rewrite. I suggest starting with a brief summary about the study, then paragraphs with general and main conclusion.

We thank the reviewer for the suggestion. Based on it, we rewrote the conclusion section (below).

"We investigated the hydrological responses of three micro-catchments with contrasting land uses in the Brazilian Cerrado biome. The selected cerrado and pasture catchments are adjacent and have similar physiographic properties and rainfall patterns whereas the cropland catchment, located 6 km away, exhibits different topographic and soil types. All three catchments have well-defined gallery forests along the streams. Hydrological and meteorological data were collected in each catchment from 2012 to 2014.

We found significant differences in the soil properties between the cerrado and pasture catchments, and between the PLU and gallery forest areas within these two catchments. We ascribe these findings to the deterioration of the soil properties due to land-use conversion and management, as indicated by the greater bulk density and smaller total porosity in the disturbed land-cover areas.

Our results show that baseflow is a major driver of streamflow in all catchments, with the highest BF:P ratio observed in the pasture catchment. Runoff ratios obtained from this study show a minimal contribution – less than 1% – of direct flow to stream discharge, which we attribute mostly to the high K_{sat} values found in the catchments.

Evapotranspiration estimated using the Penman–Monteith method associated with satellite-based image-processing models (SEBAL and METRIC) showed that the cerrado catchment exhibited greater ET than the other two catchments. The pasture catchment exhibited smaller ET (59%) and greater discharge (55%) than the cerrado catchment. In comparison to the cerrado and pasture catchments, the cropland catchment exhibited markedly smaller discharge (57%) than the cerrado catchment, which is opposed to the widely observed results from other studies showing greater cropland runoff compared to natural vegetation. While we acknowledge the need for further studies to understand groundwater fluxes in these catchments, we attributed this finding in the cropland catchment to the no-till farming practices, the generally flat topography, and the greater clay content in this catchment, promoting greater soil water storage capacities."

Specific comments:

P9916L5. Why is Amazon here? It is not necessary.

Our study area is located in the Legal Amazon (the nine Brazilian states that contribute land area to the Amazon Basin) and also in the Amazon agricultural frontier, known as the arc of deforestation (Durieux, 2003; Costa et al., 2010; Do Vale et al., 2015). As we do not mention it in other parts such as the title, we believed that it is important to present this information in the abstract to better distinguish our study area from other parts of the Cerrado biome. Taken this into account, we also updated Fig. 1 to show where our area of study is located in relation to the deforestation areas of the Legal Amazon.

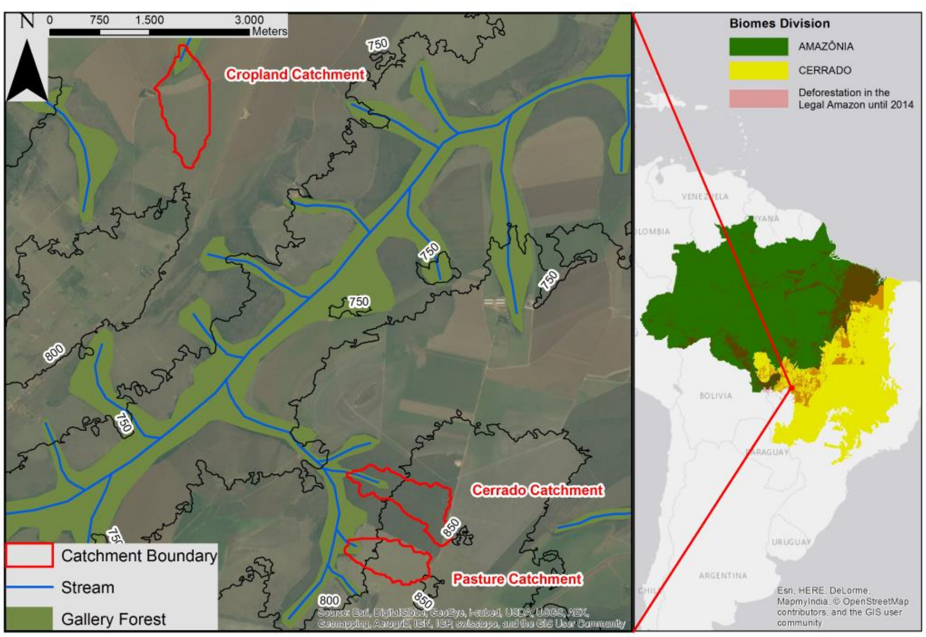

Figure 1. Cerrado, pasture, and cropland micro-catchment locations.

P9916L10."native cerrado vegetation". Make clear that the cerrado physiognomy studied was the "cerrado sensu stricto".

We added this information as “cerrado sensu stricto vegetation”.

P9916L10. Rewrite as: pasture for extensive cattle ranching

We rewrote it as suggested.

P9916L10. Rewrite as: cropland (corn-soybean rotation)

We wrote it as “cropland (soybean-maize rotation)”.

P9916L12. Exclude "Additionally". We also determined...

We changed it as suggested.

P9916L18. Rewrite as: Baseflow plays a significant

We rewrote it as suggested.

P9916L20. Rewrite as: evapotranspiration in the cerrado (986 mmyr-1) was greater than that found for the cropland (828 mmyr-1) and pasture (532 mmyr-1)

We rewrote it as suggested.

P9916L25. no-till ?

Yes. We corrected it.

P9916L24-27. The authors did not show these differences. How many soil types are there? Average slope steepness for each catchment?? croplands? / rotation? / soil tillage? The readers know nothing about it so far.

We show the differences between the catchments on P9921L23–28 and P9922L1–11, and now in Table 1 as suggested. For the specific part that the reviewer refers to (abstract), we included the rotation and soil management for the cropland catchment.

P9916L26-30. Why was the main conclusion about riparian gallery forests?

We removed this conclusion.

P9916L27-31. Exclude. It is not a adequate conclusion. Please, point out the implications for the science here.

We excluded this sentence and changed it according to the reviewer suggestions. The text with changes is shown in the first general comment.

P9917L6. Rewrite as: "underrepresented in the literature"

We rewrote it as suggested.

P9917L24-26. What of these cited papers reported that 80% of the native Cerrado vegetation has been converted in farmlands? Beuchle et al (2015) reported values of nearly 50%. Please, check it!!

We thank the reviewer for the observation. We rewrote this sentence as: "Approximately 50% of the original 2 million km² of the Cerrado biome has been converted to agricultural lands (Klink and Machado, 2005; Sano et al., 2008; Beuchle et al., 2015), compromising ca. 80% of the primary cerrado vegetation (Myers et al., 2000). Studies show that the conversion of the cerrado vegetation will continue to be a dominant process of land-use change in Brazil due to a lack of a routinized deforestation surveillance programs in this biome (Lapola et al., 2011; 2013)."

P9918L10. Rewrite as: "Cerrado conversion into farmlands"

We rewrote it as suggested.

P9919L26-28.The objective of the study is very confuse. Rewrite!!! Make your study objectives clear and straightforward. What exactly you set out to achieve and why.

We rewrote the sentence on P9919L26–28 and united it with the sentence on P9920L8–12 as a paragraph: "The objective of our study is to quantify water balance components and to contribute to the understanding of hydrological controls at catchment scale in the Brazilian Cerrado, located along the Amazonian agricultural frontier. This study focuses on three micro-catchments under contrasting land uses: cerrado sensu stricto, grass pasture for cattle ranching, and cropland (soybean-maize rotation). In the pasture and cropland catchments, the original cerrado vegetation has been removed for intensive cattle and cash crop farming in the 1980s."

We also rewrote the PP9920L19–24:

"Through this study, we aim to quantify the principal hydrological responses for the three main land-use types of the Brazilian Cerrado and answer the following questions:

i. How do the soil hydro-physical properties differ within and between the catchments?
ii. How are those differences related to the hydrological responses?
iii. Do the catchments show significant hydrological differences to each other, especially with regard to streamflow and evapotranspiration?"

We consecutively also changed the titles of sections 4.1 (P9935L15) to: "Soil hydro-physical characteristics" and section 4.2 (P9937L1) to: "Catchment hydrological responses".

P9919L28-33. Here the authors try to justify the study; however, it is better to do it before the objective.

We moved it to before the objectives, after P9919L25, as suggested.

P9920L5-8. Exclude. Unnecessary text. "The results presented in this paper are part of a collaborative research project (www.carbiocial.de) that aims to investigate viable carbon-optimized land management strategies for maintaining ecosystem services under changing land use and climate conditions in the Southern Amazon." If the authors need to cite some grant project, please make it in the Acknowledgements section.

We thank the reviewer for this observation. We removed this text from the manuscript.

P9920L9-10. Rewrite as: grass pasture for cattle, and cropland (corn-soybean rotation).

We rewrote it as: "… grass pasture for cattle, and cropland (soybean-maize rotation)".

P9920L13. Rewrite as: the undisturbed cerrado to pasture and cropland

We rewrote it as suggested.

P9920L15. "increase"

We kept the word as it was ("increased") because this word is used here as an adjective modifying the noun streamflow ("increased streamflow").

P9920L16. "increase" groundwater recharge

We removed the fragment "and groundwater recharge."

P9920L21. Does the cerrado...

We changed it as suggested.

P9920L3-28. Remove. There are several general information about the entire biome. Please, insert more details about the study areas.

We believe you meant the P9921L3–12. We removed some irrelevant general information (P9921L4–5 and P9921L23–25), and kept the remaining sentences because we believe that this general information is important as background information from the region. After P9921L12 there is no more general information about the entire biome, however more detailed information about the study sites.

P9921L9-10. "with a minimum depth of 3 m from the ground surface". This is a misleading information. For example, Villalobos-Vega et al. (2014) studied ten monitoring wells with water tables ranging from 0.18 to 15.56 m in an undisturbed cerrado. Check it!!

This is a general information about the entire biome, as observed in the previous comment. We agree that this could be misleading information therefore we excluded it.

We would like to point out that the smallest table values by Villalobos-Vegas et al. (2014) were observed close to the riparian zone (for example: well number 5, Fig. 3.1, p. 64, Villalobos-Vegas, 2010). Although the groundwater levels in the riparian zones could be used to estimate the water table change, these levels are affected by a set of variables, such as the movement of groundwater from upslope and interactions with the vegetation and stream itself (Simpson et al., 2013; Gu et al., 2008).

P9921L9-13." To reduce the effects of spatial variability". What is it means?

We meant to minimize the effects of location in space of factors such as land cover, soil properties, and rainfall. However, we believe that this information is implicit and therefore we removed it.

P9921L9-19. December through March...... March through September

We changed it to "The wet season extents from October through April, and the dry season from May through September." Due to this change we modified the P9927L2–3 from "During the rainy season from October to April, the weirs …" to "During the wet season the weirs …".

P9921-22. I suggest inserting all this into a well organized Table (location, area, land cover, soil type, texture, slope steepness....). Right now it's scattered around in the prose, and a struggle to get much from it.

To summarize the main catchment's characteristics and avoid repetition of information through other tables we added the coordinates, land cover, soil type, and texture to Table 2 as shown below:

Table 2. ~~Topographic~~ Main physical and topographic characteristics of the three micro-catchments.

	Cerrado			Pasture			Cropland		
	Gallery Forest	PLU Area	Total Area	Gallery Forest	PLU Area	Total Area	Gallery Forest	PLU Area	Total Area
Coordinates	15.797° S, 55.332° W			15.805° S, 55.336° W			15.743° S, 55.363° W		
Area (km²)	0.0496	0.7284	0.7780	0.0379	0.5461	0.5840	0.0824	0.8496	0.9320
	(6.4%)	(93.6%)	(100%)	(6.5%)	(93.5%)	(100%)	(8.8%)	(91.2%)	(100%)
Predominant land cover	Cerrado sensu stricto vegetation			Grassland			Agricultural crops (soybean-maize rotation)		
Soil type	Arenosols			Arenosols			Ferralsols		
Soil texture	Sandy loam			Sandy loam			Clay loam		
Average Elevation (m)	770.1	813.9	811.1	775.3	820.8	817.8	775.3	788.4	787.2
Average slope (%)	13.3	8.1	8.4	6.8	7.7	7.7	4.9	2.4	2.8

P9923L1-2. Which data gaps? Be more specific!

The data gaps are related to the streamflow and soil moisture time series. Considering this, we removed this sentence from P9923L1–2 and rewrote the P9933L21–22 to: "The normalized discharge values are shown in the Fig. 13. Due to equipment failure, this time series includes some data gaps." and added the following sentence to P9932L12: "The cerrado and pasture catchments show a data gap in the first months due to logistic difficulties."

P9923L15. Rewrite as: Hydrometeorological Data

We rewrote it as suggested.

P9923L16. Rewrite as: "...we used three tipping bucket rain gauges..."

We rewrote it as "… in each catchment we used three tipping bucket rain gauges with data loggers …".

P9923L22-23. " by using the Penman–Monteith equation (Allen et al., 1998)"

We changed it as suggested.

P9924-L7-25. I suggest inserting all necessary data to compute ET, Ks, TAW, and Dr,I into a well organized Table.

These data was already inserted in the Table 1. This table is now updated including the new K_c estimation as shown below:

Table 1. Parameters used for the canopy interception and E_T estimations, and wilting point results.

	Gallery forest areas			PLU areas									
	Cerrado	Pasture	Cropland	Cerrado	Pasture	Cropland							
						Soybean				Maize			
						Initial	Devel.	Mid	Late	Initial	Devel.	Mid	Late
K_c	1.2 (WS) 0.9 (DS)	1.2 (WS) 0.9 (DS)	0.9 (WS) 0.7 (DS)	1.0 (WS) 0.7 (DS)	0.6 (WS) 0.3 (DS)	0.6	1.2	1.5	0.9	0.4	0.8	1.2	0.9
Crop development stages (days)		NN		NN	NN	10	35	35	30	30	50	60	40
LAI		3.3		1.1 (WS) 0.7 (DS)	1.2	0.1	2.7	6.0	4.0	1.0	3.5	3.5	1.5
Soil water depletion fraction (p)		NN		NN	NN	0.5	0.5	0.6	0.9	0.5	0.5	0.5	0.8
Max. root depth (m)		NN		NN	NN	1.4				1.2			
θ_{WP} (%)	3.26 ± 1.11 n = 2	2.12 ± 0.50 n = 8	17.91 ± 0.78 n = 5	2.52 ± 1.48 n = 24	2.02 ± 0.42 n = 41	16.65 ± 2.70 n = 46							
References	K_c (SEBAL/METRIC method), LAI (Paiva, 2008).			K_c (SEBAL/METRIC method), LAI (Hoffmann et al., 2005).	K_c (SEBAL/METRIC method), LAI (Almeida, 2012).	K_c (Farias et al., 2001), LAI (Souza et al., 2009), p (FAO, 2015a), root depth (Torrion et al., 2012).				K_c (Guimarães and Albuquerque, 2004), LAI (Braz et al., 2005), p (FAO, 2015b), root depth (Manfron et al., 2003).			

WS = Wet season, DS = Dry season, NN = Not needed for the related estimations.

P9924-L18. Dr,i is a function of root depth. What is the main implication to use this approach considering that the authors have monitored soil moisture in a soil profile < 2 m? The root zone in the cerrado is usually deep (more than 10 m in depth) (see Oliveira et al., 2005)

We used Total Available Water (TAW) as a function of the root depth, which, in association with the Dr,I, was used to estimate the water stress coefficient (K_s). The cerrado vegetation, in contrast to monoculture crops, includes species with different ranges of root depths, therefore we initially used an average root depth value based on the existing literature. The new E_T estimation based on remote sensing techniques eliminates the need of maintaining the aforementioned approach to the cerrado catchment and eliminates its associated uncertainties.

P9924-L7-25. Why do the authors use a constant Kc=1 for the cerrado? Where did you get it? What are the uncertainty in this approach? The approach used to compute ET can works well to croplands and pasture; however, I'm not sure to use it for the undisturbed cerrado. The authors can compute ET using other approaches such as using remote sensing (see Mu et al., 2011; da Silva et al., 2014; Oliveira et al., 2015). I also suggest computing the uncertainty in the ET estimation.

We thank the reviewer for these observations. We responded to these same questions in the general comments.

P9925-L1. "the water table is more than 1m" Rewrite as: "the water table is deeper than 1m'

We rewrote it as suggested.

P9925-L6-180. I did not understand this sentence. It will be good considering rewrite to make the point clearer.

Due to the new K_c estimation we removed the sentences within P9925L6–8.

P9925-L11. How was LAI obtained? Data source?

We show the data source (references) of the LAI values in the Table 1.

P9926-L6. wilting point?

The wilting point water content in each study area was obtained using the pedotransfer function determined by Nunes et al. (2015) (P9924L24–26). Now we added the values to Table 1 determined using additional soil analyses.

P9926-L16-17. Significance level?

We used a significance level of 1%. We added this information to the text on P9926L16–17.

P9926-L18-25. How long was soil moisture monitored? What was the temporal resolution to get samples? Is the 140 cm enough to study soil moisture in the cerrado?

During the study period, soil moisture was monitored on a fortnightly basis (P9926L20). The monitored depth is enough to observe the dynamics of the soil moisture in the root zone of the cropland and pasture vegetation, however not enough to estimate the total soil water storage change in the cerrado catchment. Nevertheless, this data is important to improve the understanding of superficial hydrological processes and soil hydro-physical properties in the topsoil.

P9928-L13-19. What was the temporal resolution? Daily, Monthly or Annual. As there are several uncertainties in all computed water balance components I suggest inserting an uncertainty analysis section in this study.

We thank the reviewer for the concern. In this study section, we describe hydrological indices (R_C, R_R and BFI) that are computed using the accumulated discharge volumes. The temporal resolution used to compute the flow duration curves and the flashiness indices is daily. We included this information on P9928L8–11 associating this with the changes suggested by the Editor in this section. Additionally, the temporal resolution for the respective results is shown in Table 6, and Fig. 13 and 14.

We believe that our continuously monitored discharge data is reliable to quantify the discharge in each catchment. The very small flashiness indices found in all three catchments strongly suggests that the use of the mean discharge for the wet and dry seasons is representative. Additionally, we also believe that our efforts to improve the E_T estimation in this study reduce the need for uncertainty analysis of the water balance components.

P9929-L7. Topographic Wetness Indices (TWI)

This abbreviation was previously defined on P9923L14.

P9929-L25. In the catchment under pasture the total rainfall was ~200 mm greater than the other catchments. Catchment under cerrado and pasture are separated from each other by 1 km, So, how can explain this difference? Data gaps? Do the authors have used the same rain gauge model? or Is it common in this region?

We used the same rain gauge model and used three rain gauges in each catchment (P9923L16–18). Due to this observation, we changed the sentence on P9930L5–8 to: "The low correlation of daily rainfall between the cropland and the other two adjoined micro-catchments shows the regionally typical high spatial variability of the rainfall in this region of South America (Lenters and Cook, 1999; Jones and Carvalho, 2002; Carvalho et al., 2002; Lincoln et al., 2005; Vera et al., 2006; Santos et al., 2015)."

P9930-L18. I suggest applying a statistical test to evaluate whether these results are significantly different.

We applied the Kruskal-Wallis test to compare the data from the three catchments due the non-normality of the samples. We changed the P9930L18 to: "Figure 8 shows that the micro-catchments are characterized by similar rainfall intensity patterns ($p \approx 0.658$, Kruskal-Wallis test)."

P9931-L10. Predominant Land Use (PLU)

This abbreviation was previously defined on P9929L8.

P9931-L10. "same bulk densities". "substantially lower". I suggest applying a statistical test to evaluate whether these results are significantly different.

We applied the tests, added the p-values (P9931L9;L10;L12;L14), and rewrote the P9926L16–17 to describe it as follows: "We used Pearson's correlation analysis for inter-comparison of the obtained soil properties and a two-sample t-test with a significance level of 1% to detect differences in the mean of the soil properties."

P9931-L12. Runoff coefficients nearly 0.5 are not so small to farmland. It will be good discussing it citing other papers.

We believe the reviewer meant P9934. We thank you for the observation. Considering the suggestion, we changed the P9934L12–15 to: "We found R_Cs of 0.27, 0.40, and 0.16 for the cerrado, pasture and cropland catchments, respectively. Although R_C values are scarce in the literature for cerrado vegetation at catchment scale, our results are consistent with the available studies. Dias et al. (2015) found R_C of 0.25 a cerrado catchment and 0.58 for a pasture catchment using a model based on water balance equations. Observed literature data shows R_C of 0.38 for a pasture catchment (Tomasella et al., 2009) and R_C ranging from 0.10 to 0.76 for six cropland catchments (soybean) under no-till planting system (Dias et al., 2015)."

P9935-L10. "annual water balance"

We changed it as suggested.

P9935-L17-21. How depth? I did not understand this sentence. It will be good considering rewrite to make the point clearer.

We wrote the sentences on P9935L16–21 as: "Although the cerrado and pasture catchments have the same soil type and similar topographic characteristics, the pasture catchment showed significant greater bulk densities in the PLU areas at 0–40 cm depth ($p < 0.0001$). Our results confirms results from Valpassos et al. (2001), who reported greater bulk densities in the topsoil of a pasture compared to an area covered by cerrado vegetation. We attribute this to the compaction caused by cattle ranching and machinery use in the pasture catchment, and to the coarser roots in the cerrado catchment."

P9939-L9-251. The studied catchments have different characteristics that need to be better investigated and discussed.

We thank the reviewer for the observation. Our response to this point is in the general comments, where this suggestion was addressed.

P9940-L9-27 - P9941-L1-13. Conclusion section should be rewrite. I suggest starting with a brief summary about the study, then paragraphs with general and main conclusion. What is the study's contribution for the literature? You should point out the implications for the science here.

We thank the reviewer for the suggestion. We addressed these suggestions and respective changes in the conclusion in the reviewer's general comments.

Tables and Figures:

Table 2 and 5. PLU?? Tables and Figures should be self-explanatory... Table 6. RC?

PLU is defined on P9929L8 and R_C on P9928L4. We formatted "R_C" with subscript in the Table 6.

BFI? BF:P? Again, Tables and Figures should be self-explanatory. Figure 3 and 5. Join these Figures.

According to the HESS manuscript preparation guidelines for authors "The abbreviations used in the figure must be defined, unless they are common abbreviations or have already been defined in the text." In this case BFI is defined on P9928L6, and BF:P on P9934L17.

Concerning the tables, the guidelines are not as clear as they are for figures. We used the papers in HESS "Highlight articles" website section as a reference and applied the observed formats to our tables.

We joined Fig. 3 and 5 as suggested:

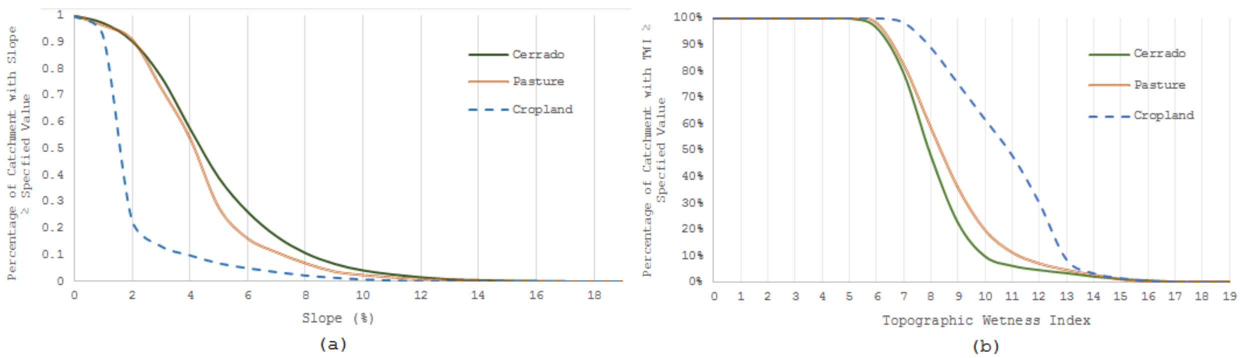

Figure 3. Cumulative (a) slope and (b) TWI distributions for the three catchments.

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RESPONSES TO RC-C4359 [C. Stamm (Editor)]

Interactive comment on "Identifying hydrological responses of micro-catchments under contrasting land use in the Brazilian Cerrado" by R. L. B. Nobrega et al. C. Stamm (Editor) christian.stamm@eawag.ch Received and published: 22 October 2015 HESSD-Manuscript "Identifying hydrological responses of micro-catchments under contrasting land use in the Brazilian Cerrado". In addition to what has been already commented by referees, I would like to add some remarks as editor handling this manuscript. There is one main issue I would like to point out first. Subsequently, I list a few minor aspects.

We would like to thank Dr. Stamm for the helpful and constructive comments, and for being responsive in the review process. Our responses (in blue) are addressed below.

Understanding baseflow generation: As clearly demonstrated in the manuscript, baseflow is the dominant flow component. W. Dawes has already pointed out that the manuscript puts too much emphasis on (local) soil physical properties for explaining the observed hydrological differences between the catchments. Information on properties and the (soil moisture) state in deeper parts of the underground is lacking. However, it is well-known that the lower boundary plays a crucial role in how a catchments responds hydrologically (see for example Boorman et al., 1995).

In this context, it is important to also consider the question about the actual catchment boundaries, which are relevant for the measured stream flow. Given the flat topography (quite pronounced for the cropped catchment) and the rather short stretch of open water course in each catchment (see Fig. 1), one has to ask where the water infiltrating into the soil will ultimately flow to. Surface topography is not necessarily a good proxy for delineating the subsurface catchment boundaries nor is it evident that all water should reach the stream network upstream of the measuring station. It might well be that the streams just intercept the most shallow parts of the groundwater flux and the remaining water that is not accounted for in the water balance leaves the catchments as deeper groundwater. How much discharge is measured may hence simply reflect the local conditions that determine how much groundwater is taped by the stream channel. Therefore, unless there are actual measurements in the saturated zone (like piezometric data on water table depths and gradients) that show where the water is flowing and what the dynamics are, the hydrology of these catchments cannot be reasonably understood. The authors have drawn similar conclusions (see e.g. p. 9938, L. 25 - 27), but I think it needs to be emphasized more throughout the manuscript.

We thank the Editor for the insightful comments. Although studies have found that some groundwater flow systems could be in some cases topographically controlled and nested (Winter et al., 2003; Gleeson and Manning, 2008), we do agree with the Editor that some of the infiltrated water leaves the catchment without being measured in the stream discharge at our monitoring point.

The effect of the groundwater flow to headwater streams has mainly been studied in the temperate zone (Uhlenbrook et al., 2004; Winter, 2007). In the humid tropics modern flow-partitioning techniques, such as isotopic tracing, were more feasible to be applied in the humid tropics mostly in the past decade, especially for hydrological analysis in the context of the land-use change (Buttle and McDonnell, 2005). Moreover, the groundwater flow presents further complexity due to the overlap of different groundwater flow systems and the movement of the groundwater boundary in response to the dynamic recharge and discharge conditions (Winter et al., 2003).

We would like to clarify that it was neither our assumption nor assertion that the delineated catchment boundaries confine the groundwater flow. However, due to the major role of topography in hydrological processes (Moore et al., 1991; Callow et al., 2007; Price, 2011), we relied on our relief data to address the research questions. To explain our point of view more clearly and taking the Editor comments into account, we replaced the paragraph on P9938L22–27 with the following text:

"Our dS/dt results, averaging ca. 25% of the total precipitation, suggests that besides the change in the storage, there very likely also exists groundwater loss from the catchments. The *das Mortes* catchment, where our micro-catchments are located, is dominated by flat relief (Guzha et al., 2013) with permeable substrate, causing water to percolate freely to the deep aquifer. This area is underlain by geological structure of cretaceous sandstone (Parana Mesozoic and Paleozonic groundwater province) supporting an aquifer averaging 200 m in thickness in the *das Mortes* catchment (Schneider, 1962), where no deep wells for groundwater monitoring exist in the *das Mortes* catchment (Diniz et al., 2014). It seems plausible, that the deep groundwater recharge in the micro-catchments is not reaching the weir station and is therefore a part of the dS/dt. Surface- and groundwater boundaries frequently do not coincide (Winter et al., 2003) and the assumption that the water table in unconfined aquifers is a subdued replica of the topography has been found to be an error in some cases (Haitjema and Mitchell-Bruker, 2005). Verry (2003) also found that the groundwater losses averaged 45% of the export of water via streamflow after analyzing the data from 32 watersheds in different parts of the world. Therefore, we encourage further studies to investigate groundwater flow mechanisms, such as the deep seepage, in the Brazilian Cerrado."

In addition to an improved data basis on the compartment that governs the hydrology in these catchments (the deeper subsurface), a more detailed analysis of the available time-series could yield valuable insight. As mentioned already in the first review, the application of a simple water-balance model could be a useful step to learn from the observed discharge dynamics. The pasture catchments for example, reveals quite a strange behavior during the dry period: There a kind of a constant flow level while the other catchments show an expected decrease over time. However, for analyzing the data in such a way one needs to explicitly deal with the pronounced data gaps in the data series. Unfortunately, this issue is not discussed at all in the current manuscript.

We agree that a more detailed analysis of the time-series based on water-balance models will be beneficial for our statements. However, we believe that the suggestion to use a simple water-balance model would reduce the chance of taking into account the heterogeneity and complexity of tropical ecosystems such as the cerrado vegetation. Models, such as SIMHYD or MODHY-DROLOG, regularly used for ungauged catchments, are prone to simplified parametrization and underuse the detailed available data, such as topography and soil characteristics. We currently aim to support the hydrologic modelling community with our field-based observations in this poorly understood region (Lamparter et al., submitted).

We performed no data manipulation or gap filling for the data series in this manuscript, as we believe that the obtained actual data represents well the catchment hydrologic trends. For the water balance, the total discharge was estimated as the average of the wet and dry season to reduce the effect of data gaps. We added this information after P9927L22, and as mentioned in the response to reviewer #2, we also added additional information concerning the existing data gaps.

We thank the observation concerning the pasture low flows. We changed the sentence on P9934L19 to: "The flashiness indices are generally small, particularly for the pasture catchment with indices as low as 0.05; this catchment shows the smaller streamflow decrease (27%) from the wet to the dry season compared to the cerrado (40%) and cropland (56%) catchments, and additionally less variations during the dry season". Additionally we added the following statement on P9937L25: "The least variant discharge during the dry season was found in the pasture catchment, which is often associated to a greater groundwater contribution (Winter, 2007), as we believe that happens in this catchment."

Please show how the data have been treated to carry out the hydrograph analysis described in section 2.2.6 and any quantitative evaluation of the data (including water balances).

We have added to section 2.2.6 (after P9928L12) the equations and how the data were treated to quantify the hydrograph-derived variables.

Detailed comments:

p. 9917, L. 12: What kind of models? Please specify.

We changed this sentence on P9917L12 to include this information: "Wohl et al. (2012) stated that the available empirical data for tropical forests are insufficient for an adequate parameterization of water balance models, which includes the understanding of the effects of deforestation on evapotranspiration and runoff ratios."

p. 9918, L. 15: How is the water balance changed?

We have added to the manuscript the associated changes. The water balance change is predominantly the increase of streamflow. To include this information we changed the mentioned sentence to: "Although studies such as those by Costa et al. (2003) and Guzha et al. (2013) show that land-cover change in the Brazilian Cerrado alters the water balance, e.g. increased streamflow, they do not allow generalization since they are based mostly on low-resolution datasets."

p. 9919, L.15: How do these outcomes differ? What is the relevance for your study? Be more precise and specific.

In this sentence, we highlight the importance of studies at field scale in the Cerrado. We rewrote the P9919L14–17 to: “Oliveira et al. (2014) determined that water balance results found in their study for the Brazilian Cerrado may be scale depended, stating that smaller areas are usually more feasible to find responses to land-use and land-cover changes. In the same context, Jepson (2005) adds that higher-scale studies are required to more effectively measure human impacts regarding land-cover change in this biome.” The P9919L2–4 is directly connected to this statement which we changed to: “Furthermore, other water balance components such as rainfall interception, surface runoff, infiltration, and groundwater recharge are poorly understood at field scale in the Cerrado (Oliveira et al., 2015).”

p. 9920, L. 21: What do you mean by deterioration of soil properties?

We mean soil physical property alteration/changes such as destruction of pore space, and changes in the bulk density and water holding capacity (Osman, 2014). Due to the observations of the reviewer #2, we changed this sentence and consequently removed this term.

p. 9923, L. 14: Which algorithm has been used for calculating the wetness index?

To include this information we changed the sentences on P9923L11–14 to: “We used the topographic data obtained from these surveys to develop Digital Elevation Models (DEM) for the catchments at 5 m resolution, and to calculate slope and Topographic Wetness Index (TWI). The TWI was computed using the algorithm described by Gessler et al. (1995) and implemented in the ArcGIS® by Evans et al. (2014).”

p. 9926, L. 3: How representative was this transect? Please show the transects in Fig. 2 or Fig. 4.

To explain how representative these transect were, we added the following information on P9926L6: “We delineated the transects for the soil sampling based on a geostatistical analysis of terrain attributes. Geostatistical methods using soil information such as topography and grain size distribution have been applied for the spatial prediction of the soil properties in small catchments in other studies (Herbst et al., 2006; Vieira et al., 2007; Wei et al., 2008). In our study, we used the topography and clay content to regionalize the soil properties through the ordinary kriging method (Voltz and Goulard, 1994; Chaplot et al., 2000). For the clay content analysis, we collected ca. 50 disturbed soil samples from randomly selected points throughout each catchment at the depth intervals of 0–20 and 40–60 cm.”

We included the soil sampling and soil moisture points in Fig. 2 as shown below, and changed P9928L22–23 to: “The slope distribution for each catchment, derived from the DEMs, and the soil sampling points are shown in Fig. 2.”, and changed the respective caption.

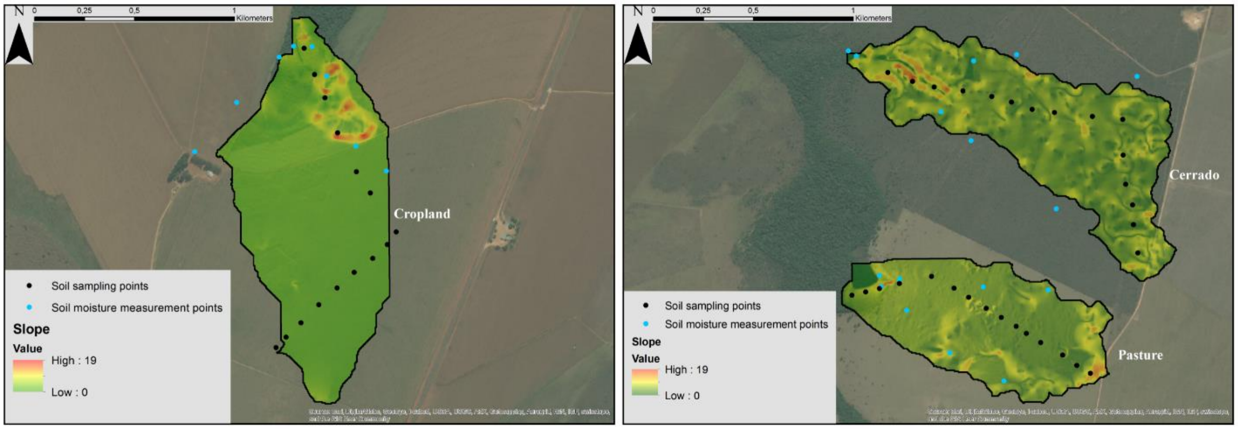

Figure 2. Slope (%) of the catchments calculated from the Digital Elevation Models (DEMs), and soil sampling and soil moisture measurement points.

p. 9926, L. 21: Are these transects related to the transect used for soil sampling? Please show the transects in Fig. 2 or Fig. 4, too.

We installed the access tubes for the soil moisture measurements based on preliminary topographic assessments and visual evaluation. We added on P9926L22: “In the cropland catchment, we also considered restrictions of the farm management due to machinery use in the area for the installation of the access tubes”. We added the transects to Fig. 2, as shown previously.

p. 9932, sec. 3.4: These results are not linked to the transects described in the method section. Is there any relationship between TWI and soil moisture dynamics?

To better show the link between the transects described in the methods and our results we rewrote the sentence on P9926L20–22 as: “In each catchment, we installed the access tubes in two transects along a toposequence of landscape positions from the upper slope to the low-gradient valley bottom, which were then evaluated in two groups, as the mean values obtained from the gallery forest and the mean values of the predominant land use positions.”

The expected relationship of greater soil moisture content in areas with higher TWI is now mentioned in the manuscript on P9932L13 as: “The greatest soil moisture values were measured in the gallery forest areas, especially in the cerrado and pasture catchments, which coincides with greater TWI values in these catchments.”

p. 9932, L. 24: You have no measurements on matric potential (which is a pity). How can you make a statement on reaching the wilting point?

The statement was based on the wilting point estimation, which was performed using a pedotransfer function determined by Nunes et al. (2015) as described on P9924L24. However, we were able to circumvent part of the technical problems concerning the matric potential measurements and we added the wilting point results to Table 1 as a result of new soil analysis. We added the description on the corresponding soil analysis after P9926L26.

Due to the new results, we rewrote the statement on P9932L23–25 to: "During the dry season, the soil moisture in the cerrado catchment reaches values near to the permanent wilting point; consequently less or no water is available to plants in the 0–80 cm soil layer (Reichardt, 1985)."

p. 9937, L. 15: An excess of water in the water balance cannot be explained by water storage capacity. The apparent excess of 500 - 600 mm yr−1 would otherwise translate into a water table that rises at about 1 - 2 m yr−1.

We acknowledge the Editor comments. We highlighted in the revised manuscript, as mentioned before (changes on P9938L22–27), that this excess of water may include groundwater leakages.

Concerning the relation between the water balance and the water storage capacity, besides the related changes mentioned in the response to the reviewer #1 (P9938L17–L21), we would like to add that an on-going work started in 2014 using data from 16 wells distributed in the riparian zone of the cropland catchment shows a change in the groundwater levels averaging 1.5 m between the wet and dry seasons of 2015 (Ziembowicz et al., submitted).

p. 9938, L. 2: Why should soil compaction contribute to an increase in flow in these catchments? Discharge is dominated by baseflow - why should that increase because of less e.g., macropores?

Usually the soil compaction decreases the K_{sat} and induces a greater superficial runoff generation. We acknowledge that the statement on P9938L2 could show an ambiguous connotation considering our study results, and therefore we removed it.

p. 9938, L. 15 - 21: This paragraph seems contradictory to me. The first sentence states that the cerrado area has the lowest recharge but the last phrase claims that this area has the highest infiltration rate. How do these two aspects go together?

We appreciate the Editor attention to detail for pointing this technical error. We changed the sentences on P9938L17–21 as mentioned in the response to reviewer #1 and, consecutively, removed the last phrase, which was causing the contradiction.

p. 9940, L. 18 - 22: I do not agree with the argument on water storage (see also above).

We do thank the Editor for the attention. The mentioned argument has been removed.

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RESPONSES TO RC-C4542 [Referee #3]

Interactive comment on "Identifying hydrological responses of micro-catchments under contrasting land use in the Brazilian Cerrado" by R. L. B. Nobrega et al.

Anonymous Referee #3

Received and published: 31 October 2015

The other reviewers already discussed many aspects and I agree with what have been written. The study focusses on soil moisture dynamic and some soil hydrological properties.

We thank the reviewer for the observations. We disaggregated the reviewer's comments in specific points to better address the reviewer's concerns in our responses (in blue).

Using classical approaches the water balance is computed and as a result, one third of the water is missing. The authors call that recharge/change in storage. Unfortunately, nothing is reported concerning the deeper soil and the geology. How important is the saprolite here? Assuming a specific yield of 0.1 a change in storage would result in an increase in water table by about 10 m in two years for pasture and crop land and still an increase of about 5 m in the cerrado. Is that realistic? I believe it is more realistic to assume that not all processes are determined. Considering the large gap in the water balance, I wonder if any specific conclusion can be drawn from this study.

We would like to clarify that the dS/dt in our water balance consists of the changes in soil water storage, recharge to groundwater and water balance errors/residuals. Considering this, our results are realistic and in accordance with the other few studies in this biome, as pointed out in our comments to reviewer #1. However, we do agree that it is important to elucidate in the discussion that not all processes were determined and therefore we emphasized this through our changes mentioned to the reviewer #1 (P9938L17–L21), to the reviewer #2 (P9919–20), and to the Editor (P9938L22–27). Concerning the deeper soil and geology information and as we mentioned to reviewer #1, there is a lack of geological data in this region of Brazil, which could lead to analysis based on dubious interpretations of the little geological data available (Wesselingh, 2008). Nevertheless, we added some geological information of this region on P9938L22-27 as described in the response to the Editor's comments.

We also would like to highlight that we believe that the nonexistence of groundwater measurements, which we attempted to explain in the response to reviewer #1, does not mean that our work is insufficient to draw specific conclusions on our results concerning the soil and hydrological analyses. Following the suggestion from reviewer #2, we rewrote the abstract and the conclusions sections to better clarify our specific contributions in this study.

I would expect a schematic diagram showing the main processes and storages.

While we acknowledge the reviewer's comment, we believe that the information contained in the water balance highlights the same information that would be represented in a diagram, which in turn indicates that more studies are demanded in order to establish a schematic diagram which fully represents the main processes and storages in each of these catchment types.

Is this really groundwater or is this just an assumption because a simple baseflow filter was used for differentiating between baseflow and direct runoff.

The purpose of using a baseflow filter was to separate baseflow from direct runoff. Since there is no available measured groundwater contribution, we used an established baseflow filter found as a satisfactory method to identify the groundwater component of streamflow (Gonzales et al., 2009). We believe this is an adequate tool to differentiate between the contribution of direct runoff to streamflow and baseflow.

It seems that one needs more information about the underground system. Is there a deep aquifer draining the catchment?

This was not investigated in this study due to logistical and resource constraints. We added some information on the existence of a deep aquifer (P9938L22-27, responses to the Editor). This information corroborates with findings from Meister (2014), who applied a hydrological model to the *das Mortes* watershed and found better calibration results when increasing the aquifer thickness to 100 m.

Does interflow play a major role?

The limited contribution of direct runoff to streamflow from our study catchments suggests that there is a major influence of interflow.

Can one compare two catchments with sandy soils (sand content >80%) with the cropland catchment with clay soils (clay content > 50%)? For me this is very difficult.

We note in the manuscript that the pasture and cerrado catchments have relatively similar catchment characteristics and makes them suitable for direct comparisons. We acknowledge that these comparisons are not trivial to do in relation to the cropland catchment. We explain the reasons for the different characteristics of the cropland in the responses to reviewer #1. Nevertheless, we would like to emphasize that we still can compare the cropland catchment by means of evapotranspiration and by showing the soil properties differences within the catchment (PLU and gallery forest areas).

Are the catchments so homogeneous that they can be characterized by one single soil profile?

As stated in the manuscript, in each catchment one disturbed sample and two undisturbed soil core samples were taken from 15 points along a transect to determine several soil properties. Data from these analyses were used to characterize catchment soil properties, which show that these small catchments have homogeneous soil properties within their respective areas. To show the locations of these 15 points, these are now included in Fig. 2 (slope).

I found Ks values of 15000 mm/d extremely high even if this is a sandy soil. From many studies it is clear that land use change will result in changed soil physical properties like e.g. Ks. It seems that this was not analyzed here.

We appreciate the reviewer's observation. The K_{sat} results in our study areas are indeed very high, even for a sandy soil. Due to this fact, still during the study period, we selected several points, recollected soil samples and repeated the laboratory analyses, which showed the same magnitude of results.

Additionally, we analyzed K_{sat} in situ using a Compact Constant Head Permeameter (Amoozegar, 1989) at 4 points and 2 soil depths (30 and 50 cm) across each catchment. Results show values up to 11 695 mm d^{-1}, 10 432 mm d^{-1}, and 3 651 mm d^{-1} for the cerrado, pasture and cropland catchments, respectively. This confirms the high K_{sat}. Further, other researchers also found very high K_{sat} values. For example, Scheffler et al. (2011) analyzed soil hydraulic properties of several catchments with a mean sand content of 55% in the Amazon biome in an area ca. 450 km from our catchments and found K_{sat} values up to 28 800 mm d^{-1}.

What has been measured within the gallery forest which can support the statement that it acts a main water retention area? It is clear that from measuring soil moisture dynamic one cannot conclude anything about water fluxes.

We do agree with the reviewer that our results could not totally support this statement, and therefore we removed this statement on P9939L27.

Why have the soil moisture data been aggregated to one single profile although it has been measured along a transect?

We have aggregated the soil moisture information in the PLU and gallery forest domains due to the similarity of the soil properties, land cover, topography, and soil moisture within these areas, and, consequently, to be able to compare these areas as we compared the other results through the manuscript.

The authors showed many figures which I found superfluous for answering the research question but they did not show where e.g. they measured soil moisture. Although the text is easy to follow, there are too many details given which are not required or not discussed in detail.

We regret that the reviewer find the figures superfluous. We did not receive any specific comment to remove any figure, but to aggregate or add, therefore we believe that the figures shown in our manuscript are important to summarize the large amount of collected and analyzed data, which are directly related to our comments and statements. For example, flow duration curves, which we show in Fig. 14, are shown to be an useful input for hydrological models calibration (Westerberg et al., 2011), specially for ungauged catchments (Yu and Yang, 2000).

The soil sampling and moisture points are now shown in the Fig. 2 (slope results).

I am afraid that this study does not significantly contribute to the understanding of the system. I have doubts that one can compare the cropland catchment with the others. More important is that a significant part of the water balance was missing and that this part (groundwater) was not studied at all. Maybe there are interesting details if one analyses soil moisture dynamics in more detail. I recommend developing a conceptual model of the processes, applying dynamic simulation models and studying the effect of land use on soil hydrological processes and evapotranspiration.

We understand the reviewer concerns. In order to analyze the groundwater dynamics and how this is connected to the vadose zone, we do believe that a study must be extended in many ways, which is beyond our scope. Our study is also not motivated by using simulation models, but, as explained to reviewer #1 and the Editor, we do believe that our work is important to improve the modelling efforts in this region. Our aim is to obtain experimental data that help to develop theories and further research directions on land-cover change impacts on hydrology in the Brazilian Cerrado. With the changes made due to the other reviewers` comments, we hope that our manuscript is more robust and the conclusions clarify our scientific contributions.

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